The Clubfoot

George W. Simons
Editor

The Clubfoot

The Present and a View of the Future

With a Foreword by M.O. Tachdjian

With 328 Figures in 523 Parts, 3 Figures in Color



Springer-Verlag
New York Berlin Heidelberg London Paris
Tokyo Hong Kong Barcelona Budapest

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Library of Congress Cataloging-in-Publication Data
The clubfoot: the present and a view of the future/[edited by]
George W. Simons.
p. cm.
Includes bibliographical references and index.

ISBN-13: 978-1-4613-9271-2 e-ISBN-13: 978-1-4613-9269-9
DOI: 10.1007/978-1-4613-9269-9

1. Clubfoot. 2. Clubfoot—Surgery. I. Simons, George W., 1937–
[DNLM: 1. Clubfoot. WE 883 C649]
RD783.C58 1993
617.5'85—dc20
DNLM/DLC 92-2336

Printed on acid-free paper.

© 1994 Springer-Verlag New York, Inc.
Softcover reprint of the hardcover 1st edition 1994

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Production managed by Natalie Johnson; manufacturing supervised by Jacqui Ashri.
Typeset by Asco Trade Typesetting Ltd., Hong Kong.

9 8 7 6 5 4 3 2 1

This book is dedicated to all the children of the world born with congenital clubfeet and to the orthopedic surgeons who care for them.

Foreword

During the past two decades, there has been great progress in the management of clubfoot. The First International Congress on Clubfeet was a landmark gathering of the leaders in the world in the treatment of clubfoot. The congress was organized by Dr. George W. Simons—a difficult and demanding task. The quality of the papers published in this monograph reflects his pursuit of excellence and attention to detail.

Still, there are many controversies in the management of clubfoot; it is evident that there is disagreement as to terminology and definition.

What is congenital talipes equinovarus? It is a deformity of multifactorial pathogenesis in which the heel is inverted, the forefoot and midfoot are inverted and adducted (varus), and the ankle and subtalar joints are in equinus position. The forefoot is in cavus with the toes at a lower level than the heel. It is vital, however, that one be more specific in the definition of talipes equinovarus.

It is in utero displacement and malalignment of the talocalcaneal, navicular, and calcaneocuboid joints; the talus is plantar flexed with its anterior end rotated laterally and its head and neck tilted medially and plantarward; the calcaneus is plantar flexed with its anterior end rotated medially and its posterior end rotated laterally and tethered to the fibular malleolus; the navicular is displaced medially and dorsally, and the cuboid is displaced medially in relation to the calcaneus. These articular malalignments are firmly fixed by capsular, ligamentous, and musculotendinous contractures.

The source of disagreement among researchers in clubfoot is due to the variability of severity of expression of a complex deformity produced by many etiologic factors. It is imperative that the pathology be delineated and the severity of the deformity of each individual case be assessed and classified.

The treatment of intrinsic, rigid, congenital talipes equinovarus is primarily surgical; nonoperative measures are preliminary steps for facilitation of definitive correction of the deformity, i.e., concentric reduction of the talocalcaneonavicular and calcaneocuboid joints. It is crucial that one not persevere with prolonged immobilization in casts, because disuse atrophy of muscles and rigidity of joints are not biologically acceptable. Motion is life! It is vital to restore mobility and function of a foot that is deformed in utero.

Another controversial issue is the value of radiography. Dr. Simons has demonstrated, without question, the importance of radiographic imaging

in the delineation of pathology and the importance of an extensive, à la carte release in correction of this complex deformity. The value of intraoperative radiography cannot be overemphasized.

There is much ado about nothing as to the surgical approach—Cincinnati, posteromedial and lateral, or posterolateral and medial; it does not matter what surgical exposure is used, provided the ligamentous, capsular, and musculotendinous contractures are released and concentric reduction is achieved. Overcorrection should be avoided.

Meticulous postoperative care is crucial for success. Postsurgical immobilization in cast should not exceed 6 weeks. Part-time splinting and the use of dynamic means to restore mobility and function are important. It behooves the surgeon to be diligent in preventing complications. No matter how meticulous and thorough the surgeon is, problems will arise. Recurrence of deformity because of scar formation may occur. The medial tilting of the head and neck of the talus may not correct with bony growth after concentric reduction. Dynamic imbalance of muscles may cause supination deformity of the forefoot and midfoot. A percentage of patients will require revision surgery or tendon transfers to restore dynamic balance of muscles acting on the foot and ankle. The calf will be atrophic; the foot will be small.

I hope that, in the future, there will be periodic congresses on clubfeet, and that advances in technology of the biologic sciences and imaging will further advance our understanding of the pathomechanics, pathology, and treatment of talipes equinovarus.

Chicago, Illinois Mihran O. Tachdjian, M.S., M.D.



Jusepe de Ribera's
The Boy with the Clubfoot

Courtesy of the Louvre Museum, Paris

About the Painting, *The Boy with the Clubfoot*

Aware that there was considerable controversy about the cause of the affliction of the subject in this painting, I nevertheless chose Jusepe de Ribera's *Le Pied Bot* as a keynote theme for the First International Congress on Clubfeet. A reproduction of the painting appeared on announcements of the congress and on the course handbook. It now also appears in this monograph.

Understandably, this choice resulted in several telephone calls and considerable correspondence, with a number of well-intentioned opinions and comments from colleagues stating that the subject, in fact, had some malady other than clubfoot—most probably cerebral palsy. Numerous aspects of the painting were cited as reasons for these comments. The most erudite of these comments came from Leo Arthur Green, M.D., of Jackson Heights, New York, who unfortunately was unable to attend the congress.

In Dr. Green's evaluation of the boy's malady, he points out several other possibilities for the differential diagnoses. These include trauma, stroke, and spastic hemiplegia.

Dr. Judy Hall, a medical geneticist in Vancouver, British Columbia, has suggested amyoplasia congenita (arthrogryposis) on the basis of the bilateral wrist flexion, elbow extension, and shoulder pronation contractures. In addition, she comments on the boy's apparent trunk-leg disproportion, but does not think he had a form of dwarfism.[1,2]

Because of the considerable interest expressed about the painting, I visited the archives of the Louvre Museum in Paris in an effort to answer a number of questions that had been asked about both the painting and the artist. After several afternoons of perusing the vast correspondence on this painting, I selected the single most informative document about *Le Pied Bot.* I have chosen to reproduce here excerpts from both Dr. Green's letter and the Louvre document. I hope that you will find these as informative and interesting as I have.

George W. Simons
Editor

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1. Hall, J.G., Reed, S.D, Driscoll, E.P.: Amyoplasia: a common, sporadic condition with congenital contractures. Part I. *Am. J. Med. Genet.,* 15:571–590, 1983.
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The Boy with the Clubfoot: Who Advised the Artist?

Leo Arthur Green

[*Dr. Leo Green has been treating clubfeet for over 50 years. In 1954, during his visit to the ALYN Orthopaedic Hospital in Jerusalem, his interest in children's foot disorders led to his establishing the American Society for Crippled Children in Israel, an organization devoted to fund-raising in the United States. I am grateful to him for allowing me to reproduce excerpts from his letter.*—ED.]

A painting of the early 17th century by [Jusepe de] Ribera, which today hangs in the Louvre Museum in Paris, was used as the keynote theme for the cover of the announcement of the First International Congress on Clubfeet at the Medical College of Wisconsin in Milwaukee, on September 5th and 6th, 1990.

The viewer's attention is drawn to several areas in the painting:

The fact that the upper and lower limbs are involved suggests that he may have a right hemiplegia and that the right foot is not a true clubfoot. . . . McCauley[3] refers to Ribera's painting as depicting "a youth with a talipes equinovarus as part of a right-sided hemiplegia." In general, however, clubfoot is not frequently associated with hemiplegia.

The right shoulder appears to be lower than the left, which supports the long, and presumably heavy, staff. There is a pouch hanging on the right hip from the shoulder. The elbow is extended and the wrist is flexed. The hand seems to be grasping the pouch, but the visible 5th and 4th metacarpophalangeal joints appear to be extended and the proximal interphalangeal joints flexed, suggesting an ulnar clawed hand. [Possibly a flaccid paralysis, i.e., polio.—ED.]

The right foot exhibits severe equinus deformity but no varus. [Cavus as well?—ED.] In addition, there is considerable shortening of the right leg, with the metatarsophalangeal joints appearing to be extended with the proximal and distal interphalangeal joints being held in flexion, forcing the full weight to be borne on the metatarsal heads. The adult with typical uncorrected equinovarus deformity walks on the outer border of the foot and not on the metatarsal heads. [This data further reinforces the possibility of a paralytic deformity.—ED.]

In summary then, it appears that a strong case may be made for questioning the name of the painting. Who, if anyone, was the artist's medical adviser? It is obvious that Ribera was a keen observer and depicted the medical condition of his subject accurately in a most detailed and artistic manner, even if the painting may have been named incorrectly.

[*Dr. Green's analysis provides considerable food for thought. I would agree that the artist depicted the subject's condition accurately, whereas medical knowledge at that time, no doubt, failed to appreciate the various*

3. McCauley, J.C., Jr.: Clubfoot—history of the development and the concepts of pathogenesis and treatment. *Clin. Orthop.*, 44:51, 1966.

pathoanatomic subtleties of the boy's deformity. Other possibilities include a form of dwarfism and, possibly, one of the many associated syndromes that occur with clubfeet.—ED.]

Ribera's *The Boy with the Clubfoot*: Image and Symbol*

Edward J. Sullivan

[*This paper was presented by E.J. Sullivan at the Frick Symposium of the History of Art, April 19, 1975, and subsequently published in* Studies in the History of Art, *Vol. 19, pages 17 to 21, published in 1978 by the University of Fine Arts, New York University, distributed by J.J. Augustin, Locust Valley, New York. It is reprinted here courtesy of the Louvre Museum, Paris.*—ED.]

Jusepe de Ribera's *The Clubfooted Boy*, painted in 1642 and now in the Louvre, is one of this artist's most intriguing works. It is also a picture of considerable iconographic complexity which, for the most part, has gone unrecognized.

Given its humble subject matter, it is a surprisingly imposing painting. We see a young boy in tattered clothes standing erect, grinning as he jauntily supports a crutch over his shoulder. In his right hand he holds a large hat and in his left there is a *cartellino*, or small piece of paper, on which are written the words *DA MIHI ELIMOSINAM PROPTER AMOREM DEI* or "Give me alms for the love of God."

Many writers in the past have sought to place *The Clubfooted Boy* in the pictorial tradition of dwarfs and jesters, which was especially strong in Spain.[2] This tradition matured in the mid-17th century with Velázquez's portraits of dwarfs . . . While Ribera does not illustrate the specific social conditions that contributed to the poverty of *The Clubfooted Boy*, he makes no attempt to dissimulate the harshness of his life by dwelling on the details of his deformity.

A relationship to northern European depictions of beggars and cripples may be noted by comparison with such works as Bruegel the Elder's *Cripples* of 1568 (Louvre). . . . In Bruegel's painting, as in some other Dutch and Flemish versions of the subject, physical defects are equated with defects of the soul, as an inscription on the reverse of the picture attests.[3] . . . Essentially, however, Ribera's image belongs to a different, particularly Spanish conception of the lame and deformed. . . .

. . . Ribera's subject, as the popular title implies, is actually deformed. The clubbed foot and the wide open mouth, in which the decaying gums are carefully drawn, make this fact perfectly clear.

Perhaps the best way to approach the painting is to take account of the features that contribute to its unusual individuality and enduring appeal. First of all, there is the broad smile. Why should a poor, lame child be

*Painting signed and dated "Jusepe de Ribera Español/F, 1642." It was acquired by the Louvre in 1869 as part of the LaCaze Bequest (Accession n. MI.893).

smiling? The almost triumphant expression maintained despite the painful mouth condition is reinforced by the way he holds his crutch over his shoulder in the manner of a young soldier, carrying his gun, instead of using it to walk, as a cripple normally would. . . .

Ribera's *The Clubfooted Boy* . . . becomes understandable within a visual tradition that used the figure with a crutch as a symbol of charity received, a tradition that developed more strongly in Spain than in any other country. Ribera, however, worked mostly in Naples and he is often thought to be more representative of the developments of baroque painting in Italy than in Spain. Yet Naples was a city under Spanish domination and Ribera was the favorite artist of the Spanish viceroys. In fact, a label on the back of the picture that was discovered in the early 1960s, points to this work as having been commissioned by Ramiro Felipe de Guzman, Duke of Medina de las Torres and Viceroy of Naples from 1637 to 1644.* Bellori[1] states that Ribera actually resided for long periods of time in the ducal palace. The fact that *The Clubfooted Boy* was executed under the aegis of Medina de las Torres is particularly significant, for it was during these years that Ribera returned to a more "Hispanic" mode in style and subject matter after years of adapting his imagery to the more classical Italianate taste of his former patron, the Count of Monterrey, who had been responsible for bringing Domenichino to Naples in 1633.

During the vice-regency of Medina de las Torres, Ribera experienced an intensification of what may be called his brilliant "naturalistic abstractions," . . . highly simplified naturalism was, of course, not new to Ribera with the advent of the patronage of Medina de las Torres. . . .

The Clubfooted Boy conforms to the known characteristics of Medina de las Torres's taste. An unidealized figure is depicted and there is an abstraction of detail, with a subtle presentation of what remains. It is the single purified image, the distilled residue of the scene that is the most significant. We see in this painting a smiling cripple, rejoicing in his poverty, embodying the words of the first beatitude: "Blessed are the poor, for theirs is the kingdom of God." As the agent through which the charity of the more fortunate is accomplished (gaining for them heavenly merit), the child encourages the generous person to enact the words of the seventh beatitude: "Blessed are the merciful, for they shall obtain mercy."

. . . This same spirit of specific detail and pious naturalism is behind Ribera's portrayal of *The Clubfooted Boy*. In the picture the viewer has nothing else on which to focus his attention but the child. The boy's smile is not the roguish grin of a trickster but an attitude radiating inner joy. He is not only gifted with true poverty but, in receiving the alms for which he asks with the *cartellino*, he becomes the means through which more fortunate souls will receive grace and, consequently, salvation. Indeed, he holds an outsized hat suggesting that a generous soul has already shared his worldly possessions with the child. *The Clubfooted Boy* represents the triumph of poverty—a militant image that is further strengthened by the crutch held over his shoulder like a musket, and by the proud, upright stance maintained despite a painful affliction.

. . . If we look more deeply into the subtle meanings of [Ribera's paint-

*This label was first published by Jeanine Baticle in the catalogue of the exhibition *Trésors de la Peinture Espagnole, Eglises et Musées de France*, Paris (Louvre and Musée de Artes Décoratifs), 1963, no. 72, 193–195.

ing] a richer and more profound artistic personality emerges. Ribera should be recognized not merely as a practitioner of an astringent Caravaggism, but as a highly original, highly innovative creator who employed earthbound naturalism for spiritual motives.

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Introduction

The first International Congress on Clubfeet, held on September 6 and 7, 1990, at Children's Hospital of Wisconsin, Milwaukee, Wisconsin, represented the culmination of 20 years of progress in the surgical correction of congenital talipes equinovarus (CTEV).

In 1970, one of the key issues on the forefront of the study of clubfeet was George Lloyd-Roberts' concept of the "horizontal breech."[32] This concept held that the talus was externally rotated in the ankle mortise around the vertical axis. He believed this occurred as the result of inadequate surgery or walking on an incompletely corrected clubfoot. Posterior position of the fibula with respect to the tibia on the lateral radiograph was thus explained by Lloyd-Roberts' concept. Working at the Hospital for Sick Children in London, Lloyd-Roberts influenced many surgeons, including myself, who were trying to improve methods of treatment.

In 1971, I joined M.O. Tachdjian at Chicago Children's Memorial Hospital. He was very encouraging and enthusiastic about exploring new ideas and techniques. Concluding that Lloyd-Roberts' concept of talar position was not supported by our own studies, and that the talus is normally aligned in the ankle mortise of the typical clubfoot, Tachdjian invited several of Europe's leading pediatric orthopedic surgeons to Chicago as visiting professors to discuss clubfeet and other pediatric orthopedic problems in great detail. These meetings were highly informative, especially in regard to our further understanding of clubfeet in general and Lloyd-Roberts' concepts in particular.

In 1973, Tachdjian organized the first of his now famous Pediatric Orthopedic International Seminars (POIS). Although that first meeting was well attended, it gave only a small indication of how successful these seminars were to become. Lloyd-Roberts joined the second POIS meeting as a member of the faculty, a task he added to his busy annual schedule until his untimely death in 1988.

Meanwhile, Goldner[7] was developing the view that the talus was internally rotated in the mortise, both around an AP as well as a vertical axis. Goldner and Fitch[8] subsequently described a "four-quadrant release" in which the soft tissue correction was directed at the ankle rather than the subtalar joint. Gould,[9,10] also concurring with Goldner's approach, advocated the use of multiple incisions including the high-loop incision to avoid skin contractures.

Turco's[34] technique, a one-stage posteromedial release with internal

fixation, had been published in 1971 and was developing a strong following throughout the world. Turco, like most orthopedists at that time, was of the opinion that the hindfoot deformity was a two-dimensional deformity, with the heel being in varus, but not rotated in the third plane (around a vertical axis). He therefore released three sides of the subtalar joint, leaving the lateral side intact. Thus, with his procedure the calcaneus rotated on the lateral capsule as though it were on a hinge. Although Turco's procedure provided significant improvement over earlier multistage approaches, in many cases it failed to produce complete correction.

Early in 1972, I attempted to address these failures by operating on the lateral side of the foot, releasing the lateral calcaneocuboid joint, the anterior portion of the subtalar joint, and the lateral talonavicular joint. This led to a "progressive approach" or stepwise series of procedures with the use of intraoperative radiographs to determine when satisfactory correction was achieved.[25] The following year (1973), Lichtblau published his technique for excision of the anterolateral aspect of the calcaneus. This was part of a simultaneous medial and lateral soft tissue release performed through two incisions.[13]

In 1975, Seringe[22–24] (Paris) described, as the main residual deformity following the conventional posteromedial release, adduction of the calcaneal pedal block [or calcaneal forefoot (CFF) block]. As a remedy for this, Seringe described a technique of soft tissue release that consisted of posterolateral, anteromedial, and talocalcaneal releases; however, they subsequently concluded that he could accomplish correction without subtalar release.

Like Lloyd-Roberts, Carroll et al.[3] also believed that the talus was externally rotated in the ankle mortise (around a vertical axis); however, he believed that this position of the talus was present at birth. They described internal rotation of the talus as a part of their extensive soft tissue release. In 1974, Lloyd-Roberts later described *medial* rotation osteotomy of the distal tibia with external rotation of the foot (by a second-stage posteromedial release (PMR) or Evans' procedure) in older cases.[14]

Meanwhile, I also believed that calcaneal rotation was fundamental to the clubfoot, but visualized this rotation as occurring around an axis located at the posterior aspect of the talus, rather than centrally in the area of the interosseuos talocalcaneal ligament.

In 1979, McKay[18] introduced his concept of calcaneal rotation beneath the talus. He recognized the importance of releasing the lateral subtalar joint completely in order to achieve calcaneal rotation around the vertical axis as well as achieving eversion of the calcaneus to correct varus.[18–20] He envisioned that the lateral rotation of the anterior calcaneus required simultaneous medial rotation of the posterior calcaneus. This could be achieved by moving the posterior calcaneus away from the fibula (in a medial direction) and fixing the calcaneus to the talus in this position by inserting Kirschner wires through the talonavicular and talocalcaneal joints.

In North America, McKay is credited with being the first to describe calcaneal rotation beneath the talus, although it appears that Bosch[1,2] of Vienna published this finding in several papers between 1953 and 1964. Bosch, however, did not describe a surgical approach to correct this pathologic anatomy. Grill,[11] who succeeded Bosch in Vienna, must be given credit for making Bosch's work generally known. However, the first published article on calcaneal rotation appears to have been one by Par-

ker and Shattock[21] in 1884. These earlier publications, however, do not detract from McKay's contribution both to the conceptual understanding and surgical treatment of calcaneal rotation.

At the 1979 POIS, John Roberts of the Children's Hospital in New Orleans asked McKay and me to join with him in a three-center evaluation of our respective techniques and their underlying theoretical models. At the end of this study, Roberts, McKay, and I agreed that McKay's concept of calcaneal rotation was correct. Moreover, we agreed that McKay's idea of releasing the entire lateral side of the subtalar joint was valid and produced better results than releasing only the anterior part of the lateral subtalar joint, as I had been doing. These findings were reported at the annual meeting of the Pediatric Orthopedic Society (POS) in 1980.[17,28] Subsequently, McKay's three-part paper on his procedure and theory appeared in 1982 and 1983.[18–20] It was McKay's lateral release that ultimately led the way to the development of improved, yet more extensive, soft tissue releases in North America in the 1980s, e.g., Barnett's modification of the complete subtalar release (CSTR) (see Chapter 9, page 268) and calcaneocuboid joint release.[33]

These concepts of Goldner, Turco, Lloyd-Roberts and Carroll, and McKay provided the basis for considerable controversy during the ensuing decade, as each of these surgeons described a different operative procedure to correct the deformities as he envisioned them. Unfortunately, no accurate method existed that could irrefutably substantiate the validity of one method over the other.

Turco's procedure was based on pathoanatomic concepts that were generally accepted at that time. It provided such great improvement over previous techniques that it became widely accepted. Although it is probably still the most widely used technique throughout the world, its use in this country has gradually decreased as the other techniques have assumed greater popularity, especially that of McKay.

Tachdjian's POIS seminars and other meetings provided a forum for discussion of new surgical procedures and an important venue where pediatric orthopedists from around the world could exchange ideas and make lasting friendships. Many important ideas were conceived as a result of the annual POIS meetings. During this time, I attempted to develop a standardized method for the radiographic evaluation of clubfeet, a method that could be used to diagnose deformities, to affirm correction intraoperatively, and to evaluate surgical results retrospectively (1978).[26] My results, as determined radiographically by the standardized method, revealed that the "progressive approach" did not eliminate incomplete corrections and that a more extensive procedure was needed.

At this time, most clubfoot surgeons were using a single medial incision. In 1980, Alvin Crawford, who had just been appointed Chief of Pediatric Orthopedic Surgery at the Cincinnati Children's Hospital, began to experiment with an alternative incision he had learned from Giannestras.[6] Crawford extended Giannestras' incision further forward in order to visualize all the structures affected in the clubfoot.[4] Having been told about this incision by Crawford, in 1981, I started using it and never returned to the old two-incision technique.

Although some surgeons expressed concern that the Cincinnati incision would not allow adequate Achilles lengthening, the incision proved very satisfactory if its distal arms were extended forward both medially and laterally so that the skin flap could be dissected as far proximally as required to achieve adequate lengthening of the Achilles tendon. The main

advantage of the Cincinnati incision, in the opinion of those who use it, is that it provides exceptional exposure for all areas requiring release, in the hindfoot and midfoot as well as in the forefoot (the incision can be extended as far forward as necessary). In addition, this incision affords a better view of the ankle and subtalar pathology than other incisions and it gives superior cosmetic results. My limited, but favorable, experience with the Cincinnati incision was reported at the annual meeting of the Pediatric Orthopedic Society of North America (POSNA) in 1982[27] and shortly thereafter, Crawford et al.[4] published their classic paper on the Cincinnati approach to the clubfoot.

By this time, it was clear that the old techniques of "analytical radiography" and the "progressive approach"[25] were superceded by the concept of "calcaneal rotation," the development of the Cincinnati incision, the CSTR, and similar extensive soft tissue procedures.[3,6,16–18]

The clinical evidence began to mount, however, that the CSTR, like its predecessors, had limitations. Many of the earlier feet treated by CSTR were overcorrected into valgus. The calcaneus in these feet was either rotated or translated into valgus position, and I, like a number of other surgeons, was unable to correctly interpret the intraoperative radiographs. After performing a retrospective study of the films of many appropriately corrected and overcorrected clubfeet, it was discovered that the chief reason for overcorrection was the placement of the navicular too far laterally on the talar head. With this placement, the medial side of the talar head and the medial surface of the navicular were flush or at the same level. After placing the navicular in different positions, it was determined that the navicular had to be placed in a slightly protruding position, medially. At the same time, it became clear that there should be no lateral protrusion or step-off at the talonavicular joint. These findings were confirmed in a series of intraoperative posteroanterior (PA) and postoperative anteroposterior (AP) radiographs, despite limited or absent ossification in the navicular, using special radiographic measurements that were subsequently substantiated once ossification of the navicular occurred.[26,29–31]

Similar problems arose in the dorsal-plantar relationship at the talonavicular joint, whereas the navicular frequently subluxated superiorly. Here again, it was determined that when the dorsal surface of the navicular and the dorsal surface of the talar head are at the same level (i.e., no dorsal step-off), and the long axis of the talus passes through the base of the first metatarsal on the lateral radiograph, the normal talonavicular position exists (i.e., dorsal talonavicular subluxation is not present).

Although critics were quick to blame overcorrection on excessive release of soft tissues, particularly the interosseuos talocalcaneal ligament, the studies cited here demonstrated that the majority of overcorrected feet were overcorrected at the time of surgery, being internally fixed in the overcorrected position.

A set of clinical criteria for positioning the navicular and the use of intraoperative radiographs were recommended as solutions to this problem. Unfortunately, many people have found the technique of taking intraoperative radiographs too demanding and the radiographs difficult to interpret. Papers on preliminary experience with the CSTR specifically discussing the causes and prevention of overcorrection appeared in 1985 and 1987.[30,31]

A second cause of overcorrection was failure to recognize and correct significant calcaneocuboid subluxation. As the 1980s drew to a close, de-

formity at the calcaneocuboid level began to attract considerable attention.[15,33] Several of the papers in this volume discuss this newly understood deformation.

This was the apparent state of the art at the beginning of 1990, and yet, in my travels, I have learned of additional work being done on various aspects of the clubfoot problem. Some of this work could be described as basic research; some consists of clinical studies; some is highly theoretical. It was apparent that this work should be synthesized and reported.

John S. Gould, Chairman of the Department of Orthopaedics at the Medical College of Wisconsin, and I worked with the leaders of SICOT (Societé Internationale de Chirurgie Orthopédique et de Traumatologie) to organize a congress on clubfeet that would be scheduled to precede the Montreal meeting of SICOT in September, 1990. Sir Dennis Patterson, SICOT president, and Maurice Duhaime, vice president of the SICOT congress, were very helpful in the planning that led to this first International Congress on Clubfeet (ICC).

The initial call for papers for the congress included a list of topics on which the organizers believed further research was needed. Two limitations were placed on papers: they had to be presented and written in English, and they could not be devoted to presentation of surgical results. Although surgical results are ultimately of the greatest importance to all surgeons, the organizers felt that in the absence of a well-documented, generally accepted set of criteria for the evaluation of CTEV, either preoperatively or postoperatively, it would be futile to attempt comparisons of results. In fact, recent symposia have shown that attempts to compare one study with another can be grossly misleading. A few papers on surgical results were eventually accepted, however, because of the light they shed on other issues.

It is now recognized that one of our major endeavors for the next few years must be to establish a common set of criteria for the evaluation of the unoperated CTEV and for the results of the various conservative and surgical procedures still in use.

The organizers hoped for a submission of 25 to 30 strong papers. Over 100 abstracts were received, and the meeting had to be extended from one day to a day and a half. Despite the extension, many fine papers had to be turned away; a further extension would have caused conflict with the SICOT and POSNA meetings in Montreal.

A total of 84 papers presented at the International Congress on Clubfeet appear in this monograph. These were presented by 65* surgeons from 30 nations. Although many of the papers were presented by surgeons from the United States, the number of papers and participants from other countries made this a truly international congress. Most of the papers presented here have been rewritten and embellished to provide more scientific documentation than the versions that were presented at the meeting, with its limits on time. Most of the papers fall into two general categories: scientific presentations on clinical and basic research, and anecdotal or theoretical papers. The latter type was judged to be highly important, given the rapid advances being made in the study and treatment of clubfeet. Although some of the procedures suggested in this volume are little more than concepts at this time, some of them may eventually represent major advances in the field of clubfoot surgery.

*This number does not include the authors whose papers are included in Chapter 17 but who were not presenters at the congress.

It is with great pleasure that the editor presents this compilation of papers in the form of a monograph on the first International Congress on Clubfeet.

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Acknowledgments

I would like to acknowledge the generosity of the following individuals who helped to organize the congress on which this monograph is based:

Robert M. Barnett, Sr., M.D.
Minneapolis, Minnesota

S.S. Coleman, M.D.
Salt Lake City, Utah

Paul Griffin, M.D.
Charleston, South Carolina

W.B. Lehman, M.D.
New York, New York

M.O. Tachdjian, M.D.
Chicago, Illinois

Raymond C. Waisman, M.D.
Milwaukee, Wisconsin

I want to extend personal thanks to J.E. Handelsman, M.D., Long Island Jewish Medical Center, New Hyde Park, New York, for writing a special paper at my request on the understanding of muscle pathology. In addition, John Gould, M.D., Chairman, Department of Orthopaedics, Medical College of Wisconsin, has been extremely helpful in providing monetary support as well as an abundance of advice. Without his encouragement and generosity, neither the congress nor this monograph would have become a reality.

The daily support of my editorial assistant, Mr. Robert Henderson, was of paramount importance as was his help in preparation of the manuscript.

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Definition of Terms and Abbreviations

For purposes of clarity, it is necessary to use some standard terminology to describe various elements of the foot. Many of these terms enjoy popular usage in the United States, whereas in Great Britain and other English-speaking countries other terms are used. The terms most commonly used in the United States are the ones that will be used in this monograph.

Throughout the text the term *congenital talipes equinovarus* (CTEV) will be used to signify the idiopathic clubfoot as opposed to other forms, such as neurologic, teratologic, functional, etc. In addition, abbreviations frequently used in this monograph will be indicated here.

Supination is defined as rotation around the longitudinal (anteroposterior) axis of the foot, with elevation of its medial border, and *pronation* is the opposite.

Adduction is defined as internal rotation of the foot around the vertical axis, bringing the forefoot closer to the midline of the body, and *abduction* is the opposite.

Dorsiflexion and *plantar flexion* of the ankle refer to the upward and downward rotation of the foot around a mediolateral axis passing through the talar body.

The term *varus* often has been applied to the forefoot to imply the presence of the combined deformities of adduction and supination. However, in this discussion, varus will be used to define pathologic degrees of inversion of the calcaneus beneath the talus.

Rotary movements of the hindfoot will be described as occurring around either the longitudinal (anteroposterior) axis, the vertical axis, or the mediolateral axis. The *AP axis* passes horizontally through the foot in the sagittal plane at the level of the midtalus. The *vertical axis* passes upward through the calcaneus, through the interosseous talocalcaneal ligament, through the talus, and up the tibia. The mediolateral axis passes through the foot in the coronal plane at the level at the malleoli.

The following terms are used in preference to those enclosed within the parentheses: *ankle* (crural), *talus* (astragalus), *calcaneus* (os calcis), and *navicular* (scaphoid).

The following abbreviations will also be used:

AP	anteroposterior (dorsiplantar)
APTC angle	anteroposterior talocalcaneal angle
Cal. Ost.	calcaneal osteotomy

CC joint	calcaneocuboid joint
CC joint and TN joint	Chopart's joint
CCR	calcaneocuboid release
CCS	calcaneocuboid subluxation
CSTR	complete subtalar release
Cub. Ost.	cuboid osteotomy
Cun. Ost.	cuneiform osteotomy
FFA	forefoot adduction
FFS	forefoot supination
HFV	hindfoot varus
IP joint	interphalangeal joint
Lat.	lateral
Lat. TC angle	lateral talocalcaneal angle
Med.	medial
M. Ost. (1–5)	metatarsal osteotomies—first through fifth
MTP (or MP) joint	metatarsophalangeal joints (Lisfranc's joint)
Pl. Rel.	plantar release
PMLR	Posteromedial and lateral release (peritalar release)
PMR	posteromedial release
PR	posterior release
TAL	Achilles tendon lengthening
TMT joints	tarsometatarsal joints (Lisfranc's joint)
TN joint	talonavicular joint

1
Etiology

Introduction

This chapter begins with two brief review articles that were added to the original text of the congress. These have been written by **Handelsman** and **Glasser** and myself with the hope that they may enhance the recall of the most common theories of etiology and the pathoanatomy of muscle, which for many practitioners are very remote. Handelsman and Glasser have done an excellent job in making this material meaningful and easier to understand.

The papers by **Mellerowicz et al., Kojima et al., Handelsman** and **Glasser, Shimizu et al.,** and **Martin et al.** all deal with the neurogenic theory of etiology, whereas that of **Sodre et al.** deals with the myogenic theory, and those of **Hootnick et al.** and **Schwartz et al.** discuss the vascular theory.

Mellerowicz et al.'s paper describes the results of morphometric examinations of muscle biopsies. **Kojima et al.** present an evaluation of muscle biopsies using histochemical studies, whereas **Handelsman** and **Glasser's** second paper is an extension of their previous work on the neurogenic theory, but they also relate changes seen in congenital talipes equinovarus (CTEV) to those seen in other lower motor neuron diseases.

Shimizu et al. present a study in which patients with talipes equinovarus (CTEV) are compared with patients with Streeter's dysplasia and a case of sacral agenesis. They attempt to demonstrate a spectrum of neurogenic involvement in these patients. **Martin et al.'s** paper, an electromyogram (EMG) study, also relates to the neurogenic origin of talipes equinovarus, whereas **Sodre et al.'s** paper describes anomalous muscles in CTEV.

In the second part of the chapter, **Hootnick, Packard**, and **Levinsohn** collaborate to produce a very interesting paper, presented as three separate papers at the congress, in which they introduce the vascular theory as a potential cause of clubfeet. This represents the culmination of 15 years of work by these authors, who discuss the frequent absence or underdevelopment of the anterior tibial and dorsalis pedis arteries in clubfeet as determined by arteriography.

The final paper, by **Schwartz et al.**, a sequel to that of Hootnick et al., presents an evaluation of the arterial anatomy of CTEV using the latest in Doppler technology (color Doppler).

Etiological Theories of CTEV

George W. Simons

The etiology of CTEV remains unknown. At present there are at least six well-established theories of etiology, as follows:

1. Chromosomal theory. This theory states that the defect is in the unfertilized germ cell. That is, the defect exists before fertilization.
2. Embryonic theory. This theory states that the defect occurs within the fertilized germ cell. This is the germ cell theory of Irani and Sherman and of Settle that implies that the defect occurs between conception and 12 weeks.
3. Otogenic theory. This theory states that there is an arrest of development. An arrest may be permanent, temporary, or cause slowed growth. A permanent arrest produces congenital malformations, whereas a temporary arrest produces such things as Harris lines. Slowed growth may occur following steroids. Of the three, the temporary arrest is the most plausible cause of clubfoot. If a temporary arrest occurs at the 7th to 8th week, a marked clubfoot deformity occurs, whereas if the arrest occurs after the 9th week, a mild to moderate clubfoot deformity results.

   It has been theorized that this arrest of development is related to a change in a genetic factor known as a "cronon."[1] The cronon guides the precise timing of the progressive modifications that every structure undergoes during its development. Thus, the clubfoot is caused by a disruptive element (local or general) that causes a change in the genetic factor (cronon). Structural changes are then arrested, but growth continues under the impulses that the cronon received before being damaged (between the 8th and 12th week). Thus, the foot is under the influence of a controller that can be pathologically affected and guides the development in the wrong way. At the end of the growth arrest phase, growth resumes but only from a later point of development.[1]
4. Fetal theory. This theorizes a mechanical block to development.
5. Neurogenic theory. This theory suggests a primary defect in neurogenic tissue.
6. Myogenic theory. This theory asserts that the primary defect is in muscle.

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Understanding Muscle Pathology

J.E. Handelsman and R. Glasser

Human skeletal muscle is divided and subdivided into smaller muscular components. The gross muscle is composed of multiple fasciculi; these are in turn divided into the muscle fibers, which are subdivided into myofibrils and, finally, into myofilaments. The longitudinal and cross-sectional appearance of the muscle fibers can be identified with the light microscope (Figure 1.1A). The electron microscope identifies the myofibril and the various components of the two membrane-limiting networks surrounding the myofibril, i.e., the sarcoplasmic reticulum and the T system. The electron microscope further identifies various bands and lines seen on the surface of the myofibril (Figures 1.1 to 1.3).

In order to understand the results of muscle biopsies, it must be recognized that conven-

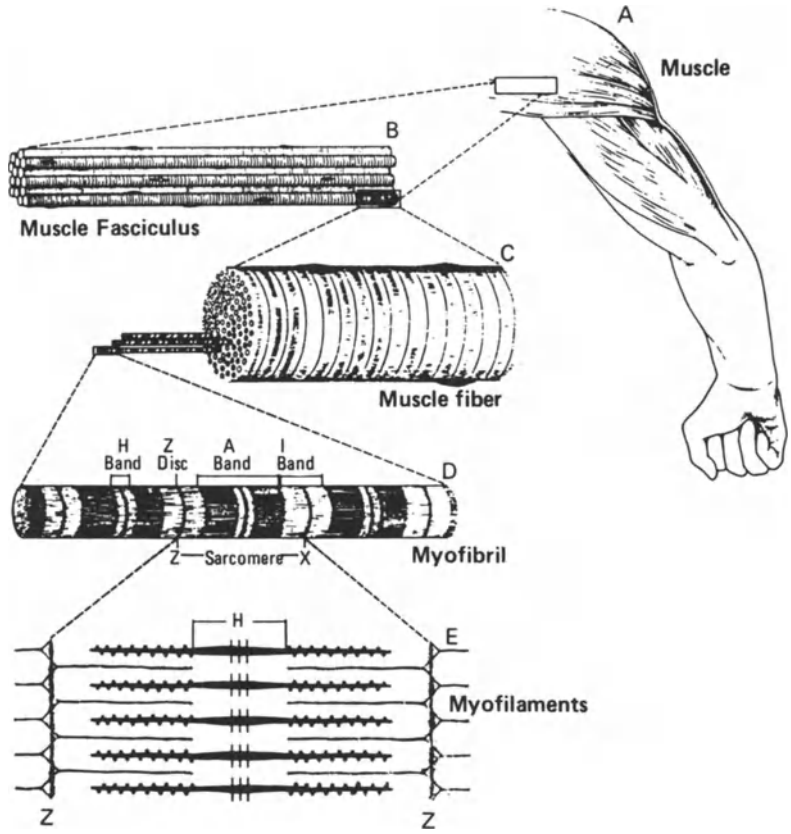


FIGURE 1.1. The various subgroups of muscle tissue are shown in A–E. Notice that the myofibril (D) shows multiple bands, lines, and zones. (Reprinted with permission from Walton.[5])

tional stains such as hematoxylin and eosin do not allow differentiation or identification of the muscle fiber types nor do they show pathological changes due to neuromuscular damage. On the other hand, histochemical stains that are specific for oxidative and glycolytic enzyme systems are able to differentiate two main types of fibers in mammalian muscle tissue. The type I, slow-twitch, muscle fibers utilize oxygen and are rich in oxidative enzymes. The type II, fast-twitch, fibers derive their energy from stored glycogen and thus contain glycolytic enzymes. In many mammals, the two types of fibers tend to occur in separate muscle bellies. By contrast, all human skeletal muscle contains both type I and type II fibers in a ratio that varies between 1:1 and 1:2. Different histochemical stains that are specific for the enzyme systems in the type I and type II fibers typically stain one fiber dark and one light. At the light microscopic level, normal muscle tissue then presents a typical "checkerboard" or "mosaic" appearance (Figure 1.4).

The metabolic differences that distinguish the two muscle fiber types are not inborn, but depend entirely upon the characteristics of their nerve supply. This was established by Buller et al.[1] and confirmed by Dubowitz and Brooke,[2] who performed nerve crossover experiments in the domestic cat. Slow-twitch and fast-twitch muscle fibers congregate into different muscle groups in this animal. By severing and cross-anastomosing the adjoining nerve supplies to the slow-twitch soleus muscle and the fast-twitch flexor hallucis longus muscle, they showed that, after regeneration, a reversal of both enzyme content and fiber characteristic resulted. Thus, the slow-twitch soleus muscle became fast-twitch, and the initially fast-twitch flexor hallucis longus was converted into a slow-twitch muscle (Figure 1.5).

These experiments suggest that the action of

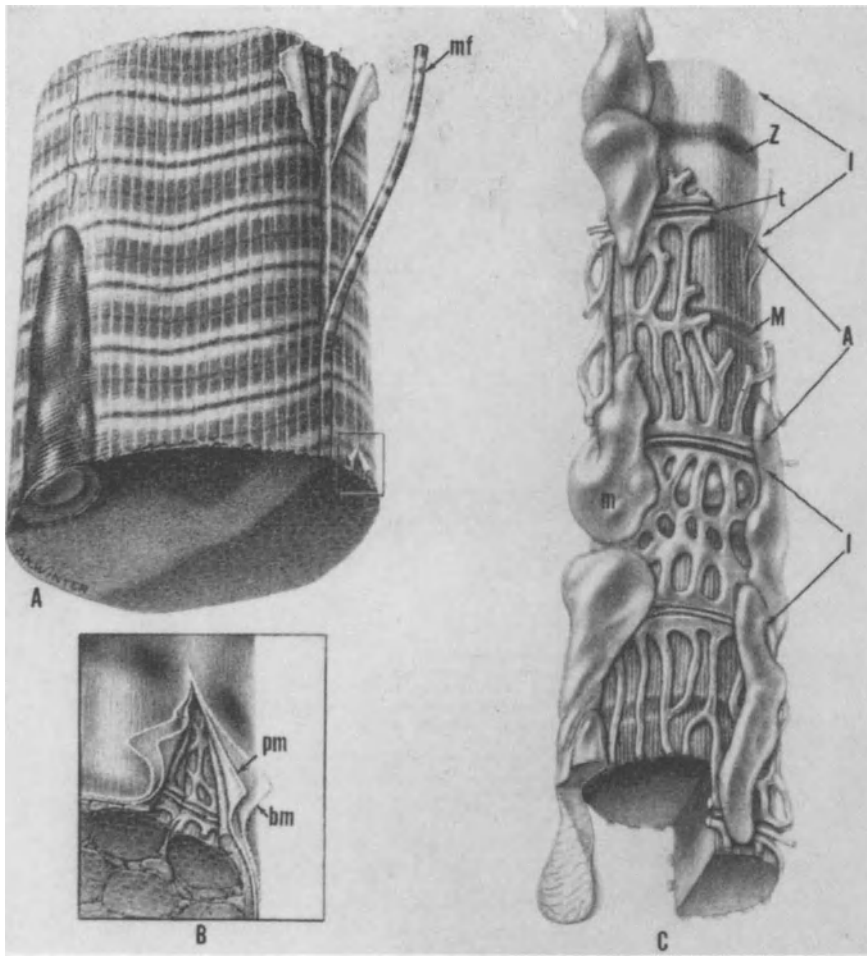


FIGURE 1.2. A: A longitudinal segment of muscle as seen by light microscope (mf, myofibril). B: The basement membrane (bm) and plasma membrane (pm) that surround each myofibril. Deep to this the elements of the sarcoplasmic reticulum and the T system can be seen overlying the myofibril (seen by electron microscopy). C: The isolated myofibril with the basement and plasma membranes removed. The components of the two tubular systems are seen extending over the surface of the myofibril. The components of these two tubular systems form a complex called the triad, which is composed of an intermediate transverse tubule of the T system, bounded on each side by transverse cisterna of the sarcoplasmic reticulum. T, transverse tubule of the T system; I, I band; A, A band; M, M line; Z, Z line; m, mitochondrion. (Reprinted with permission from Walton.[4])

a nerve on a muscle is twofold. Its main function is the transmission of excitatory stimuli, causing muscle contraction. Every nerve also has secondary trophic effects on the muscle fiber it supplies. The first determines the enzyme content and, therefore, the twitch speed and staining characteristics of the fiber. Other trophic factors may also regulate the size and alignment of muscle fibers. Thus, reversal of recognized enzyme patterns, variation in the size of muscle fibers, and the disruption of the alignment of fibers are all features that suggest a disturbance in the motor nerve supply.

A further characteristic relevant to the study is the ability of partly denervated muscles to stimulate the axons of adjacent healthy motor units, to divide, penetrate, and reinnervate the nonfunctioning fibers.[3] Since the enzyme func-

FIGURE 1.3. A higher magnification view of the myofibril showing the various bands and lines. (Reprinted with permission from Walton.[4])



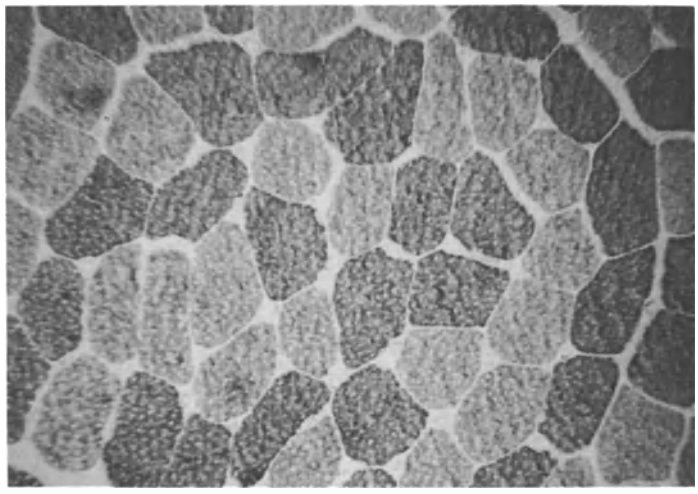


FIGURE 1.4. Normal muscle (control). Histochemical stains at the light microscopic level present a typical "checkerboard" or "mosaic" appearance of type I and type II muscle fibers.

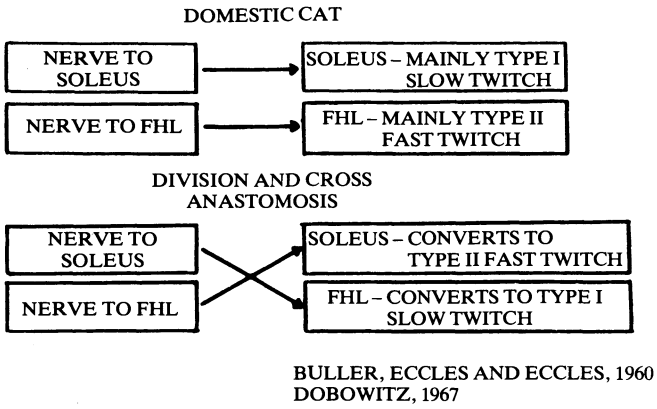
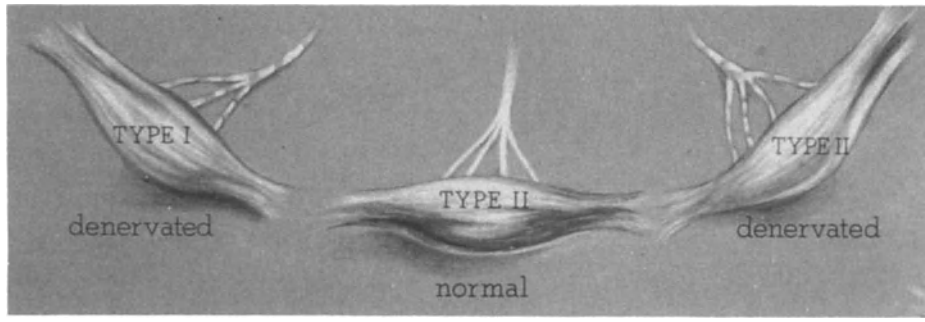
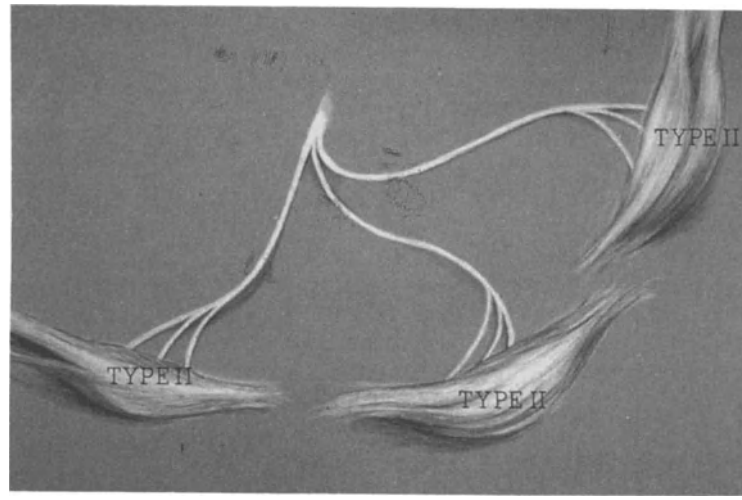


FIGURE 1.5. Cross-anastomosing the nerve to soleus and flexor hallucis longus (FHL) in the domestic cat converts type I slow-twitch fibers to type II fast-twitch fibers, and vice versa.[1,2]



A



B

FIGURE 1.6. A and B: After muscle denervation, the surviving axons divide, penetrate, and reinnervate nonfunctioning fibers. The invading axons impose their own fiber type, thus producing an area of "grouping" in an area of mixed fiber types.

tion and, therefore, the fiber type of all muscle is determined by its nerve supply, the reinnervated fiber always takes on the characteristic of the invading axon (Figure 1.6). If one axon invades several previously denervated fibers, they will all have the same fiber characteristics and, when stained histochemically and studied with light microscopy, will produce a cluster of similar-looking fibers situated within the normal mosaic pattern of human striated muscle. This appearance is termed "grouping," and is evidence of denervation and subsequent reinnervation of an area of muscle. Atrophy, fibrosis, and cytoplasmic architectural abnormalities are changes associated with denervation.

The electron microscopic appearance of normal muscle tissue shows myofilaments that lie in parallel rows, forming myofibrils (Figure 1.3). These present recurring light and dark bands, the I and A bands, respectively. The I band is divided by a dense, broad Z line and down the center of the A band is a lighter zone, the H zone, which itself is bisected by a dark M line. A sarcomere is that portion of a myofibril bounded by two Z lines. The length of the A band is fairly constant at 1.5 μm, but the I band shortens with muscle contraction. Mitochondria separate the myofibrils as do glycogen granules, some triads, and occasional lipid bodies. Type I and type II muscle fibers are not easily distinguishable with the electron microscope. However, type I fibers tend to have more mitochondria and thicker Z lines. Z-line streaming refers to the irregular wavy appearance of the lines as denervation takes place.

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Morphometric Study of Muscles in Congenital Idiopathic Clubfoot

H. Mellerowicz, M. Sparmann, A. Eisenschenk, S. Dorfmuller-Kuchlin, and G. Gosztonyi

The etiology of congenital talipes eqinovarus (CTEV) is still unknown and the subject of considerable discussion.[2–5,7–9] Rabl and Nyga[5] found the bones in the foot of the newborn with idiopathic clubfoot to be normal. So the research interest turned to the soft tissue. As an increase in connective tissue could not be established[10] the reason for the small calf in CTEV should be in the musculature (Figure 1.7).[4]

Gray and Katz,[2] Handelsman and Badalamente,[3] Shimizu et al.,[7] and Sirca et al.[8] detected in the histochemical and electron-microscopic examination of muscle biopsies structural changes and a high proportion of type 1 fibers.

These findings indicated CTEV to be a neuromuscular disorder. Although this fiber distribution anomaly was prominent in nearly all examinations, its relation to function or age has not yet been described.



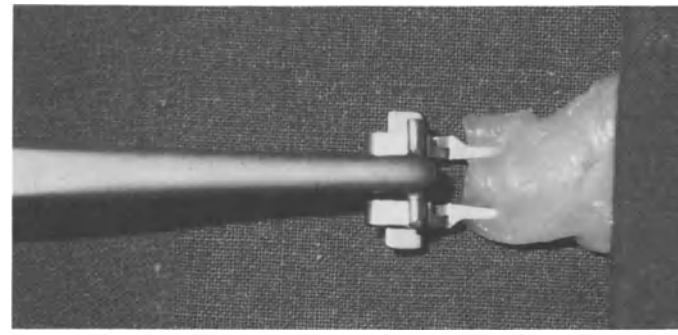
FIGURE 1.7. Small calves in a 12-year-old child with CTEV.

Materials and Methods

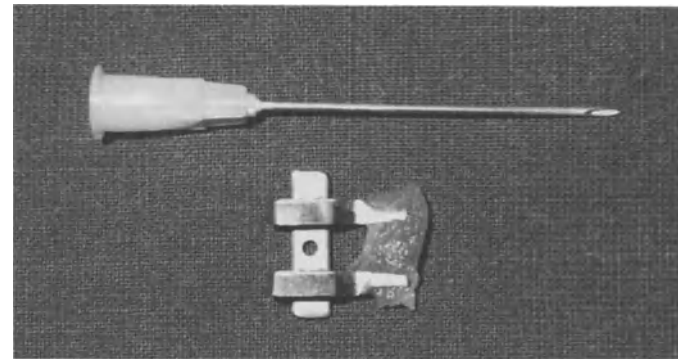
During corrective surgery 48 muscle samples were taken from 46 children using a specially designed forceps. This forceps allows the surgeon to take reasonable amounts of material without any further damage or "supercontractions" and to provide secure transport until final fixation (Figure 1.8). Muscle samples were taken from the flexor group (40 biopsies), most frequently from the gastrocnemius muscle. In one case, in addition to a flexor muscle, the anterior tibial was biopsied, and in two further cases samples from the quadriceps muscles were also removed. The age of the children varied from 6 weeks to 12 years (Figure 1.9). In most of the children, biopsies were taken during the first operative foot correction at the age of 4 months. In the elder children operations were indicated because of relapses.

After removing the biopsies a large piece was deep frozen in liquid isopentane −160°C, and a small piece fixed in 2% glutaraldehyde for electron-microscopic examination. The deep frozen specimen was transversely cut by cryostat and stained according to conventional histological and histochemical techniques. For morphometric purposes, adenosine triphosphatase (ATPase) preparations of pH 4.6 and 4.3 were used. According to Brucher et al.[1] muscle fiber diameters were measured and calculated with a semiautomatic morphometry system. Biopsies of healthy children at various ages were not used as measurements if reference values of normal healthy children were already available.[6]

FIGURE 1.8. 2A and B: Specially designed forceps for muscle biopsies.



A



B

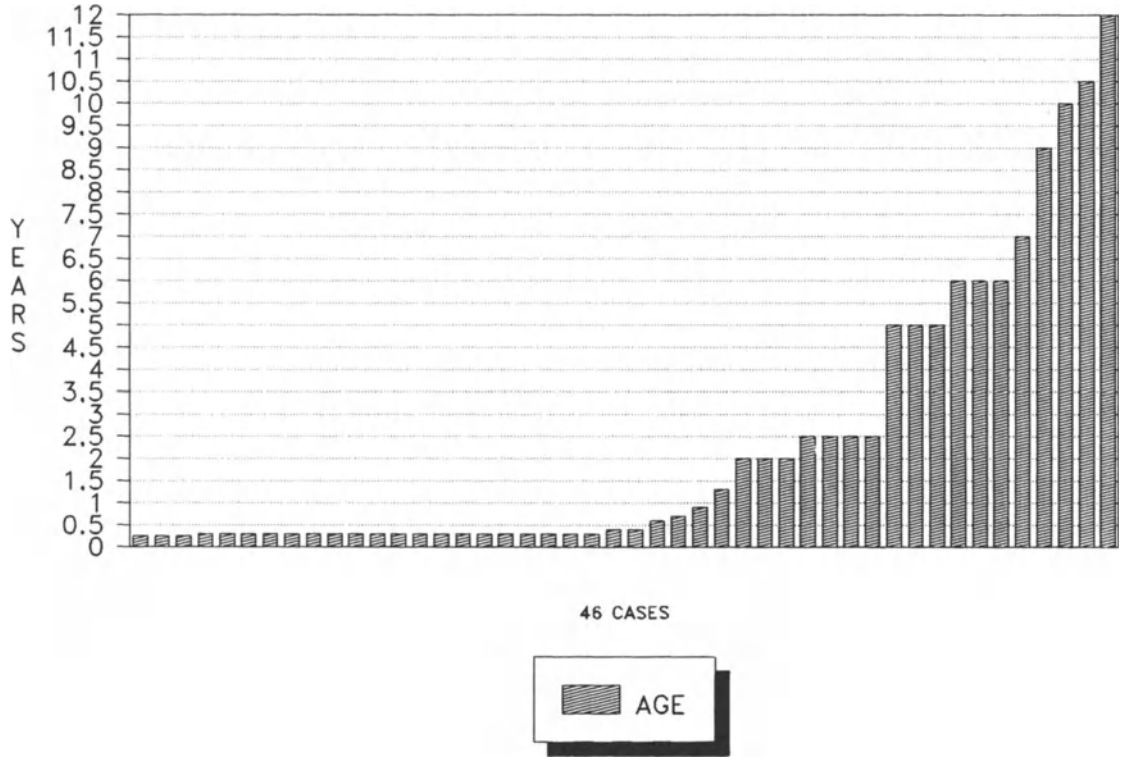


FIGURE 1.9. Age distribution of biopsies in CTEV (46 cases).

Results

Light Microscopy

Light-microscopic examination did not show any pathological changes besides the morphometric parameter of type 1 fiber predominance.

Distribution of Fiber Types

A normal fiber type distribution was found in only 8 of the 46 biopsies of the leg muscles. In 37 cases, an outstanding predominance of the type 1 fiber was shown (Figures 1.10 and 1.11). The number of type 1 fibers increased to 86% to 90% in some cases (Figure 1.12). This specific distribution was found in all age groups (Figure 1.13). Two muscle biopsies from extensor muscles were similar with type 1 predominance.

Morphometric Examinations

The mean fiber-type diameters (Figure 1.14), in the first 6 months, were 10 μm for type 1 and 10.5 μm for type 2 fibers. Biopsies of the older children showed a progressive increase in the fiber diameters, which corresponded roughly to the normal values of the specific age groups.

In two children, additional muscle samples were examined from the quadriceps femoris. These samples were normal in every respect.

Electron-Microscopic Examination

Electron-microscopic examinations were performed on every muscle sample. Only very slight changes could be found. They consisted of circumscribed or diffusely distributed myopathic muscle fibers. Generally these changes are reversible. In one case ring fibers could be found in several muscle fibers (Figure 1.15).

Discussion

As in previous reports of our studies we have found an overwhelming predominance of type 1 fibers in the calf muscles in CTEV. The proportion of type 1 fibers in the flexor group is 72% in this series and 61% in that of Gray and Katz.[2] The normal value in this muscle group is 50.8% according to Schröder[6] and 44.5% according to Gray and Katz.[2] Whereas Sirca et al.[8] reported in older groups no significant alteration in muscle fiber distribution for the abductor hallucis muscle, we found the type 1 fiber predominance independent of age.

This permanent finding indicates a congenital abnormality of the clubfoot itself and is not a consequence of the abnormal position in the leg in utero. The children are born with a deficit of type 2 fibers and this deficit remains constant during their development. There are no other pathological changes to be

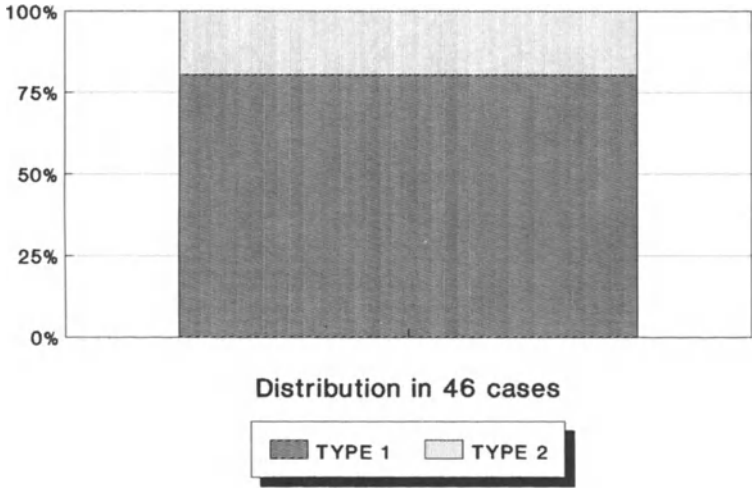


FIGURE 1.10. Distribution of mean fiber types in 46 biopsies of gastrocnemius muscle.

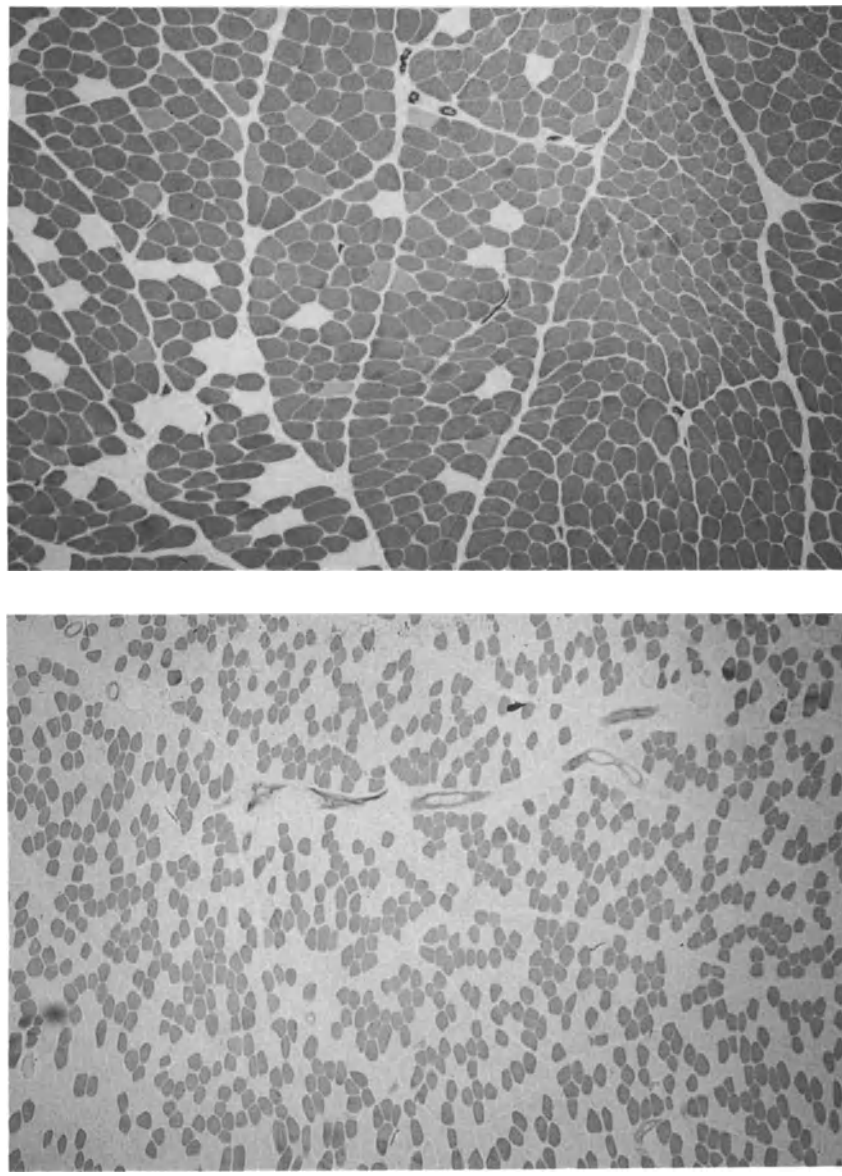


FIGURE 1.11. A: Type 1 fiber predominance in the gastrocnemius muscle of a 2-year-old child with CTEV. ATPase reaction, pH 4.6 (magnification ×150). B: Age-matched control sample from the gastrocnemius muscle with normal fiber type distribution. ATPase reaction, pH 4.6 (magnification × 150).

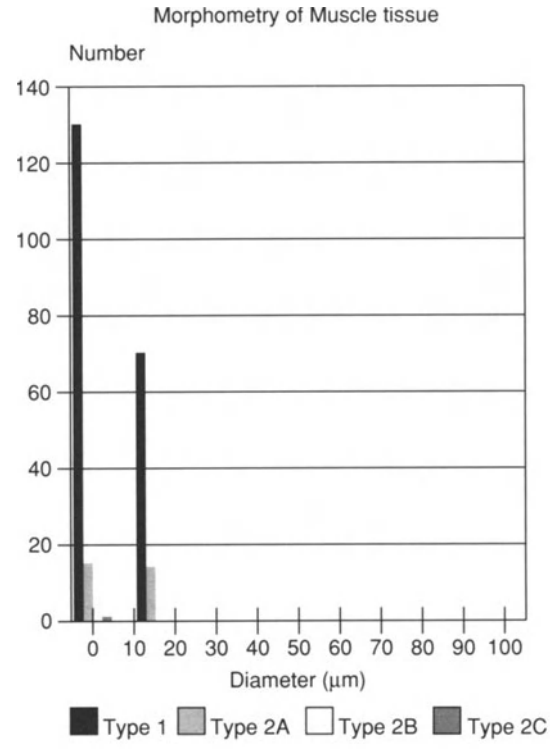
found in our study in the leg muscles, no signs of denervation, and only very small myopathic changes.

The leg musculature grows normally as the fiber diameters develop according to the child's age. The smaller volume of the calf musculature can only be explained by the deficit of type 2 fibers. This deficit is localized. The cases of simultaneously removed muscle biopsies from quadriceps muscles did not show any abnormality.

Thus, we could prove this type 2 deficit to be localized to the distal part of the lower extremity. Our electron-microscopic findings show

type	DIAMETER average(μm) (N = 60 +/- 20)		variation (N < 250)
	10	2	208
	10	3	261

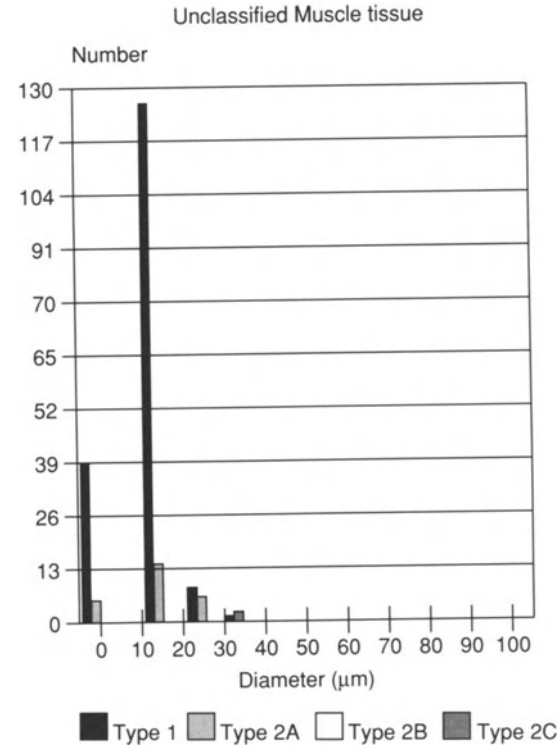
DISTRIBUTION (%) FACTOR			
Type	Number	Area	Normal
1	84	83	34–52
2A	12	15	22–40
2B	3	2	22–40
2C	0	0	0–3



A

type	DIAMETER average(μm) (N = 50 +/- 20)		variation (N < 250)
	10	2	208
	10	3	261

DISTRIBUTION (%) FACTOR			
Type	Number	Area	Normal
1	84	83	34–52
2A	12	15	22–40
2B	3	2	22–40
2C	0	0	0–3



B

FIGURE 1.12. Type 1 predominance in morphometry of a 3-month-old (A) and 9-year-old child (B).

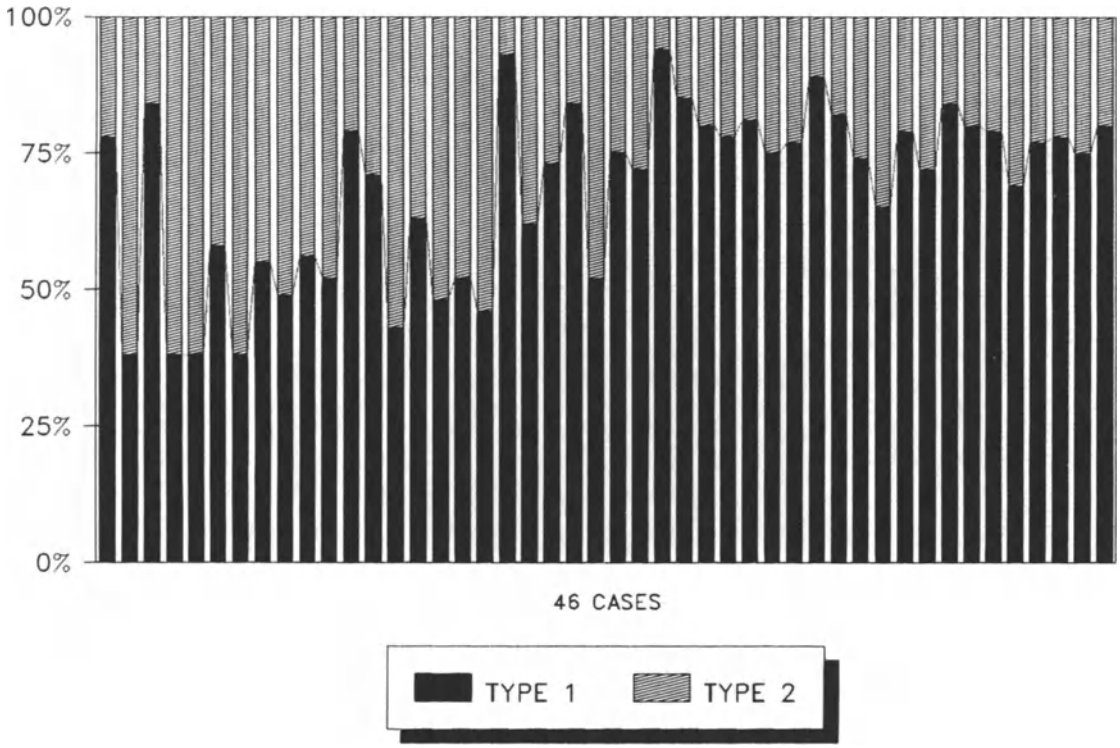


FIGURE 1.13. Muscle fiber types and age (46 cases).

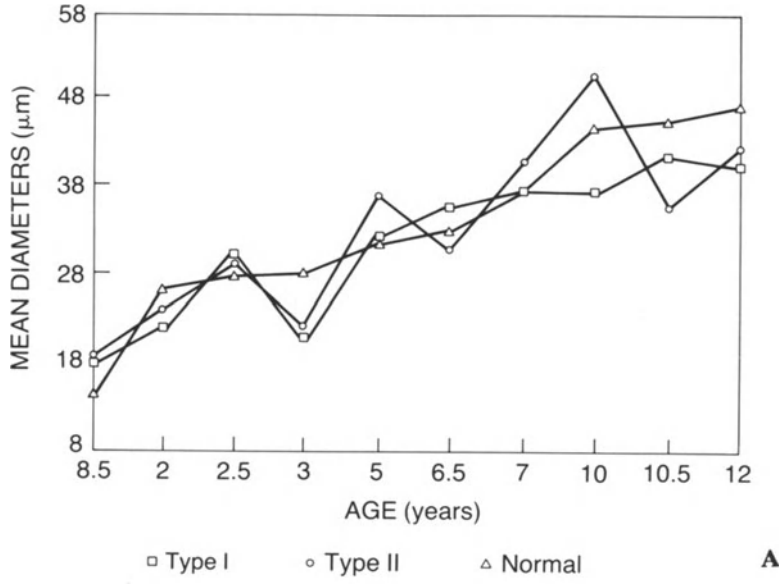


FIGURE 1.14. Increase of mean diameters of type 1 and 2 fibers as function of age.

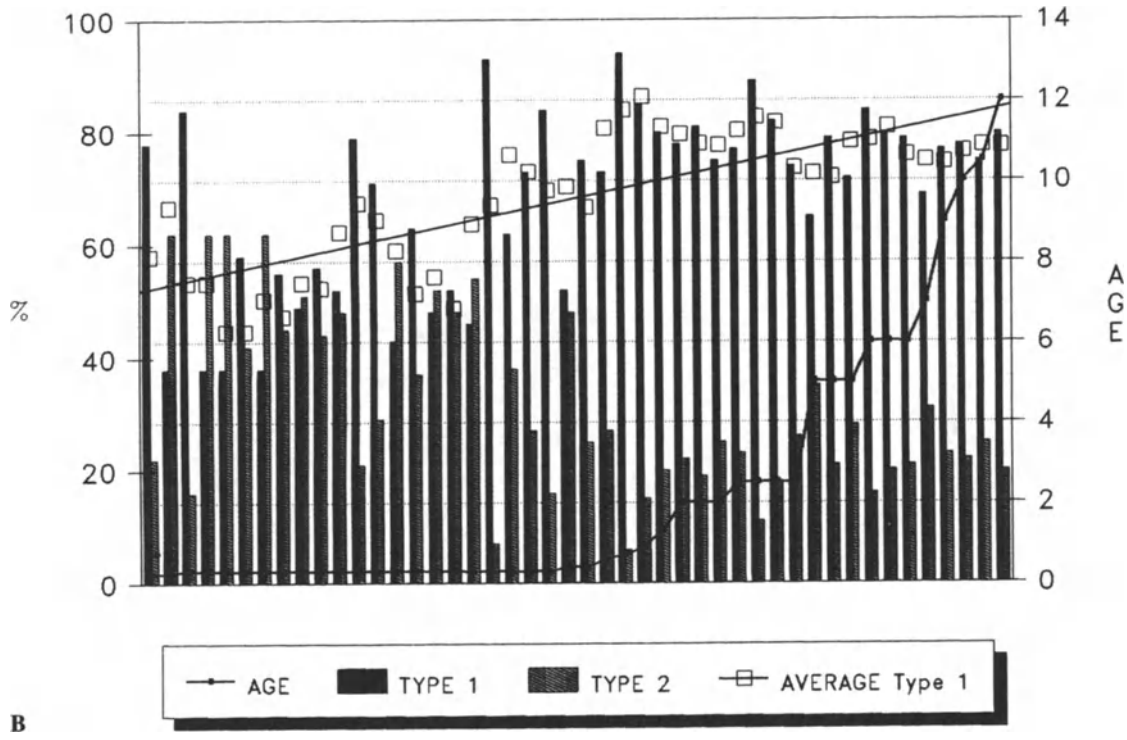


FIGURE 1.14. (cont.)

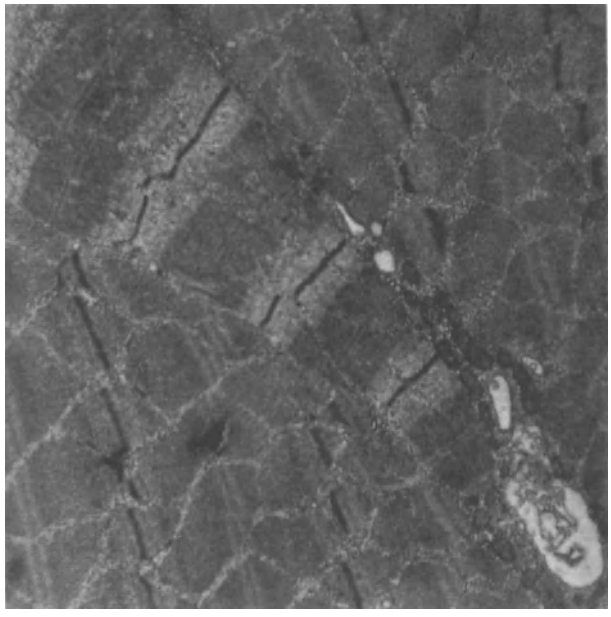


FIGURE 1.15. Electron micrograph of a ring fiber (identified by arrows) from a transverse cut of gastrocnemius muscle fiber. The ring fiber lies like a ring around the muscle fiber and has been cut longitudinally in an oblique position (magnification ×13,500). Ring fibers are regarded, in general, as a consequence of abnormal muscle tension, which could be caused by the foot deformity itself or by previous conservative therapy. The slight structural changes in the muscles can be interpreted in this context.

very slight and reversible myopathic changes, and so our results agreed with previous studies by Wolff and Tönnis.[10]

Ring fibers in muscles of patients with CETV have not been described. Generally they appear under abnormal muscle tension, which could be interpreted as a result of the previous conservative treatment.

Tönnis[9] was the first to point out the importance of an imbalance of agonist and antagonist muscle groups in the development of the clubfoot deformity. A possible explanation may be found in the findings of an abnormal composition of the fiber types with predominance of slow-twitch type 1 fibers, which was age independent, from an imbalance in muscle tone. This may offer an explanation for a clubfoot deformity.

The question remains, as type 2 fibers remain undeveloped, have they been damaged early in fetal life or is this special fiber deficit genetically determined? Perhaps further research will give an answer to these questions. Now, as the corrective measures do not influence the basic abnormality, relapses or "rebellious clubfeet"[11] are explainable.

Summary

In recent years many efforts have been made to discover the etiology of congenital talipes equinovarus (CTEV). Neuropathological examinations using histochemical, morphometric, and electron-microscopic examinations indicated neuromuscular anomalies in many of these cases. Our study consists of muscle biopsies from 46 patients with congenital idiopathic clubfoot deformities, taken during the surgical correction of the anomaly. In order to get a reasonable amount of muscle material and to avoid damage and "supercontractions" of the muscle and further trauma to the patient, we used a specially designed forceps to remove the specimen.

The muscle biopsies were taken mainly from the flexor group. The age of the patients varied from 6 weeks to 12 years. Histological and histochemical findings did not show any pathological changes. Electron-microscopic examination disclosed fine structural changes, which could be related to the conservative treatment.

Semiautomatic morphometric examinations showed an increased predominance of type 1 fibers with age, compared to the normal composition in the flexor group. The small calf of the children in CTEV and the high incidence of relapses related to the fiber distribution show the clinical importance of these alterations.

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Histochemical Studies in Congenital Clubfeet

A. Kojima, H. Nakahara, N. Shimizu, I. Taga, K. Ono, I. Nonaka, and K. Hiroshima

The etiology of congenital clubfoot is still unknown although this condition has been well described since ancient times. There are many hypotheses about the etiology, such as primary bone dysplasia,[14] aberrations of tendon insertions,[4,18] abnormalities in tendon sheaths, abnormal intrauterine posture,[1] and neuromuscular defects.[5,7,10] Histologically, some authors reported no remarkable findings in muscles and nerves,[4,5,9] but others recognized remarkable findings using histochemical technique and electron microscopy.[5,7,10,19] In an attempt to evaluate the neuromuscular abnormality in congenital clubfeet, we have carried out histochemical studies of muscles in patients with congenital clubfeet.

Materials and Methods

From 1986 to 1990, we surgically treated 39 patients with talipes equinovarus deformity (CTEV). We made histochemical investigations in 30 of these patients. Five patients with arthrogryposis multiplex congenita (AMC) and

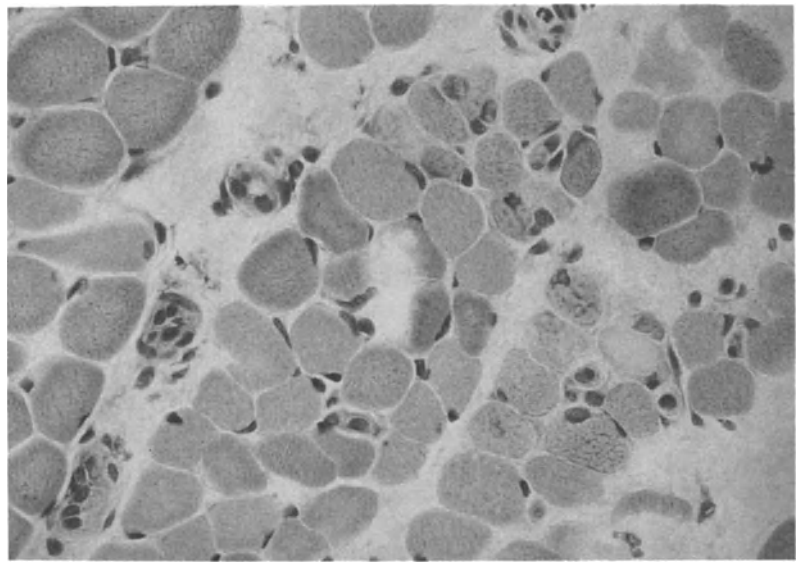


FIGURE 1.16. Flexor hallucis longus muscle of a child 1 year and 1 month old. Moderate fiber size variation and mild fibrosis H&E, ×100).

TABLE 1.1. Categories of muscle biopsies used in the histochemical study.

	Extrinsic muscle ($n = 34$)		Intrinsic muscle ($n = 42$)	
Plantar flexor muscle ($n = 55$)	Tibialis posterior	3	Abductor hallucis	27
	Flexor hallucis longus	16	Flexor hallucis brevis	1
	Flexor digitorum longus	5		
	Gastrocsoleus	3		
Dorsal extensor muscle ($n = 21$)	Peroneus longus and brevis	6	Extensor digitorum brevis	14
	Extensor hallucis longus	1		

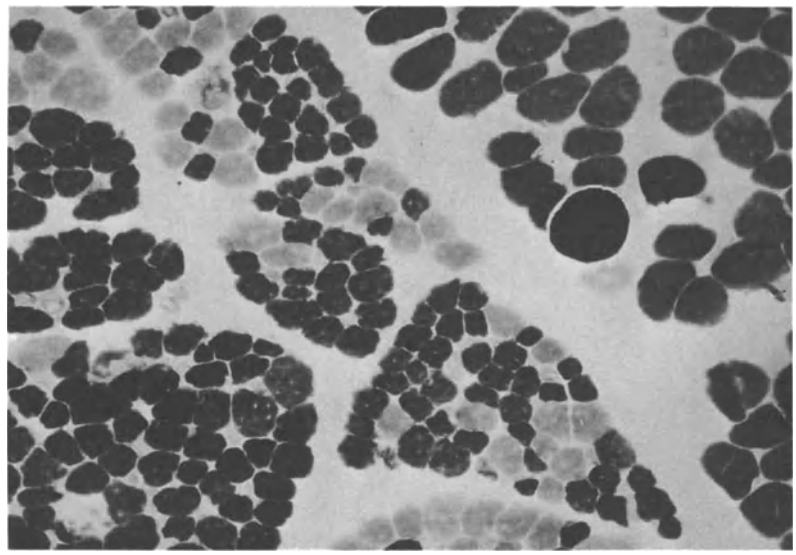


FIGURE 1.17. Flexor hallucis longus muscle of a 5-year-old girl (obtained at second operation). Marked fiber type grouping. (ATPase preincubated at pH 4.6, ×33.)

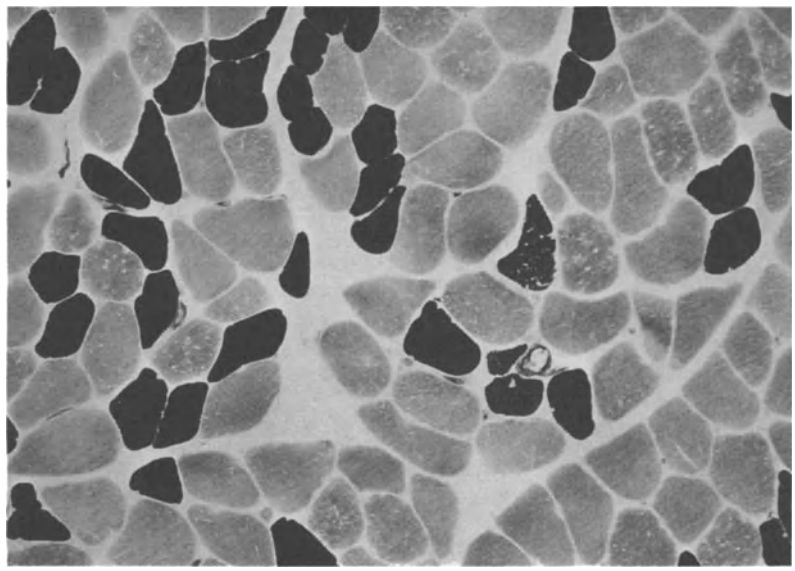


FIGURE 1.18. Abductor hallucis muscle of a 10-year-old boy (obtained at third operation). Type 1 predominance, type 2B fiber deficiency. (ATPase preincubated at pH 9.6, ×33.)

spina bifida were excluded from this study. Thus, 25 patients with CTEV were analyzed.

Before their operations all patients were treated with serial corrective casts followed by splints. Seventy-six muscle specimens were procured from these patients during surgery. In 6 out of 25 patients, specimens were taken at reoperation. The patients consisted of 18 boys and 7 girls (15 bilateral cases and 10 unilateral cases). The age at operation ranged from 10 months to 14 years 4 months, with an average age of 3 years 2 months.

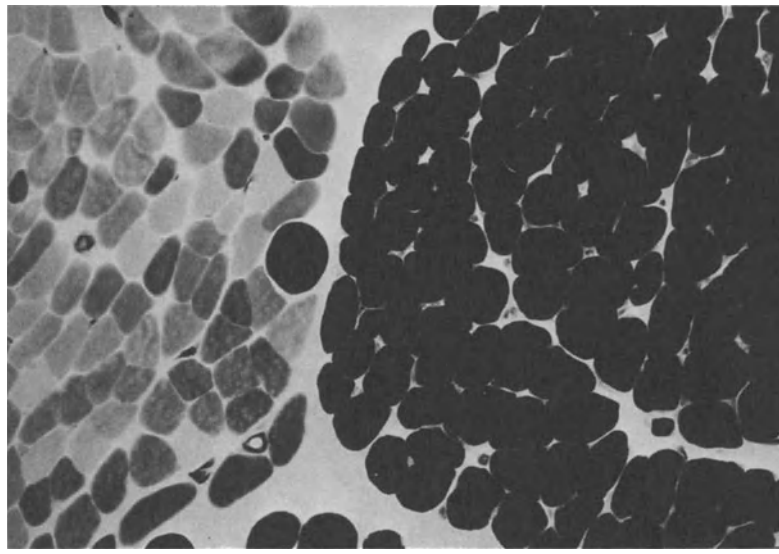


FIGURE 1.19. Extensor digitorum brevis muscle of an 11-month-old baby. Group atrophy, type 1 fiber predominance, fiber type grouping. Also type 2B fiber deficiency was diagnosed with other stains. (ATPase preincubated at pH 4.6, ×80.)

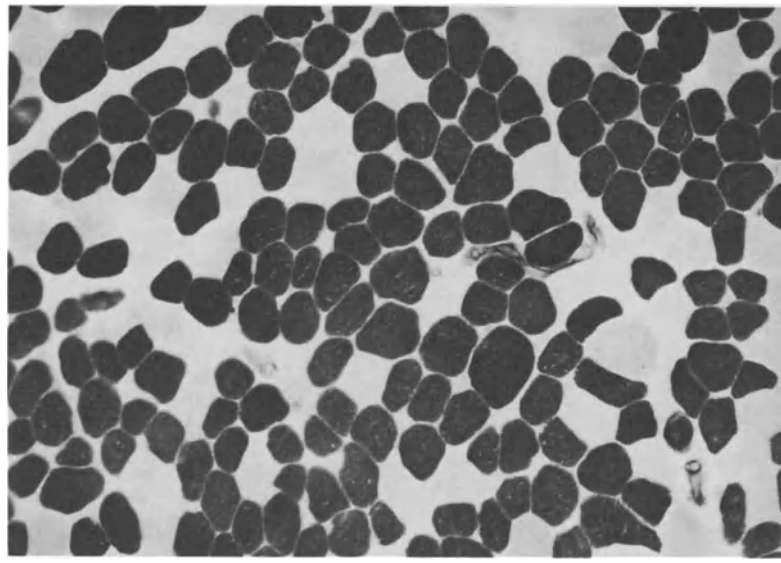


FIGURE 1.20. Extensor digitorum brevis muscle of a 1-year-old baby. Type 1 fiber predominance and type 2B fiber deficiency. (ATPase preincubated at pH 4.6, ×66.)

Muscle biopsies were taken from 34 extrinsic muscles [16 flexor hallucis longus (Figures 1.16 and 1.17), 5 flexor digitorum longus, 3 tibialis posterior, 3 gastrocsoleus, 6 peroneus, and 1 extensor hallucis longus muscle] and 42 intrinsic muscles [27 abductor hallucis (Figure 1.18), 1 flexor hallucis brevis, and 14 extensor digitorum brevis muscles (Figures 1.19 and 1.20)] (Table 1.1).

All specimens were frozen in isopenthane cooled by liquid nitrogen, and then examined by stains such as hematoxylin and eosin, ATPase (at pH 9.4, at 4.6 and at 4.3), nicotinamide-adenine dinucleotide, reduced (NADH-TR), modified trichrome, periodic acid-Schiff, oil red 0, phosphorylase, and nonspecific elastase.

Results

In specimens stained by hematoxylin and eosin, there was mild to moderate variation in fiber size in most of the cases (Figure 1.16). There was fibrosis in 12 muscles, and there were small angulated fibers in eight muscles. Increased numbers of regenerated fibers and hypertrophic fibers were seen in three muscles respectively. There was group atrophy in one muscle (Figure 1.17). No muscle showed necrosis.

In histochemical analysis, there were distinct abnormalities, especially in fiber type distribution (Figure 1.20). Type 1 fiber predominance (over 55% of fibers) was seen in 17 muscles (22%) (Figure 1.20), of which 4 were extrinsic muscles and 13 were intrinsic muscles. An increased number of type 2C fibers (over 5% of total fibers) were found in 21 muscles (28%).

On the other hand, type 2B fiber was deficient in 17 muscles (22%); all of these were intrinsic muscles (40% of intrinsic muscles). Fiber type grouping was observed in 13 muscles (17%). There was specific fiber type atrophy in 13 muscles, all but one of them showing type 1 fiber atrophy. Only 21 muscles (28%) were histochemically normal. As for extrinsic muscles, 14 muscles (41%) were normal, and of the intrinsic muscles, 7 (17%) were normal.

When muscles were divided into two groups, the plantar flexor group (55 muscles) and the dorsal extensor group (21 muscles), there was no significant difference in the ratio of abnormal findings between two muscle groups except for fiber type grouping.

With regard to age, type 1 fiber predominance was somewhat frequent in older children, and type 1 atrophy was rare in patients

TABLE 1.2. Findings on muscles and fibers in the histochemical study.

	Total ($n = 76$)	Extrinsic muscle ($n = 34$)	Intrinsic muscle ($n = 42$)	Flexor muscle ($n = 55$)	Extensor muscle ($n = 21$)	Age distribution 0–1 ($n = 32$)	Age distribution 1–2 ($n = 18$)	Age distribution 2 and over ($n = 26$)	Primary operation ($n = 61$)	Reoperation ($n = 15$)
Type 1 fiber predominance (over 55% of total fiber)	17 (22.4)	4 (11.8)	13* (31.0)	14 (25.5)	3 (14.3)	5 (15.6)	3 (16.7)	9 (34.6)	14 (23.0)	3 (20.0)
Type 2C fiber increase (over 5% of total fiber)	21 (27.6)	8 (23.5)	13 (31.0)	17 (30.9)	4 (19.0)	7 (21.9)	7 (38.9)	7 (26.9)	18 (29.5)	3 (20.0)
Type 2B fiber deficiency	17 (22.4)	0 (0)	17** (40.5)	12 (21.8)	5 (23.8)	10 (31.3)	2 (11.1)	5 (19.2)	14 (23.0)	3 (20.0)
Type 1 fiber atrophy	13 (17.1)	7 (20.6)	6 (14.3)	10 (18.2)	3 (14.3)	7 (21.9)	4 (22.2)	2 (7.7)	12 (19.7)	1 (6.7)
Fiber type grouping	13 (17.1)	3 (8.8)	10 (23.8)	6 (10.9)	7* (33.1)	3 (9.4)	0 (0)	10** (38.5)	6 (9.8)	7** (46.7)
Histochemically normal muscle	21 (27.6)	14 (41.2)	7* (16.7)	16 (29.1)	5 (23.8)	11 (34.4)	7 (38.9)	3 (11.5)	18 (29.5)	3 (20.0)

Numbers in parenthesis indicate percent.
*$p < .05$; **$p < .005$.

over 2 years old. Normal muscle was seen less frequently in patients over 2 years old. Muscle specimens obtained at reoperation showed a significantly elevated ratio of fiber type grouping. These findings were summarized in Table 1.2.

Discussion

Congenital clubfoot deformities are rigid, and frequently accompanied by atrophy of calf muscle as well as atrophy of the foot. They are also, at times, accompanied by leg length discrepancy. So there should be fundamental pathology in the etiology of clubfoot. The etiology of this disease remains unknown.

In routine histological examinations, no overt findings other than fiber size variation have been reported.[10] But histochemical studies have revealed some abnormalities.[5,7,10,19] Enzymatic activity of muscle has been reported to depend on its nerve supply;[2,3,15] and, therefore, the neuromuscular defect theory has been advocated. [5,7,10] In this study, we found abnormalities such as type 1 fiber predominance, type 1 fiber atrophy, type 2C fiber increase, and type 2B fiber deficiency.

Type 1 fiber predominance does not appear to be due to treatment, but rather to the disease itself, because immobilization or stretching did not change the muscle fiber type.[5,7,13,17]

In normal soleus and abductor hallucis muscle, type 1 fiber increases in number with age, but in clubfoot patients there has been reported early maturation of type 1 fiber.[5,19] Some authors speculated that type 1 fiber predominance of the posteromedial muscles produced subtle but continuous muscle imbalance, and speculated that the muscle imbalance is the primary cause of the deformity.[5,7,10]

In the present study and that reported by others,[10] however, type 1 fiber predominance was also found in the dorsal extensor muscle group, so it is questionable that type 1 fiber predominance by itself produces the deformity.

As for type 1 fiber atrophy, it may be caused by immobilization, but may also be caused by a neurotrophic factor.[6,12] In a normal control study, distal muscles, especially extensor digitorum brevis, differed from other muscles, showing fiber type grouping.[11]

It may not be pathological that intrinsic muscles and dorsal extensor muscles showed fiber type grouping more frequently in this study (two-thirds of dorsal extensor muscles were extensor digitorum brevis muscles). In the reoperated cases, specimens showed fiber type grouping very frequently, whereas the ratio of normal to abnormal findings was similar to those of specimens' at primary operation. A high ratio of fiber type grouping in specimens at reoperation may not be iatrogenic, but fiber type grouping may have some influence on recurrence of the deformity.

The pathological implication of fiber type grouping has been postulated to be the presence of denervation or the presence of developmental disorders of neuromuscular innervation.[16] The type 2C fiber has been reported to be immature and to increase in number in the recovery from denervation. Group atrophy was found in only one muscle, so the presence of an active denervation process is not apparent.

These findings, such as fiber type grouping and increase in type 2C fiber without an active denervation process, may suggest full recovery has occurred from temporary denervation early in the fetal period, or it may suggest anomalous innervation to developing muscles.[8] When all of the above facts are considered, our results suggest abnormal muscle development and maturation possibly due to defective neuronal influences.

A normal control study alone is not enough, especially in foot muscles, to determine clearly the etiology of clubfoot. Still, we believe that a neuromuscular defect is one aspect of the basic pathology in congenital clubfoot.

Conclusion

In the present study, histologically there was no structural abnormality other than fiber size variation. However, histochemical abnormality in fiber type distribution was frequent. Increase of type 2C fiber in number, type 1 fiber predominance, and type 2B deficiency were the most common and frequent findings, the latter two findings being more frequent in intrinsic muscles.

On the other hand, group atrophy was found in only one muscle, so denervation was not apparent. These findings suggest abnormal muscle development and maturation, perhaps due to defective neuronal influences.

Summary

Histochemical studies were made of 25 patients with congenital clubfeet. Our findings of abnormal type 1 fiber predominance, type 1 fiber atrophy, type 2C fiber increase, and type 2B fiber deficiency suggest abnormal muscle development and maturation due to possible neuronal influences.

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Muscle Pathology in Clubfoot and Lower Motor Neuron Lesions

J.E. Handelsman and R. Glasser

Physicians have disagreed about the fundamental cause and pathogenesis of clubfoot since the time of Hippocrates. More recently, Bohm [3] suggested that the deformity was an arrest of embryonic development. Gardner et al.[13] however, could find no clubfoot-like stages of development. Intrauterine crowding was proposed by Browne.[6] This still popular theory is indeed a factor in foot deformities that are mobile at birth, but true rigid clubfoot



FIGURE 1.21. Child with severe bilateral clubfeet. Calf muscle bulk is markedly diminished.

is already present when the developing fetus is so small that crowding would not be a factor. Aberrations of tendon attachments have been evoked by several authors.[10,12,24,25,27] Described anomalies, however, have been seen by one of us (J.H.) in 66 otherwise normal feet in cadaveric dissections, suggesting that these are not fundamental to the pathology.[14] Many deformities, particularly of the head and neck of the talus, are frequently present in clubfoot at birth[1,5,9,17–19,21–23,26] An abnormal talus, however, does not explain the more significant multiple joint subluxations that are also present.

Growing bone and cartilage respond rapidly to external forces and it is our belief that these osseous abnormalities may be secondary adaptive changes to unbalanced forces that are operative from an early intrauterine stage. The consistent finding in rigid clubfoot, however, is a diminution in calf muscle bulk.[2,19] Indeed, the more severe the deformity, the thinner and more atrophic is the appearance of the calf (Figure 1.21). This fact, and the unstretchability of the posteromedial extrinsic muscles, suggest that a neuromuscular defect is a fundamental pathogenic entity in clubfoot. This concept is suggested by the fact that clubfoot deformity is seen in neurogenic conditions such as myelodysplasia and lumbosacral agenesis.

The possibility that a neuromuscular defect is present in clubfoot prompted a pilot study that was started in 1979.[15] Ninety muscle biopsies were obtained from the posteromedial musculature at surgical release of 13 clubfeet. Specimens were studied with the light microscope, using enzyme-specific histochemical stains, and with the electron microscope.

Consistent ultrastructural abnormalities were observed in all specimens. Histochemistry revealed a dominant type I fiber population and a type I fiber grouping. A correlated increase in type I neuromuscular junctions was found to occur in these areas. These changes suggested that a neuromuscular abnormality was present. More specifically, the finding suggested that there was a process of denervation and reinnervation of muscle, and that this is significant in the etiology of clubfoot.

Purpose

In 1983, a further study was undertaken to confirm the findings previously noted in clubfoot musculature, and to compare the changes found in clubfoot muscle to those occurring in other peripheral deformities.

Material

We obtained 357 biopsies from 84 patients during surgical correction of lower limb deformities; 159 were from clubfoot patients, and the rest were from patients suffering from Charcot-Marie-Tooth disease, arthrogryposis, myelodysplasia, congenital vertical talus, poliomyelitis, lumbosacral agenesis, cerebral palsy, and post–head-injury hemiplegia. Samples were also obtained from a patient with Down syndrome and another with trisomy 18 syndrome. Control muscle was obtained from 29 normal children who underwent surgery for different reasons (Table 1.3). Except for the controls, the muscles sampled are depicted in Table 1.4. When the medial side of the foot was exposed, access to the peroneal muscles was obtained by making a small incision in fascia close to the fibula to expose the peroneal muscles. Biopsy was taken without any attempt to distinguish

TABLE 1.3. Biopsies obtained.

Clubfoot	159
Charcot-Marie-Tooth	22
Arthrogryposis	10
Myelodysplasia	27
Congenital vertical talus	5
Poliomyelitis	5
Lumbosacral agenesis	7
Cerebral palsy	72
Post–head-injury hemiplegia	3
Down syndrome	12
Trisomy 18 syndrome	6
Normal controls	29

TABLE 1.4. Muscles sampled.

Soleus
Tibialis posterior
Flexor hallucis longus
Flexor digitorum longus
Peroneus longus and brevis
Abductor hallucis

between the peroneus longus and the brevis muscles.

Methods

Biopsies were taken from the substance of the muscle, away from tendon attachments. Each was laid flat on a saline-soaked sponge to maintain resting length. As soon as possible, the biopsy specimen was dissected. The first portion was immediately transferred to a cold Karnovsky's fixative, processed, embedded in Spurr's resin, sectioned longitudinally on a Sorval MT2B ultramicrotome, and stained with uranyl acetate and lead citrate. Sections were viewed under a Sieman's 1A electron microscope and any ultrastructural anomalies were recorded and photographed.

The second section was snap frozen in a dry ice and acetone mixture, sectioned transversely on a Tissue Tek II cryostat, and stained for routine histology with hematoxylin-eosin and modified trichome stains. Type I and type II fibers were distinguished by staining for adenosine triphosphatase, preincubated at pH 10.4. Motor end plates of the respective muscle fiber types were demonstrated by the combined nicotamide adenine dinucleotide–α-naphthyl acetate esterase procedure.

At the electron-microscopic level, anomalies were sought particularly in the sarcomeres, Z lines, mitochondria, and the triad system. The light microscopic examination included studies of fiber type disproportion, grouping, atrophy, cellular structural abnormalities, and fibrosis. The numbers of different fiber types and corresponding neuromuscular junctions were examined for correlation. Random samples were selected for histomorphometry using a Zeiss videoplan to determine fiber size and percentage of type I and type II fibers. Histograms were generated for statistical analysis.

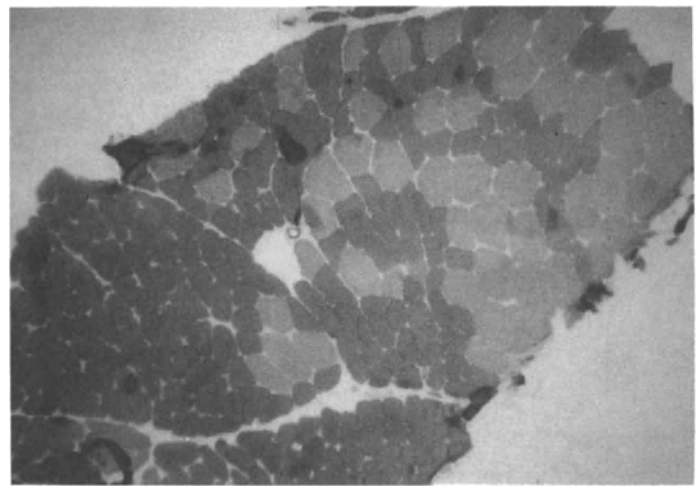


FIGURE 1.22. Clubfoot. Light microscopy, histochemical stains. Type I fiber grouping and atrophy (lower left).

Results

Light-Microscopic Studies

Virtually every muscle biopsy in the clubfoot patients revealed some abnormality. The most striking were type I fiber predominance, fiber grouping, type I fiber atrophy (Figure 1.22), and fiber size variation (Figure 1.23). Occasionally, there was an absolute increase in type II fiber population. Intracellular anomalies existed in the form of an increase in the number of central nuclei, and extracellular fibrosis was occasionally seen (Figure 1.24) (Table 1.5). In many of the specimens examined, more than one anomaly was seen.

TABLE 1.5. Clubfoot: light-microscopic results.

Type I fiber predominance	56%
Fiber grouping	52%
Fiber size variation	17%
Type II fiber population increase	1%
Increased central nuclei	7%
Extracellular fibrosis	4%
Fiber regeneration	3%
Target fibers	<1%
Cellular structural changes	<1%

Specimens obtained from the patients with Charcot-Marie-Tooth disease were strikingly similar to the clubfoot specimens. Type I fiber preponderance and fiber grouping were the

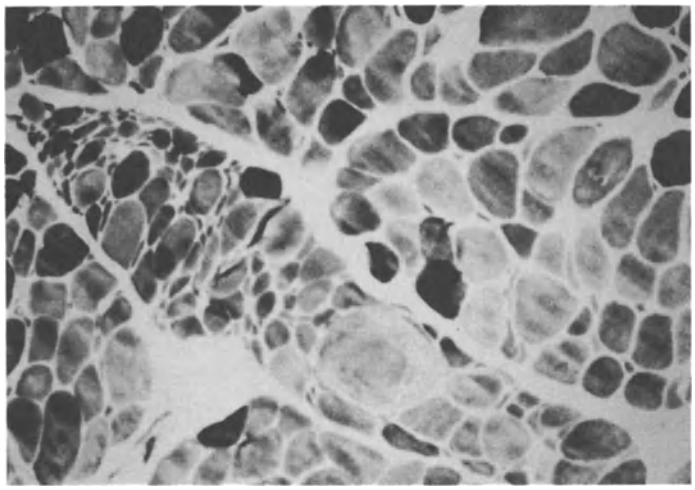


FIGURE 1.23. Clubfoot. Light microscopy, histochemical stains. Fiber size variation.

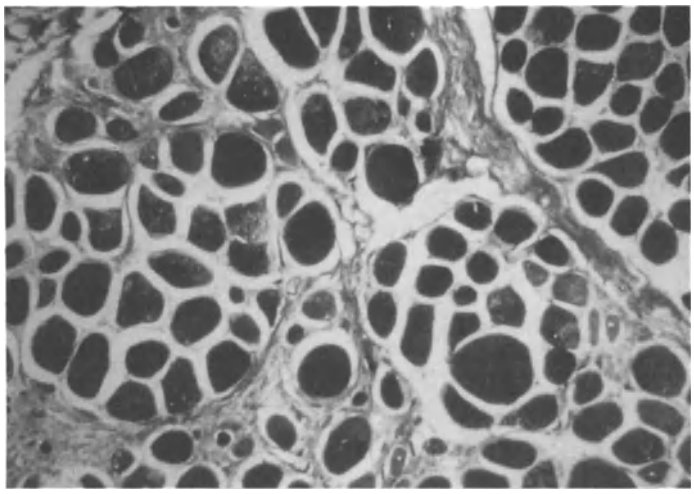


FIGURE 1.24. Clubfoot. Light microscopy, extracellular fibrosis.

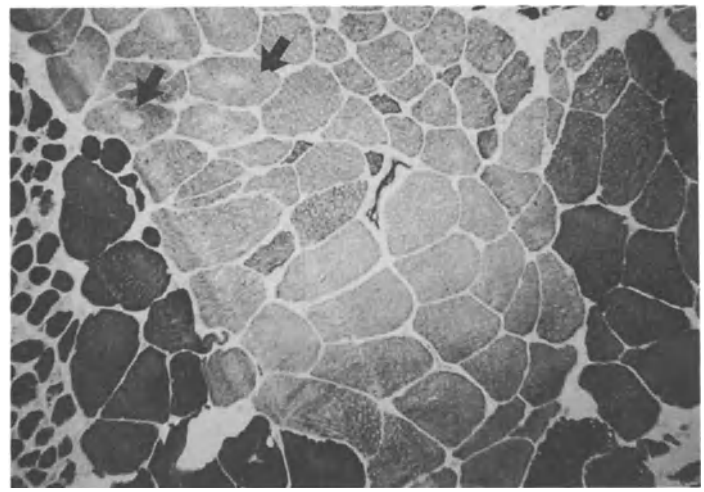


FIGURE 1.25. Charcot-Marie-Tooth disease. Light microscopy, histochemical stains. Type II fiber grouping and atrophy, target fibers (arrows).

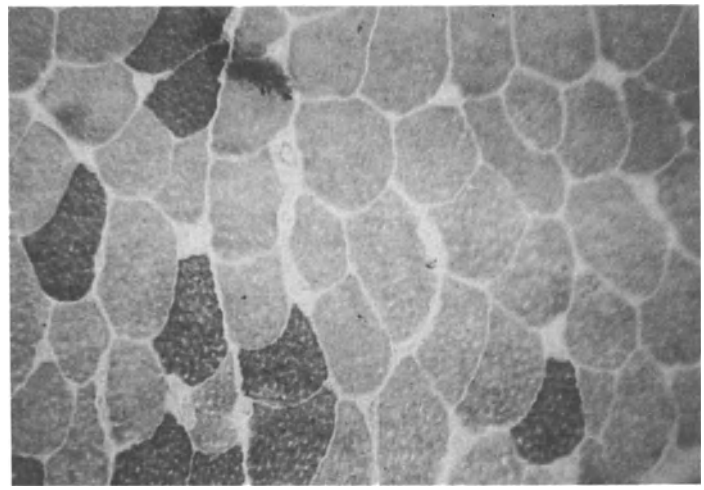


FIGURE 1.26. Myelodysplasia. Light microscopy, histochemical stains. Type I fiber grouping.

main anomalies noted, but in these specimens, a reversed fiber size ratio was observed, as was marked type II fiber atrophy (Figure 1.25). Core fibers were also occasionally seen.

The same pattern of anomalies seen in clubfoot and Charcot-Marie-Tooth disease were also found in myelodysplasia (Figure 1.26), arthrogryposis (Figure 1.27), congenital vertical talus, poliomyelitis, and lumbosacral agenesis (Figure 1.28).

Specimens from cerebral palsy and post–head-injury hemiplegia patients revealed consistent abnormalities, but the pattern was somewhat different. Type II fiber preponderance was greater than that of type I fibers, and many atrophic fibers were seen. There was a considerable fiber size variation, particularly in the type II fiber population. Grouping was only occasionally seen; internal nuclei were more common, and fibrosis was noted from time to time.

Neuromuscular Junctions

A review of the light-microscopic sections showed an increase in neuromuscular junctions in areas of obvious type I fiber grouping and population increase. Measurement of these fibers revealed that they were between 20 and 30 μm in diameter. This size established that nerve endings were type I in nature, and it was clear that type I nerve endings were present in

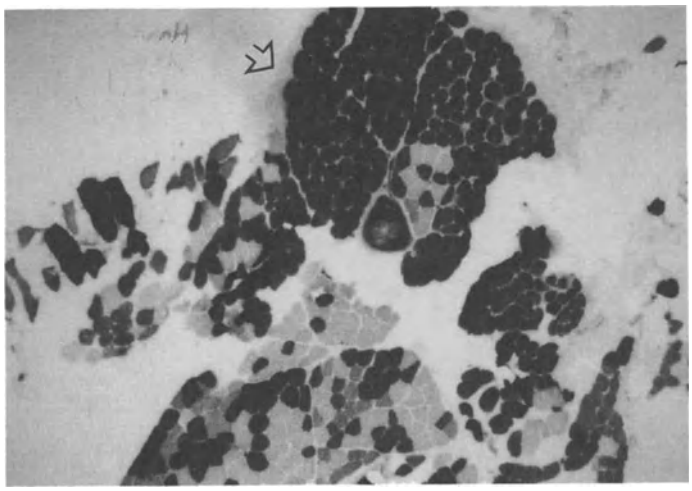


FIGURE 1.27. Arthrogryposis. Light microscopy, histochemical stains. Fiber grouping (arrow) and atrophy.

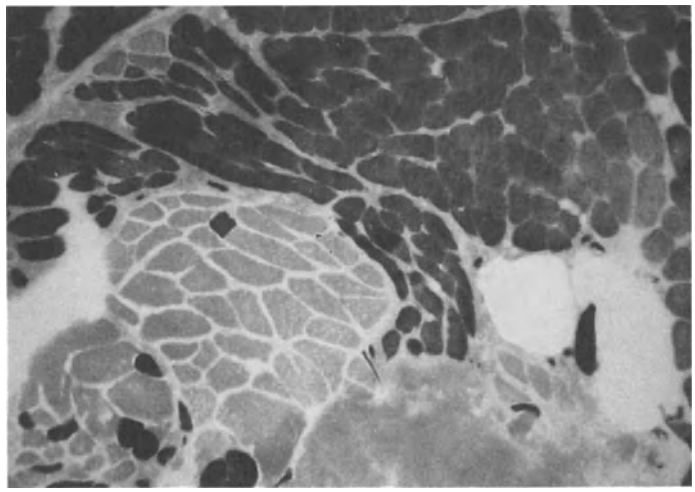


FIGURE 1.28. Lumbosacral agenesis. Light microscopy, histochemical stains. Fiber grouping.

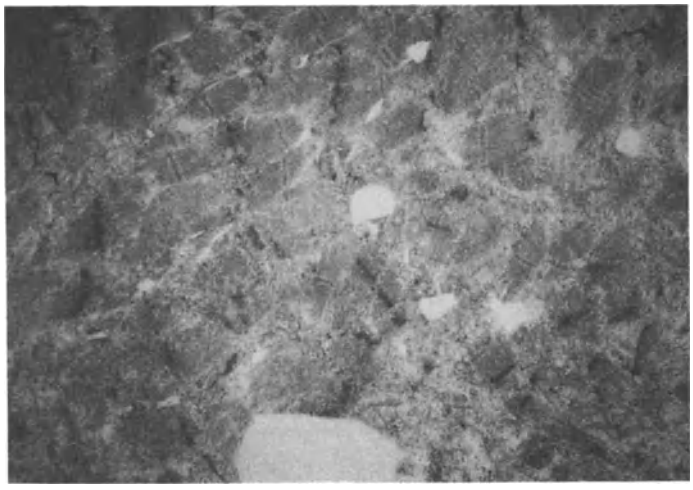


FIGURE 1.29. Clubfoot. Electron microscopy. Sarcomere and myofibril dissolution.

greater numbers as the ratio of type I to type II muscle fibers increased.

Electron-Microscopic Studies

Every specimen in the clubfoot series showed some area with an altered muscle structure. A loss of myofibrils was seen commonly (Figure 1.29). Dilated sarcoplasmic reticulum was frequently observed. Dilation and other anomalies of the T system and triad irregularities were also frequent. Streaming and sometimes loss of Z lines in portions of muscle fibers were quite common as were mitochondrial anomalies. Disorientation and misdirection of myofibrils was occasionally in evidence (Table 1.6).

The electron microscopic studies in Charcot-Marie-Tooth disease, myelodysplasia, arthrogryposis (Figure 1.30), congenital vertical talus (Figure 1.31), poliomyelitis (Figure 1.32), and lumbosacral agenesis (Figure 1.33) revealed a virtually identical pattern of anomalies with minor variations in the proportions of their occurrence. An occasional aberration at the ultrastructural level was evident in the biopsies from the Down syndrome and trisomy 18 patients. Specimens from the control group were essentially normal with an occasional minor aberration in some fields.

The electron microscope revealed consistent abnormalities in the biopsies obtained from cerebral palsy and post–head-injury hemiplegia patients. However, the pattern was different. The most common features were a myofilament loss, vacuolization, and the presence of myeloid figures. Less frequent features were the presence of internal nuclei, satellite cells, an increase in glycogen levels, and subsarcolemmic inclusions.

TABLE 1.6. Clubfoot: electron-microscopic results.

General alteration of muscle structure	100%
Loss of myofibrils	75%
Dilated sarcoplasmic reticulum	73%
Abnormal T system (T tubules and triads)	68%
Z-line streaming	42%
Abnormal mitochondria	48%
Myofibril misdirection	5%
Core fibers	>1%

Discussion

This study has confirmed previous observations that the extrinsic musculature in clubfoot is abnormal. The main findings at the light microscopic level, an alteration in fiber type ratio and grouping, are both suggestive of a remarkable change of innervation. The increase in fiber type I population was seen in over two-thirds of the specimens. Since the fiber type is entirely a function of its nerve supply, this alteration is assumed to be neurogenically determined.[8] This concept is further supported by the findings of an increased number of type I nerve endings associated with areas of type I fiber increase.

The distribution of the histological material

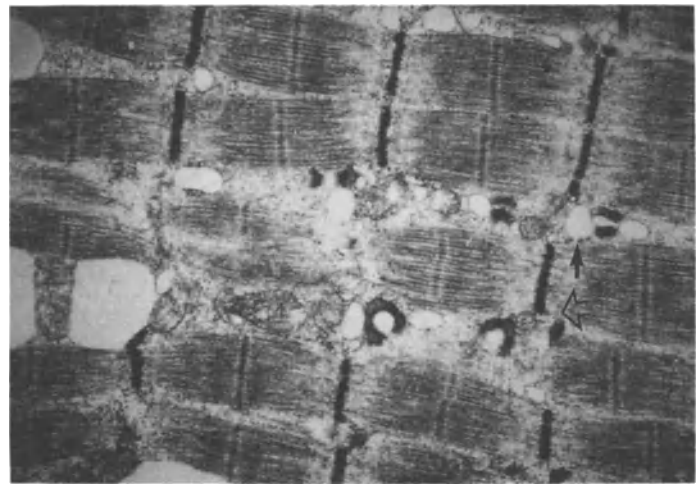


FIGURE 1.30. Arthrogryposis. Electron microscopy. Malaligned triads (open arrow), T-tubule dilation (black arrow).



FIGURE 1.31. Congenital vertical talus. Electron microscopy. Z-line streaming (open arrow).

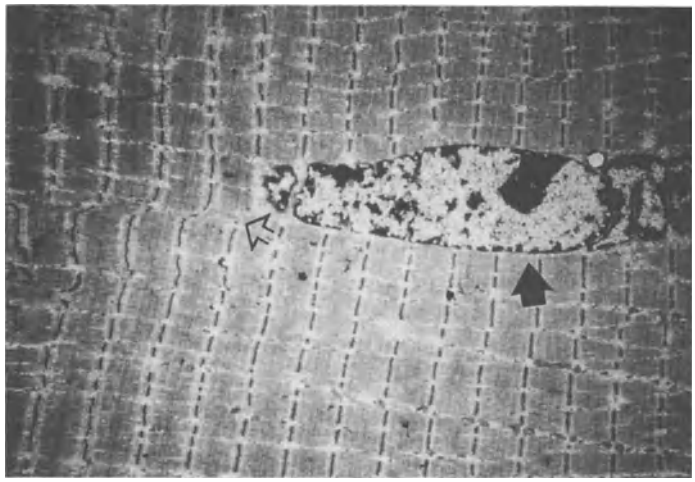


FIGURE 1.32. Poliomyelitis. Electron microscopy. Internal nucleus (black arrow), early Z-line streaming (open arrow).

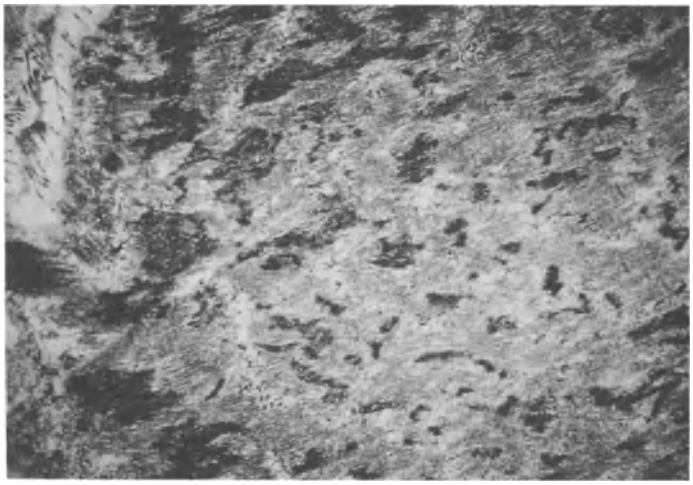


FIGURE 1.33. Lumbosacral agenesis. Electron microscopy. Myofibrilar disorientation.

suggested that the increase in type I fiber population was caused, in part, by an increase of type I fiber grouping. The phenomenon of grouping is known to be the result of a process of denervation and reinnervation, a fact that further supports the concept of underlying neurogenic disease.

The electron microscopic study in clubfoot patients revealed abnormalities with sufficient consistency to form a pattern. Although some of the overt changes usually associated with neurogenic disease were not observed, anomalies of the sarcoplasmic reticulum, the mitochondria, and the T systems, as well as the loss of myofibrils, are all compatible with a neurogenic etiology.[4]

Although the findings in clubfoot musculature confirm previous studies,[15,16,20] the most striking observation in this study was the marked similarity between clubfoot and the peripheral deformities that appear to be lower motor neuron in origin. Clearly, Charcot-Marie-Tooth disease, poliomyelitis, and most of the myelodysplastic patients fall in this group. A peripheral nerve anomaly exists in lumbosacral agenesis. A diminished number of anterior horn cells and, thus, lower motor neuron deficit is a factor in the cause of arthrogryposis.[7,12] All these conditions appear to share in common a deficit in lower motor neuron input. It is not unreasonable to place clubfoot and congenital vertical talus, mirror image deformities in the foot, into the same category.

The specimens from cerebral palsy and post–head-injury hemiplegia patients were not normal, but the pattern was somewhat different. These are upper motor neuron lesions with excessive nerve input to the muscle. A feature of cerebral palsy was an increase in type II fibers. It is speculated that uncontrolled high-frequency firing of lower motor neurons may convert type I to type II fibers.

It is noteworthy that the main change in muscle in clubfeet and in the lower motor neuron group of deformities is an increase in type I fiber population. Since these fibers are characteristically slow-twitch and high-tension fibers, it is interesting to speculate that they may be relatively overactive and provide a minor, but persistent, deforming force. Experience in poliomyelitis has established that a minor muscle imbalance may, in time, produce a major joint and bone deformity. By the same token, a small but persistent muscle imbalance, operative from an early intrauterine stage, will produce a rigid deformity by birth. These unbalanced forces could be sufficient to produce angulation of the talus and other bony deformities known to occur early in the development of the clubfoot deformity.

This study supports previous evidence that a specific pattern of deviations exists in clubfoot musculature. It is suggested that this is a major etiological factor and that the bony deformity is adaptive to subtle but persistent muscle imbalanced forces operative from an early intrauterine stage. Muscle changes other than



FIGURE 1.34. A dorsiflexing night splint used during sleep periods only, in a child with a corrected equinus deformity. The plastic has been partly cut away at the sides so that the footpiece has some mobility into dorsiflexion. Medial and lateral Velcro straps allow the foot to be brought into progressive dorsiflexion, permitting the splint to be used in a dynamic fashion.

deforming conditions where the lower motor neuron is primarily involved closely resemble those found in clubfoot. Although different muscle groups may be involved, the mechanisms that result in deformity appear to be closely related. Upper motor neuron lesions also produce muscle changes, but of a different pattern. This evidence suggests that muscle integrity is disturbed by both diminished and excessive nerve input.

These concepts have a practical bearing on the management of clubfoot as well as other peripheral deformities. The tendency to relapse is constant so that successful treatment may need to be continual. Once correction is achieved, it is appropriate to counteract the out-of-balance forces by the prolonged use of night splints (Figure 1.34).

Summary

In a previous study of 90 muscle biopsies obtained from 13 clubfeet, electron-microscopic examinations and enzyme-specific histochemical stains at the light-microscopic level revealed specific anomalies and a numerical increase and grouping of type I muscle fibers. The changes suggested a neurogenic cause, particularly a process of denervation and reinnervation.

Since 1983, a further study of 357 muscle biopsies (84 patients) was undertaken to confirm these findings and to compare the changes found in clubfoot muscle to those occurring in other peripheral deformities, e.g., Charcot-Marie-Tooth disease, arthrogryposis, congenital vertical talus, poliomyelitis, lumbosacral agenesis, Down syndrome, cerebral palsy, and post–head-injury hemiplegia. Twelve muscle biopsies from normal patients who had the muscles exposed for other reasons were obtained. Each biopsy was taken from shortened or tight muscles. Half of the biopsies were obtained from those with clubfoot deformity.

A preponderance of type I slow twitch fibers was consistently found in all of the disorders, with type I fiber grouping found in four: clubfoot, Charcot-Marie-Tooth disease, cerebral palsy, and lumbosacral agenesis. The ultramicroscopic studies revealed T-tubular dilation, Z-line streaming, mitochondrial abnormalities, and loss of myofilaments in the lower motor neuron conditions. These changes were not seen in the control specimens.

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Etiological Considerations of Congenital Clubfoot Deformity

N. Shimizu, S. Hamada, M. Mitta, K. Hiroshima, and K. Ono

The exact cause of congenital clubfoot is still unknown. Certain etiological influences, however, have been considered. These include (a) intrauterine mechanical factors, (b) arrest of fetal development, (c) primary germ plasm defect, and (d) neuromuscular defect.[10]

In the literature, some authors have suggested that neuromuscular dysfunction is the cause of congenital clubfoot.[3,5] Biopsied muscle specimens have been studied by histochemical and electron-microscopic methods, and pathological nerve changes were observed in most cases of congenital clubfoot.[5]

Clubfoot deformity associated with arthrogryposis multiplex congenita resembles the deformity of idiopathic clubfoot, and some authors consider that idiopathic clubfoot is a localized form of arthrogryposis multiplex congenita. Recently the etiology of arthrogryposis multiplex congenita has been clarified. Decreased movement of the extremities caused by intrauterine insults, such as a viral infection, that destroy motor neurons in the developing spinal cord is considered to be the cause of arthrogryposis multiplex congenita.[5,9]

Persistently imbalanced leg and foot muscles secondary to such a neuromuscular abnormality arising during embryonal development may produce a fixed foot deformity. However, the presence of this kind of neuromuscular abnormality is not consistent with idiopathic clubfoot. Distribution of the abnormality is neither confined to a particular muscle nor to a particular nerve. Therefore, the combination of a neuromuscular abnormality with idiopathic clubfoot is generally considered to be of equivocal significance as regards the etiology of this condition.

In this report, based on our experience of a distinct case of congenital clubfoot deformity, the neuroembryological etiology of this deformity will be discussed.

For this purpose, a patient with congenital clubfoot deformity due to aberrant muscle innervation is compared with 15 patients with clubfoot deformities due to Streeter's dysplasia (constriction band syndrome) and with one patient with clubfoot deformity due to sacral agenesis.

Case Presentation

A Case of Idiopathic Clubfoot with Aberrant Innervation of the Ankle Muscles

H.I. was an 8-year-old Japanese girl with clubfoot deformity of the right lower extremity (Figure 1.35). This deformity was noted from birth, and she was treated by the serial casting method from the neonatal period onwards.



A



B

FIGURE 1.35. Case H.I. Front (A) and back (B) views of feet. The right foot shows characteristic features of neurogenic talipes equinovarus (TEV).

After conservative treatment, elongation of the Achilles tendon was performed at 3 months, a medial release operation at 2 years, and transfer of the tibial posterior tendon at 4 years of age.

She had a residual deformity of the hind- and forefoot when she was admitted to Osaka University Hospital at 6 years of age.

Several neurological abnormalities were revealed by routine neurological tests. On manual muscle testing of her right leg, no contraction of the peroneus longus or brevis was observed and muscle weakness of the tibialis anterior was detected. Normal strength in the extensor hallucis longus and gastrocnemius muscles was noted. Hypalgesia and hypoesthesia were observed in the areas supplied by the superficial and deep peroneal nerves in her right leg. On electromyographic examination, neurogenic abnormalities were observed in the tibialis anterior muscle of her right leg, such as long duration and low-voltage waves on voluntary contraction.

To correct the deformity and restore muscle balance, we performed a posteromedial release operation and a tendon transfer of the flexor hallucis longus to the fourth metatarsal of her right foot at the age of $6\frac{1}{2}$ years. At operation, the common peroneal nerve was exposed and muscle biopsies were performed on the peroneus longus and tibialis anterior muscles. A common peroneal nerve deficiency was noted, and the peroneal group of muscles was found to be innervated by a thin aberrant nerve running over the posterolateral aspect of the lateral head of the gastrocnemius muscle. Stimulation of this thready nerve by a nerve stimulator caused contraction of the peroneus longus but not all the pretibial muscles contracted. We could not locate the nerve supplying the tibialis anterior muscle (Figures 1.36 and 1.37). Histochemical studies showed no detectable abnormal fiber patterns in either the peroneus longus or the tibialis anterior muscles (Figures 1.38 and 1.39). Five and a half years after operation, she had no residual deformity.

Constriction Band Syndrome with Clubfoot Deformity

Between 1965 and 1983, 62 cases of constriction band syndrome were admitted to our hos-

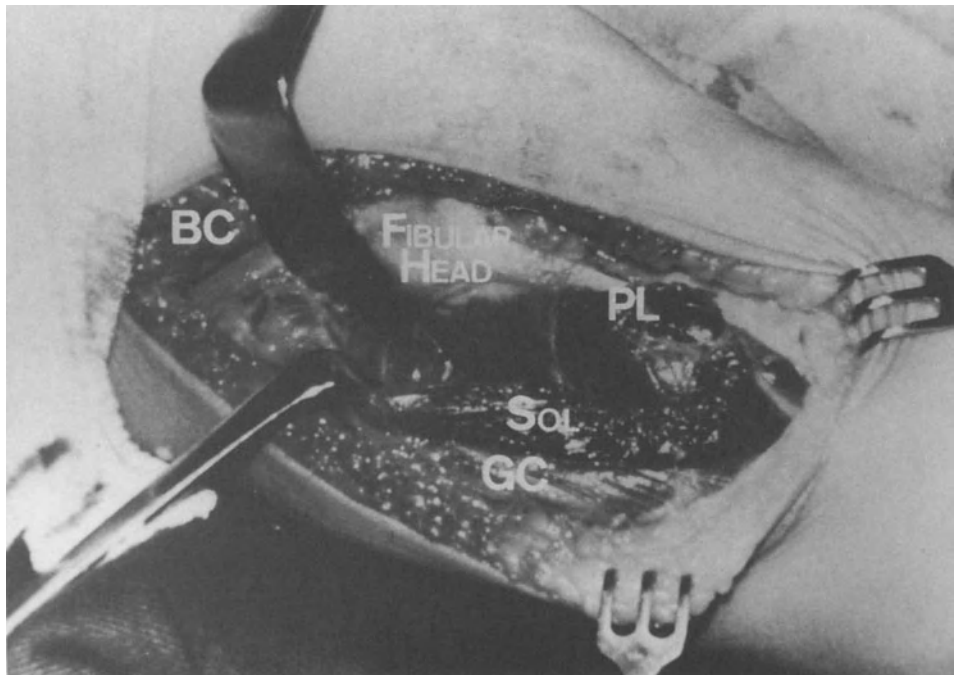


FIGURE 1.36. Case H.I. The common peroneal nerve was not detected between the peroneus and the gastrocnemius (GC) muscles. BC, biceps; PL, peroneus longus muscle; SOL, soleus.

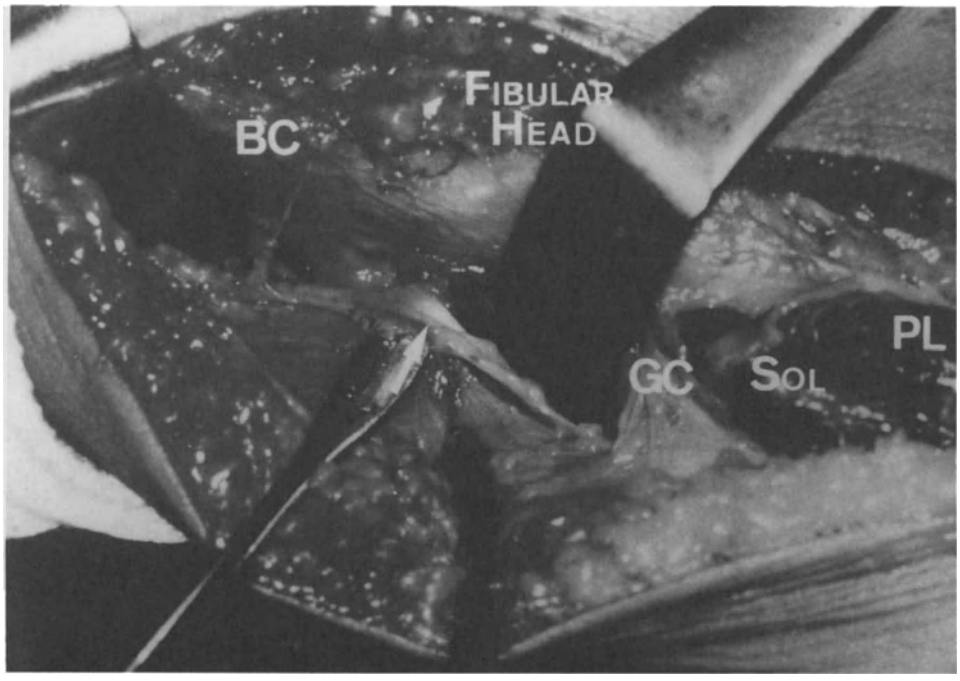


FIGURE 1.37. Case H.I. The peroneus longus (PL) muscle was innervated by a thin aberrant nerve (white arrow) that ran over the posterolateral aspect of the lateral head of the gastrocnemius (GC) muscle. This nerve originated from the popliteal neurovascular bundle.

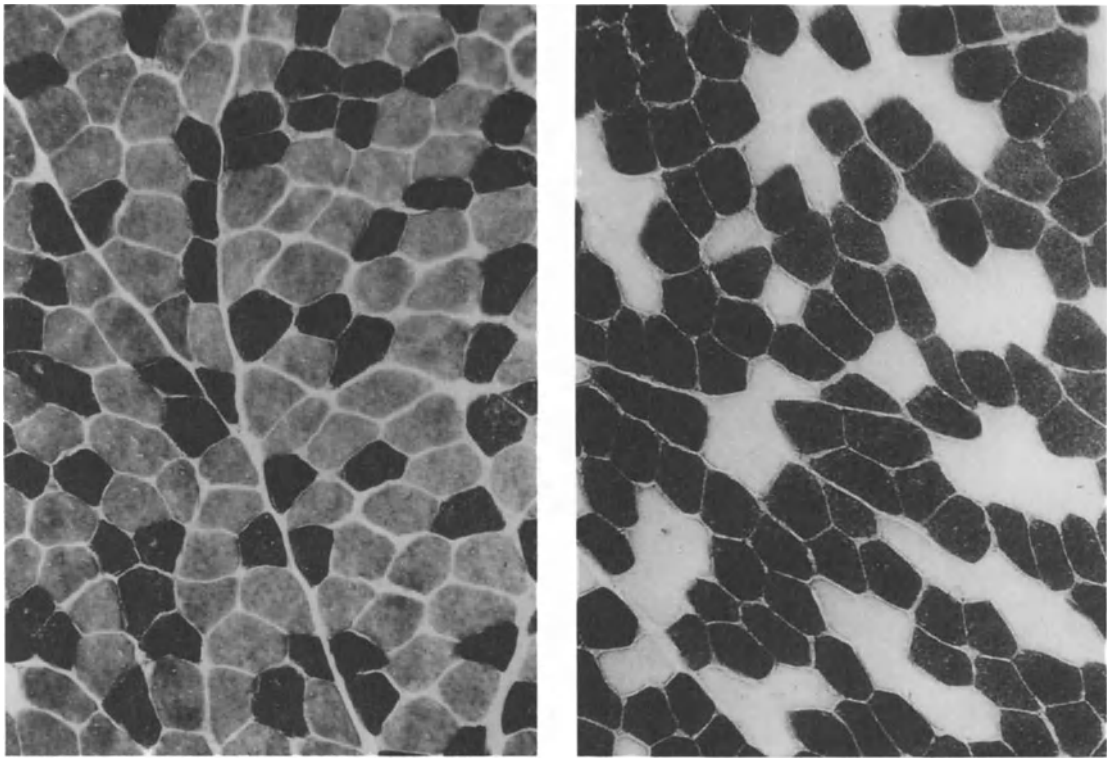


FIGURE 1.38. Case H.I. Normal structure of peroneus longus muscle. [ATPase preparation, pH 4.3 (left) and pH 9.3 (right).]

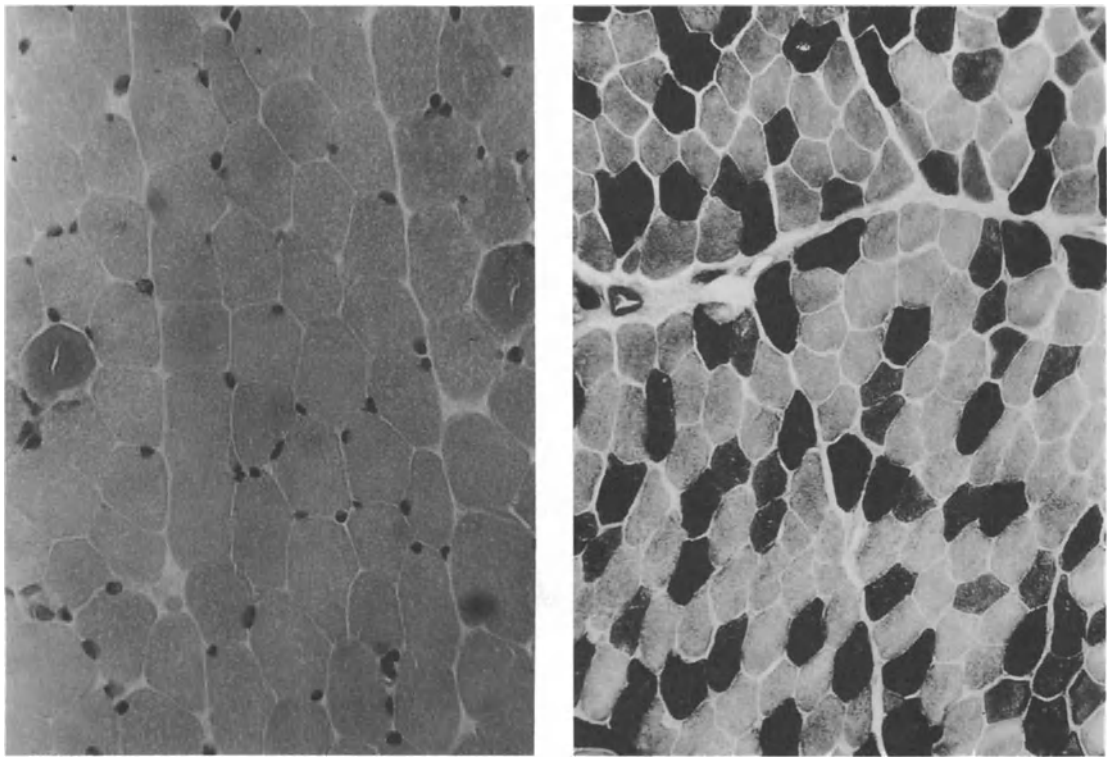


FIGURE 1.39. Case H.I. Normal structure of tibialis anterior muscle. [Hematoxyline-eosin staining (left) and ATPase preparation, pH 4.3 (right).]

pital (33 males and 29 females). Sixteen out of 62 patients with constriction bands had a congenital foot deformity. Fifteen had clubfoot deformity and one had pes equinus deformity with contracture of the Achilles tendon. There were no pes valgus deformities.

There was a significant difference in the sex ratio between group A (cases without clubfoot deformity, male 22, female 25) and group B (cases with clubfoot deformity, male 11, female 4), namely a predominance of males in group B. In group A, more cases had bands in several extremities than in group B (Table 1.7).

TABLE 1.7. Distribution of bands in the cases with congenital constriction bands.

	Number of extremities			
	1	2	3	4
Group A (47 cases)	8	15	12	12
Group B (15 cases)	6	3	4	2

In group B (15 cases, 17 clubfeet), the clubfoot was not always on the same side as the constriction bands (Table 1.8). At the operation of case 1, the common peroneal nerve was exposed. It was thin, and only the tibialis anterior muscle contracted when the nerve was stimulated by a nerve stimulator. Histochemical studies on the tibialis anterior muscle revealed no detectable abnormality. In this case, triceps surae and the long flexor muscles of the toes showed normal function.

A Case of Sacral Agenesis with Clubfoot Deformities

Y.U. was an 8-month-old Japanese boy with a bilateral clubfoot deformity. His mother suffered from diabetes mellitus. Atrophy of the leg muscles and paralysis of the peroneus longus and brevis, exterior digitorum longus, and tibialis anterior muscles were noted from the neonatal period.

He was admitted to our hospital when he

TABLE 1.8. Cases with clubfoot deformity from birth in the series of constriction band syndrome.

Case	Age	Sex	Clubfoot	Constriction band	Motor paralysis
1	6	M	L	Distal third of L leg	L superficial peroneal nerve
2	11	M	L	Proximal third of L leg and L foot	L superficial peroneal nerve and deep peroneal nerve (partially)
3	12	M	R	L foot and R fingers	
4	5	M	R	R thigh and distal fourth of R leg	
5	18	M	L	R fingers	L deep peroneal nerve
6	12	F	L	Distal third of L leg	
7	20	F	L	R knee	
8	15	M	L	Distal third of L leg, L toes and R fingers	L superficial peroneal nerve
9	17	F	L	L wrist	
10	11	M	R	R fingers	
11	10	M	Bil.	Bil. fingers and toes	
12	15	M	Bil.	Proximal and distal third of L leg and bil. fingers	Bil. common peroneal nerve
13	21	M	L	Distal third of L leg	
14	18	M	R	Distal third of L leg, L forearm, L fingers	
15	1	F	R	R upper arm and R fingers	

Bil, bilateral; L, left; R, right.

was 3 months old. His buttocks were small, there was continuous outflow of urine from the urethra. Both feet showed severe pes equinovarus deformities. Roentgenography of his lumbar spine and pelvis revealed a defect of the vertebral body of L5 and the sacrum. On neurological examination, normal patellar tendon reflex and loss of the Achilles tendon and Babinski reflexes were noted.

Active contraction of the anterolateral ankle muscles was not observed, although the two flexors and triceps surae muscles contracted actively. The flexor and extensor muscles of the hip and knee joints functioned normally. The area innervated by sensory branches of the tibial and common peroneal nerves was not analgesic. Electromyographical examination showed normal activity in the gastrocnemius and the long toe flexor, but no activity was detected in the anterolateral ankle muscles.

We performed a posteromedial release operation and tendon transfers of the long toe flexors to the insertion of the peroneus brevis muscle on both sides at 6 months of age. The common peroneal nerve was exposed at operation. There was a bundle of fibrofatty tissue but no common peroneal nerve. The peroneal muscles, long toe extensors, and tibialis anterior muscles were atrophied, but the gastrocnemius and soleus muscles were normal in appearance.

Discussion

The common factor in the cases of the clubfeet described was an absence or thinning of the common peroneal nerve and consequent varying degrees of dysfunction in the pretibial muscles.

We treated a case of congenital clubfoot that had an abnormal innervation of the anterolateral ankle group of muscles (case of H.I.). Histological and histochemical studies of the peroneal muscles did not reveal any detectable abnormalities such as atrophy or regrouping of muscle fibers, but electromyography showed a neurogenic abnormality.

An aberrant nerve that innervated the peroneal muscles was judged to have preserved gross anatomical and histological muscle structure, but these muscles were not able to function normally.

Minor dysfunction in particular muscles may cause an imbalance of the leg muscles resulting in a clubfoot deformity.

We also treated some cases of clubfoot deformity with congenital constriction bands.

The etiology of congenital constriction bands is considered to be that of amniotic rupture and oligohydramnios.[2,11] Of the cases with congenital constriction bands in our series, 20% suffered from a clubfoot deformity. Such a high incidence of association suggested a common etiology for these two congenital deformities, such as amniotic rupture.

This group of cases showed a different sex ratio and distribution of constriction bands from the rest of our series. The sex ratio of this group was similar to that of congenital clubfoot. Of those six clubfeet accompanied by peroneal nerve palsy, the constriction bands failed to coincide with the level of palsy in four cases (cases 1, 5, and 8, and the right foot of case 6). This indicates that direct compression of the peroneal nerve by constriction bands is not necessarily the cause of all the clubfoot deformities that accompany such bands. In case 1, a thin common peroneal nerve was exposed, and the stimulation of this nerve failed to evoke contraction of peroneal muscles. Another possibility is that clubfoot deformities accompanied by congenital constriction bands result from defective innervation of the peroneal muscle group.

Although peroneal nerve deficiency in clinical cases of congenital clubfoot has not been described, animal studies suggesting this have been reported. Nakamura et al.[7] studied mice with hereditary ankle muscle atrophy and paralytic clubfeet. These homozygotic mutant mice exhibited bilateral supinated equinus foot, common peroneal nerve deficiency, and atrophy of the anterolateral ankle muscle group. In normal control mice, the common peroneal nerve and the tibial nerve innervate the anterior and lateral ankle muscles, respectively. Nakamura et al. indicated that the tibial nerve originates from the motor nuclei of L3 and L4, and the common peroneal nerve from the motor nuclei from T8 to L5. They also found that the peroneus longus and brevis showed a relatively normal profile, and horseradish peroxidase (HRP) injection into these muscles resulted in the demonstration of HRP-labeled cells in the spinal areas from which the tibial nerve originates in homozygotic mutant mice. They conclude that the peroneal muscles with a relatively normal appearance were innervated by fibers sprouting from the tibial nerve.

During the development of the motor neuron in the spinal cord, the programmed cell death of anterior horn cells and the specificity between nerve and target organ (muscle fibers) result in the complex structure and relationships of the motor neuron system.[4,8] Among many motor neurons, only those anterior horn cells that reach the muscle fibers and form end plates can survive. Each mammalian muscle fiber has a single motor end plate and, as a rule, will not accept any more. Therefore, the first motor nerve terminal to arrive at the muscle fiber will innervate it.[1]

If a mammalian skeletal muscle is denervated and then reinnervated by the original or a nearby motor nerve, the two nerves supply the muscle fibers at random.[6] Cross-innervation of muscle fibers occurs after regeneration at any age after birth, by which myotypic specification between motor neuron and muscle fibers will not occur, and recovery of voluntary or reflex movement is always incomplete.[6]

These facts of developmental biology are considered to support the hypothesis that death of the motor neurons that innervate the anterolateral ankle muscles occurs at an early stage of fetal development in mutant mice as well as in clinical cases with clubfoot deformity in constriction band syndrome, and that compensatory reinnervation from the anterior horn cells in other spinal cord sites fails to preserve all the muscle fibers.

The last case, Y.U., had sacral agenesis with bilateral clubfoot deformities. The patient showed distinct motor dysfunction, such as common peroneal nerve palsy and vesicoanal dysfunction. Certain insults during fetal development can be considered to have caused cell death in the anlage of vertebral column and spinal cord below the level of L5. In this case, the distribution of motor paralysis was not consistent with the location of the defect in the vertebral column. It is reasonable to consider that motor neurons, from which the tibial and peroneal nerves originate, degenerated, and that triceps surae muscles and long toe flexors were then reinnervated by other anterior horn cells, but reinnervation of the anterolateral ankle muscles failed to occur. Sensory reinnervation seems to have occurred partially, since the patient's leg and foot were not analgesic. This difference between motor and sensory loss may indicate that cell death of a motor neuron in the developing spinal cord

might occur after the cell migration that formed the dorsal root ganglion.

H.I., who had abnormal innervation of the peroneal group of muscles, showed neuromuscular abnormalities similar to the case of sacral agenesis and to case 1 in our series of congenital constriction band syndrome, though there was no gross atrophy of the anterolateral muscles. The common peroneal nerve deficiency and the abnormal innervation of the anterolateral ankle group of muscles in H.I. might have been caused by the death of the motor neurons that innervate the peroneal muscles during fetal life and their reinnervation by an aberrant nerve that originated from other anterior horn cells in the spinal cord. When cell death of a motor neuron occurs in intrauterine life, compensatory reinnervation by other anterior horn cells can be expected to preserve almost normal structure and function of the neuromuscular unit. These cells could preserve the histochemical structure of the pretibial muscles, but were unable to initiate normal contraction of the anterolateral ankle muscles.

Conclusion

The clinical cases described in this paper showed neuromuscular abnormalities in the anterolateral ankle muscles from the severest form (total loss of innervation and no reinnervation in a case of sacral agenesis) to a milder form (partial loss of innervation and no reinnervation in a case of constriction band syndrome with clubfoot deformity), and the mildest form (partial loss of innervation and reinnervation in a case of congenital clubfoot deformity).

Summary

The etiology of congenital clubfoot deformity was discussed. From the clinical observation of a case with congenital clubfoot (CTEV) with an aberrant innervation of the anterolateral ankle muscles, from selected cases of constriction band syndrome with peroneal nerve palsy, and from a case of sacral agenesis with clubfoot deformity, neuromuscular dysfunction is considered to be the cause of this foot deformity. The abnormal death of a motor neuron in the developing spinal cord and the inappropriate reinnervation of the ankle muscles are responsible for dysfunction and imbalance of the ankle muscles.

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Neurogenic Origin of Talipes Equinovarus

R.F. Martin, G. Milo-Manson, A. McComas, and S. Levin

Although congenital talipes equinovarus (CTEV) has many theories of etiology, no clearly defined etiological process has been agreed upon.

Recurrent deformity occurs in approximately 40% of cases despite excellent correction. This is usually a subtle, progressive, and dynamic process.[1] It is, therefore, attractive to postulate an ongoing deforming mechanism. Many authors have looked for neuromuscular abnormalities.[4–6,8,9]

In an effort to show a neuropathic process, we undertook an electromyographic study of a series of patients, and particularly, looked at motor unit counts as markers of neurological function.

Materials and Methods

Twenty-five patients from 1 to 12 years of age with CTEV not associated with any neurological, muscular, or skeletal condition or syndrome were examined clinically and by electromyography. Eleven cases were bilateral, 5 were left, and 9 were right, for a total of 36 feet. Electromyography included motor unit counts of extensor digitorum brevis as a marker for the common peroneal nerve and counts of abductor hallucis as a marker for the tibial nerve, as well as motor conduction velocities and conduction amplitudes of the common peroneal and tibial nerves.

A motor unit represents a single motor nerve axon or fiber and the colony of muscle fibers that is supplies. It also represents the associated anterior horn cell in the spinal cord. A motor unit count is obtained by applying a threshold stimulus to evoke a single motor unit potential. The stimulus is then progressively increased with increased amplitude of the wave, indicating increasing numbers of motor units responding until a potential of 10 motor units is evoked. A maximal stimulus is applied to measure the response of all the motor units. The number of motor units is derived by dividing the amplitude of 10 units into the total amplitude. The technique requires a simple muscle, hence the choice of a marker such as the extensor digitorum brevis. Complex muscles, such as hamstrings, with differing numbers of motor units at different levels, do not lend themselves to easy study (Figure 1.40).

In the population in general, sampling of motor unit counts of extensor digitorum brevis from infancy to old age has shown a wide varia-

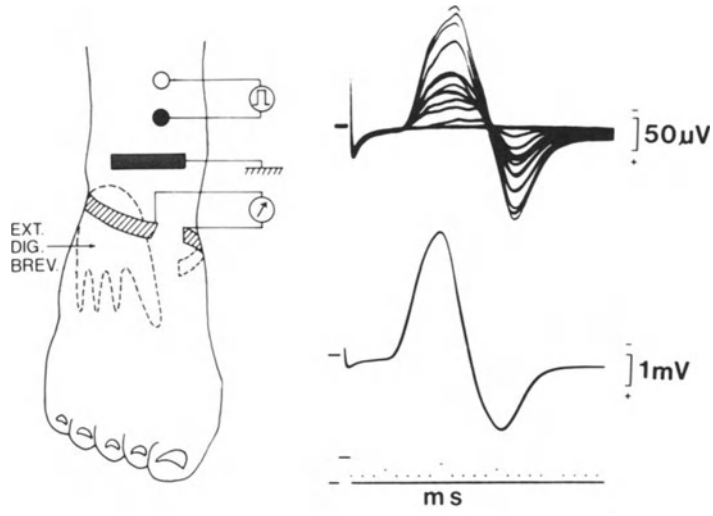


FIGURE 1.40. A motor unit count is obtained by threshold stimulation of a motor nerve until a minimal response is obtained. The stimulus is then progressively increased with increasing amplitude of the wave, indicating increasing numbers of motor units responding. The amplitude of 10 units is measured. A maximal stimulus is applied to measure the response of all the motor units. The number of motor units is calculated by dividing the amplitude of 10 units into the total amplitude.

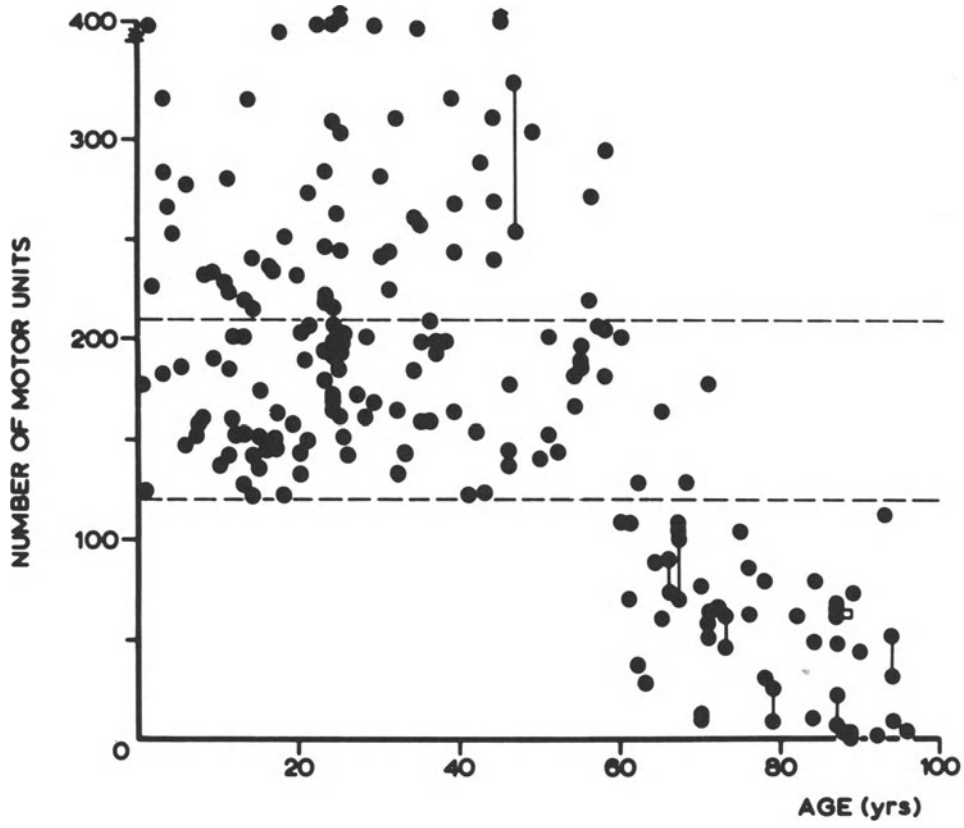


FIGURE 1.41. Sampling of the motor unit counts of extensor digitorum brevis from infancy to old age.

tion, but in no case has the motor unit count in the population under age 60 ever been below 120 (Figure 1.41). The motor unit count for the abductor hallucis is normally over 250.

Clinical Findings

Patients had typical clubfoot findings with reduced bulk of the leg below the knee, small foot size, and weakness of tibialis anterior and peroneal muscles. All had pronounced wasting of extensor digitorum brevis. Sensory examination was normal.

Previous Treatment

Ten patients had been treated by casts and splints only [all of whom had abnormal electromyograms (EMGs)]. The remaining patients all had surgical treatment in addition to casts and splints.

Results

The findings of 25 patients who were examined electromyographically showed that 21 had abnormal EMGs, whereas 4 had EMGs within normal low values. The motor unit count of the extensor digitorum brevis in all feet with abnormal EMGs was below 120, i.e., abnormal. The other four feet had counts over 120 (Table 1.9). In these four cases, although the motor unit counts were above 120, they were relatively low compared with the normal side (Table 1.10).

In all but one case where the motor unit count of the abductor hallucis was reduced, the patient had a previous plantar release and a possible surgical nerve injury.

TABLE 1.9. Electromyogram findings.

Motor unit counts	Normal	Abnormal
EDB*$n \geq 120$	4	21
AH†$n \geq 250$	24	1
Motor nerve conduction velocity $n \geq 38$/sec		
Peroneal	25	0
Tibial	25	0
Motor nerve conduction amplitude $n \geq 2$ mV		
Peroneal	15	10
Tibial	25	0

* Extensor digitorum brevis.
† Abductor hallucis.

TABLE 1.10. Normal motor unit counts in extensor digitorum brevis $n \geq 120$.

Patient	Side of clubfoot	Motor unit count	
1	Right	Right	122
		Left	139
2	Right	Right	135
		Left	147
3	Right	Right	150
		Left	289
4	Right	Right	159
		Left	225

Motor nerve conduction was normal in all 25 cases (Table 1.9). There was evidence of pressure neuropathy at the neck of the fibula. Motor nerve conduction amplitude was normal in 15 cases (Table 1.9). We attribute the normal amplitude to surviving fibers sprouting collaterals.

Discussion

Reduced motor unit counts reflect neuropathy somewhere between the anterior horn cell and the muscle. Digital muscle wasting with no evident thigh involvement suggests distal neuropathy, however, a similar picture appears in sacral agenesis where pathology is more proximal. The abductor hallucis innervated by the tibial nerve has very high motor unit counts, yet there was wasting of the calf, which is also innervated by the tibial nerve. Handelsman and Badalamente[5] and others[8] have shown these muscles to have an abnormally increased number of type 1 fibers, suggesting reinnervation.

In considering a hypothesis for the etiology of CTEV, one wonders if intrauterine neuropraxia with variable recovery may be responsible. However, demonstration of clubfeet in 12-week-old embryos[7] makes intrauterine pressure less likely than primary failure of neurological development.

Conclusion

We have demonstrated reduced motor unit counts in the distribution of the common peroneal nerve as a consistent finding in congenital talipes equinovarus. These findings correspond to clinically demonstrable muscle weakness. This suggests a neuropathic etiology, but we are unable to identify the level and nature of the neuropathy.

Summary

Based on the conviction that relapsing clubfoot is not the result of a basic underlying skeletal deformity but is, instead, the result of continuing dynamic factors, this study reviewed the clinical findings and electromyographic examinations of 21 children with persistent or relapsing TEV. Clinical findings showed wasting of muscle groups below the knee, including the peroneals, tibialis anterior, gastrocnemius, and soleus muscles. There was striking atrophy of the extensor digitorum brevis muscle. Nine patients had weakness, particularly in the evertor muscles. All patients had contracture of the Achilles tendon and normal sensation.

EMG findings were abnormal in 16 patients; there were significantly reduced extensor digitorum brevis motor unit counts and reduced motor nerve conduction amplitudes. All patients had normal motor nerve conduction velocities.

These findings support a neurogenic etiology in clubfoot of possible in utero axonal damage of the common peroneal nerve. The severity of the clubfoot is presumably dependent on the degree of initial neurological insult. In some cases, relapse has been arrested following split anterior tibial tendon transfer. These findings may be useful in predicting recurrent, relapsing TEV.

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Anomalous Muscles in Clubfeet

H. Sodre, S. Bruschini, A.A.C. Magalhaes, and A. Lourenco

Muscle anomalies of the lower limb have been well described in anatomical textbooks in the past.[6,7,15,19,30,33] However, clinically symptomatic cases have been reported only recently in the literature.[1,2,9–14,18,23,27,31]

The clinical complaints in the presence of muscle anomalies are most often associated either with an accessory soleus muscle (Figure 1.42) or with a flexor digitorum accessorius longus (Figure 1.43).

Usually the patient complains of a mass in the posteromedial aspect of the ankle that can be painful on exertion.[1,2,9,11,23] It can also present as an asymptomatic mass simulating a soft tissue tumor.[10] In very rare instances, anomalous muscles are present as a cause of deformity of the foot.[4,10,13,16] Other anatomic studies on clubfoot do not mention muscle anomalies as a possible cause of the deformity.[29,32]

This present study documents the association of muscle anomalies and clubfoot.

Clinical Data

The authors observed muscle anomalies in 11 out of 72 patients (15.3%) with talipes equinovarus treated at the Foot Clinic of the Escola

TABLE 1.11. Clinical date of the muscle anomaly cases.

Sex	Age at surgery	Muscle anomaly
M	1Y 7M	Accessory soleus
M	1Y 1M	Accessory soleus
M	11M	Accessory soleus
M	2Y	Accessory soleus
M	8M	Accessory soleus
M	3Y 9M	Accessory soleus
M	10M	Flexor digitorum acc. L.
M	1Y 1M	Flexor digitorum acc. L.
M	2Y 3M	Flexor digitorum acc. L.
M	1Y 3M	Flexor digitorum acc. L.
M	1Y 7M	Agenesis of post. tibial

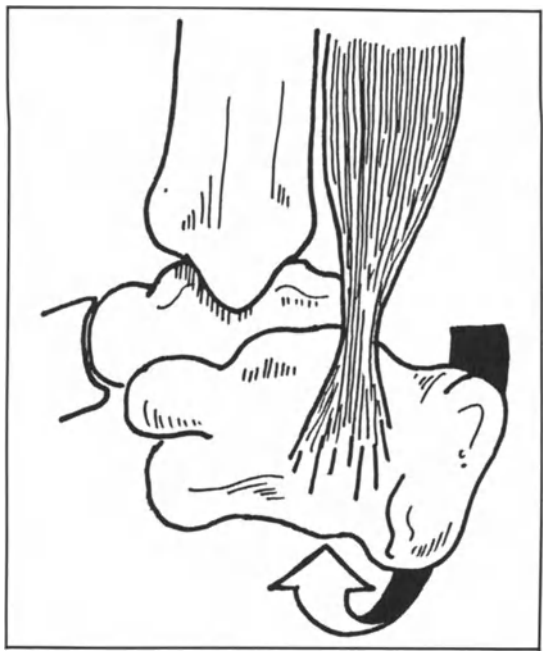


FIGURE 1.42. Schematic drawing of the accessory soleus muscle.



FIGURE 1.43. Schematic drawing of the flexor digitorum accessorius longus muscle.

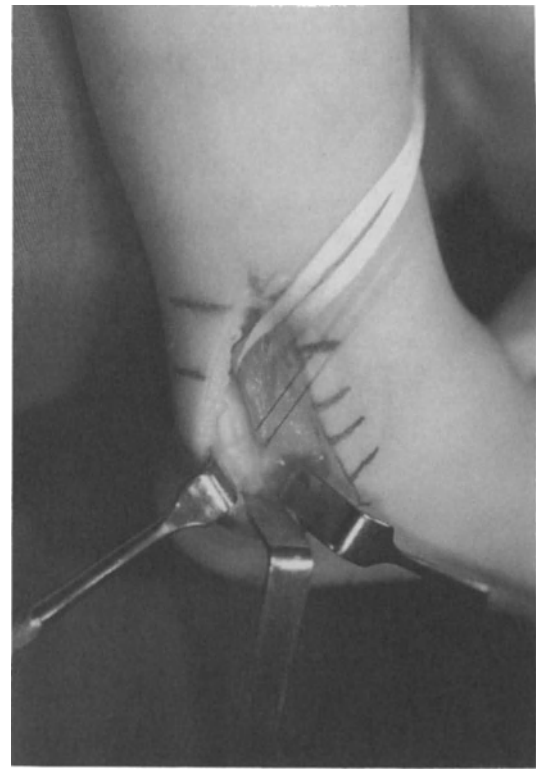


FIGURE 1.44. Case 3—tenotomy and partial resection of the accessory soleus muscle through a longitudinal incision.

Paulista de Medicina in the last 5 years. Among these anomalies, the authors found six patients (8.3%) with an accessory soleus muscle, four patients (5.6%) with a flexor digitorum accessorius longus, and one patient (1.4%) presented with agenesis of the posterior tibial muscle. The clinical data of our cases of muscle anomalies are presented in Table 1.11.

Case 11, which presented with agenesis of the posterior tibial muscle, was the only patient with unilateral talipes equinovarus. All the other cases had bilateral anomalous muscles with either the accessory soleus muscle or the flexor digitorum accessorius longus muscle associated with bilateral congenital talipes equinovarus (CTEV).

Except for case 3, all of these patients had

both feet surgically corrected on the same occasion. The Cincinnati approach with posteromedial and lateral soft tissue releases was performed routinely. No cases had previous surgical procedures.

In the patients with an accessory soleus muscle a tenotomy of the anomalous muscle was performed and part of its tendon, about an inch, was resected (Figure 1.44). In the patients with a flexor digitorum accessorius longus the anomalous muscle was released from its insertion on the medial aspect of the calcaneus.

Discussion

Muscle anomalies in and around the foot and ankle have been reported in the literature since the last century.[6,7,15,19,30,33]

Accessory Soleus Muscle

The accessory soleus muscle was first described by Pye-Smith in 1869[3,15] (Figure 1.45). He wrote that this muscle arose from the oblique line on the tibia and from the aponeurosis of the long flexor of the toes and was attached to the medial aspect of the calcaneus by a distinct tendon.

Testut[31] observed an analogous anomaly and thought of it as a variation of the plantaris muscle. Le Double[3,15] disagreed, reporting that the muscle originates from the deep surface of the soleus, and not from the femur like the plantaris, and it is located away from the toe flexors and, in particular, the short flexor, as opposed to the plantaris, which is nothing but a differentiated portion of the latter.

The accessory soleus muscle may have four different varieties of insertion[17]: (a) along the tendon of Achilles, (b) fleshy to the upper surface of the calcaneus, (c) by a separate tendon to the upper surface of the calcaneus, and (d) fleshy to the medial aspect of the calcaneus.

This muscle may have its blood supply and innervation independent of the soleus muscle or in common with it. It can be unilateral or bilateral.[3,8,15]

However, despite such historical anatomical concern, clinical cases are not commonly described in the literature.

This anomaly is generally agreed to be rare.[10,12,13,18,24] We could not find its incidence in the overall population, but in view of the large number of surgeries performed around the ankle throughout the world, it seems to us that this condition would be more frequently noticed if it were common.

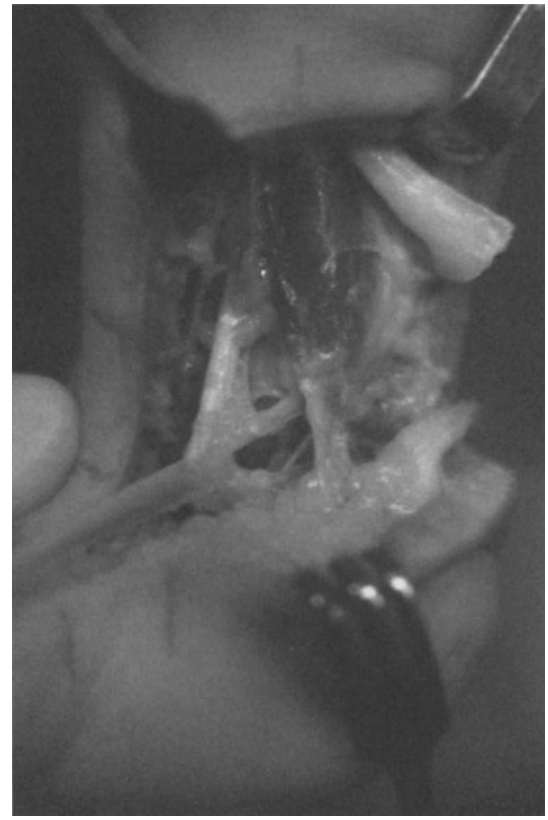


FIGURE 1.45. Case 2—revealing the accessory soleus muscle.

The majority of the clinical cases presented with complaints of a mass posterior to the medial malleolus that can be painful on exertion or completely asymptomatic.

When pain is present it is due to an ischemic process. Either there is poor blood supply or a compartment syndrome develops. Another source of pain is from symptoms of a tarsal tunnel syndrome caused by the muscle's course on the neurovascular bundle.[27]

The presence of an accessory soleus muscle can be suspected on physical examination when the mass becomes firm with plantar flexion. This, of course, is not enough to establish the diagnosis, and additional tests are necessary. Dunn[10] described one of his two cases based only on physical examination.



FIGURE 1.46. Case 3—MRI showing the accessory soleus muscle.

Lateral radiographs may show an obliteration of the fat triangle of Kager[17,22,23] which only confirms the presence of a soft tissue mass. Xerograms and echograms are not specific either.[29]

Ger and Sedlin[11] reported the usefulness of electromyogram (EMG), which they used after operative exploration.

Dokter and Linclau[9] observed that computed tomography (CT) scans can facilitate the correct operative diagnosis with the aid of EMG. Nichols and Kalenak,[21] Nidecker et al.,[22] Apple et al.,[1] Romanus et al.[25] also used CT scanning in some of their patients. However, Petterson et al.[24] suggested that CT scan is not so specific, as it is possible for a tumor to mimic the anomalous attenuation on CT. They advocate the use of magnetic resonance imaging (MRI) because it is superior to CT in distinguishing soft tissue tumors from normal muscle. MRI can lead to a safe diagnosis and dispense with the need for a biopsy[26,34] (Figure 1.46).

Flexor Digitorum Accessorius Longus

The flexor digitorum accessorius longus (or the accessory muscle of Turner; second accessorius of Humphry) is also considered to be an unusual anomaly (Figure 1.47).[4,15] However, its incidence varies among different authors from 1% to 11%. Wood,[33] in 1867, noted only 1% incidence, whereas in a later study he recorded its presence in 8 out of 204 legs (4%).[3,9] Lewis,[16] in 1962, found 3 muscles in 2 of 18 cadavers (11% of cases on 8% of legs) and Nathan et al.[20] found this muscle in 7% of 200 dissected limbs.

This muscle varies greatly in its origin and can be attached to any deep structure of the posterior compartment of the leg. It may have a single or a double head.[4,15,16] It courses through the tarsal tunnel deep to the neurovascular bundle, but occasionally it may cross the bundle superficially and may be a cause of tarsal tunnel syndrome. It inserts on the lateral head of the quadratus plantae.

Although less frequently reported, there are a few cases of anomalous muscles associated with deformity.

Bonnell and Cruess[5] reported a case of bilateral accessory soleus muscles in a 9-year-old boy with a resultant fixed equinus deformity in the feet, which had been present since birth. Ger and Sedlin[11] suggested that this muscle can be responsible for producing a deformity, and their case had a tendency to inversion. Lozach

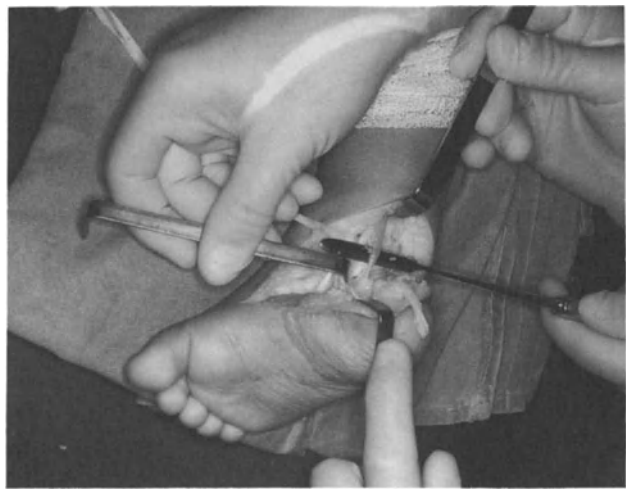


FIGURE 1.47. Case 8—revealing the flexor digitorum accessorius longus muscle.

et al.[18] reported a case of a 26-year-old woman with a varus deformity of the left foot associated with an accessory soleus muscle.

Grogono and Jowsey,[14] in 1965, reported a case of bilateral clubfoot associated with a flexor digitorum accessorius longus. The anomaly was found only in the left foot. They warned, though, that this muscle may have been overlooked in the right foot. They believed that this anomalous muscle may have contributed to the persistence of the foot deformity.

Del Sol et al.,[8] in a study carried out at our university, found two cases of accessory soleus muscles in 254 dissected legs (0.8%), one of which had an equinovarus deformity. No flexor digitorum accessorius longus was observed.

Discussion

The presence of these supernumerary muscles in many of our patients with talipes equinovarus suggested an association with the deformity of the hindfoot.

The puzzling factor is that some of our patients may have these muscles and have neither symptoms nor deformities. Nidecker et al.[22] presented one case that had an accessory soleus muscle that appeared to be lacking in function and did not contract. Beasley[2] also noticed that in one of his cases, although the accessory soleus muscle was inserted on the anteromedial aspect of the calcaneus, it surprisingly did not work as an invertor but simply as a plantar flexor.

On the other hand, one of our patients (case 3) with bilateral talipes equinovarus had his left foot corrected by the Cincinnati approach and posteromedial soft tissue release. He had an accessory soleus muscle that inserted in the medial aspect of the calcaneus. Its tendon was cut and about an inch was resected. The operation was completed in the classic fashion. The right foot had an MRI exam preoperatively that revealed the presence of an accessory soleus muscle. Three months later, this patient was taken to surgery to release this muscle from the calcaneus by means of a small longitudinal incision behind the medial malleolus. This was sufficient to obtain a satisfactory result, both clinically and functionally, 14 months after surgery.

In our study on arterial abnormalities in talipes equinovarus,[28] we observed that only one of the 17 patients that underwent arteriography had no abnormal vascularization but showed an accessory soleus muscle in both legs.

Conclusion

We believe that these anomalous muscles may play an important role in the equinovarus deformity, depending on their insertion and dynamic action.

If the diagnosis can be made by MRI prior to

surgery, a small insertion to release these muscles from the calcaneus may be enough to correct the deformity of the hindfoot and to prevent major surgery.

Summary

This paper discusses the significance of anomalous muscles in relation to the etiology and treatment of clubfeet. Our clinical data revealed a 15.2% incidence of two primary muscle anomalies in patients with CTEV treated at our institution over the last 5 years: the accessory soleus muscle and the flexor digitorum accessorius longus muscle. This exceeds the general incidence reported in the literature.

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A Vascular Hypothesis for the Etiology of Clubfoot

D.R. Hootnick, D.R. Packard, Jr., E.M. Levinsohn, and A. Wladis

Introduction

Investigators, who have had difficulty defining the exact nature of the clubfoot deformity,[10] usually apply the term *clubfoot* to any human limb in which the foot remains congenitally positioned in rigid equinus, varus, and adductus. Since clubfoot may be seen in combination with disparate syndromes,[23] including chromosomal abnormalities and with other limb deformities, clubfoot may result from a number of different pathologic mechanisms.[10] Previously proposed etiologies, therefore, have included genetic mutations, as well as mechanical or neurogenic deformation. In the course of studying various human lower limb defects,[7] we have observed that limbs with a clubfoot almost always contain consistent arterial pattern anomalies.[4,24] Based in part on this observation, we propose a vascular etiology for the origin of clubfoot.

Basic Developmental Mechanisms and Clubfoot

As mesodermal cells of the vertebrate limb bud are instructed to form particular tissues, that process, termed "specification,"[26] proceeds in a wave-like fashion from the most proximal portion of the developing limb to its distal extremity (Figure 1.48). Comparison of the morphology of the developing human limb to that of other vertebrates suggests that limb specification in humans occurs during the fifth week of embryonic development.[13,14,19]

We have proposed a classification of human limb defects based on the time during development that the teratogenic event occurred.[6,8,9] Teratogenic insults occurring before or during specification of a particular part of a limb might lead to a "specification defect." The absence of bony and related soft tissue structures or the presence of supernumerary structures[6,8] (Figure 1.49) distinguish such defects. Malformations from a teratogenic event occurring after a particular portion of the limb was specified might result in a "postspecification defect," featuring misshapen, diminished, or absent bony structures accompanied by relatively normal soft tissues.[3,5] In the case of a missing bone resulting from a postspecification insult, a soft tissue remnant of the bone, the anlage, may be present[6,7] (Figure 1.49). The same limb[8] may contain both types of defects (e.g., absent tibia with diplopodia) if the teratogenic event occurs before specification is complete (Figure 1.49). The more proximal portions of the limb already specified would exhibit postspecification defects (e.g., an absent tibia). The limb distal to the level where specification had progressed at the time of the insult would

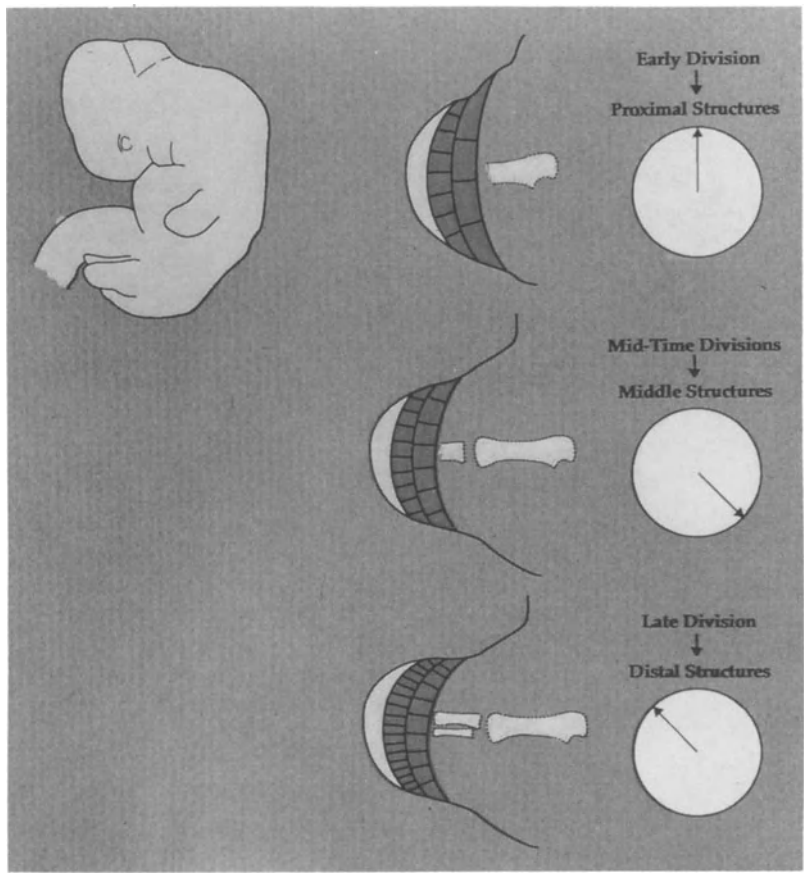


FIGURE 1.48. Progression of "specification" from the most proximal portion of the developing limb to its distal extremity results in successively more distal structures.

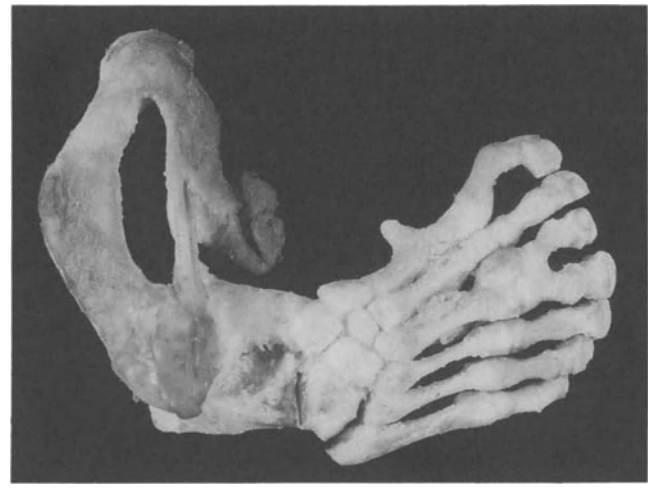


FIGURE 1.49. Dissection specimen of a limb demonstrating tibial deficiency and diplopodia after a through knee amputation. This dorsal view shows the tendinous band and connective tissue, which occupies the place of the tibia. The fibula is enlarged and bowed. Six metatarsals and 7 toes are evident.



FIGURE 1.50. Anteroposterior radiograph of a foot in a limb with midline metatarsal dysplasia, clubfoot, and fibular deficiency.[3,5] (Reprinted, with permission, from Hootnick et al.[5])



FIGURE 1.51. Dorsal photograph of the foot in a limb with a short femur, tibia, and fibula, clubfoot with tarsal synostoses, metatarsal absence, and midline dysplasia with a bifid hallux after below-knee amputation.

exhibit the specification defects (e.g., diplopodia).

Most of the proposed etiologies for clubfoot suggest a postspecification injury.[10] Since other entirely absent or reduplicated structures rarely present in the same limb with a clubfoot, these proposals are consistent with clubfoot anatomy. However, other malformations of the post-specification type, such as congenital short femur,[6] short tibia, absent fibula,[3] tarsal coalitions, and midline metatarsal defects,[5] are occasionally associated with clubfoot. We have reported two limbs with a clubfoot deformity that featured missing or dysplastic midline metatarsals[5,6] (Figures 1.50 and 1.51). A specification error cannot explain such metatarsal malformations. They must, therefore, result from postspecification injury.

We also believe that the rare clubfoot[6] featuring specification defects, such as supernumerary toes, also remains consistent with the notion of clubfoot as a postspecification defect. To our knowledge, the specification defects that are associated with clubfoot occur only distal to the talus. Although the events that cause clubfoot usually occur shortly after specification is complete, we suggest that they may rarely occur just before specification is complete; in other words, here the teratogenic events occur after specification of the talar region, but prior to specification of the metatarsals and digits. Therefore, the same limb may contain a postspecification defect of the talus (clubfoot) and metatarsals and one or more specification defects distal to the talus (such as polydactyly). This happened in an amputation specimen we dissected in great detail.[6]

If many clubfoot malformations result from teratogenic events that occur after the specification of the talar region of the foot, what

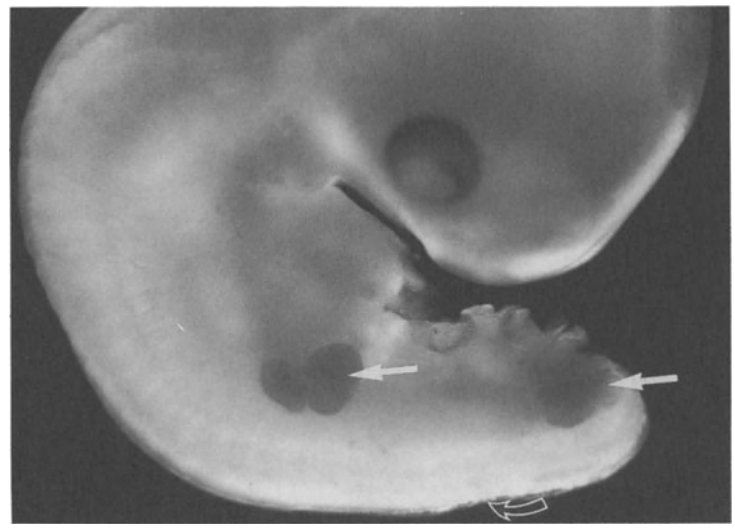


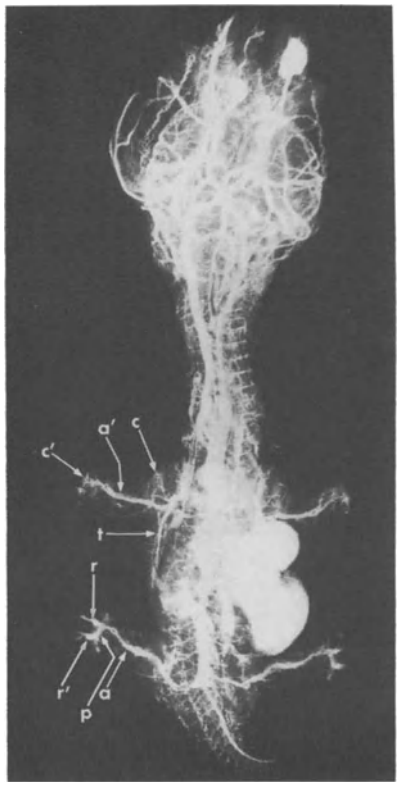
FIGURE 1.52. Lateral photomicrograph of a 5-day-old chick embryo exhibiting chemical teratogen-induced simultaneous hemorrhages (arrows) of the developing limb buds and caudal neural tube.

could be the nature of these events? A physical deformation may cause some of them.[10] Neurologic damage associated with spina bifida[10] may cause others. Traditionally, researchers have claimed that such damage leads to muscle imbalance that produces a clubfoot. However, we observe (in as yet unpublished experiments on chicken embryos) that a chemical teratogen causing both spina bifida and severe hind limb malformations also produces hemorrhaging in both the caudal neural tube and the hind limb bud prior to the appearance of the malformations (Figure 1.52). The simultaneous hemorrhages, therefore, may possibly be responsible for both defects.

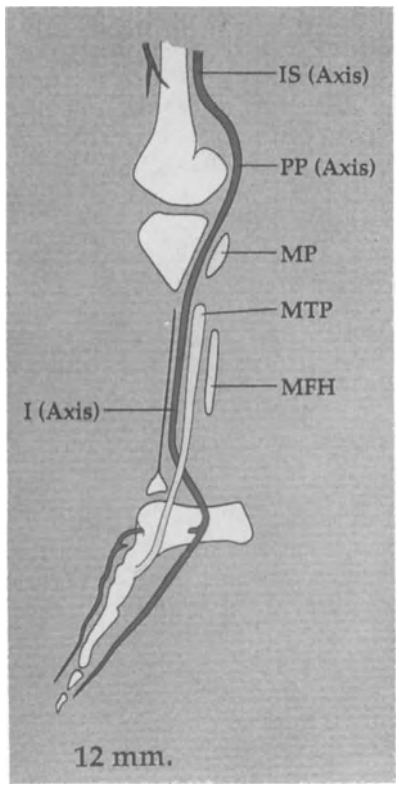
Nearly 90% of human limbs with clubfoot malformations that require surgical correction[24] contain an abnormal arterial pattern characterized by absence or severe reduction of the anterior tibial and dorsalis pedis arteries. After carefully dissecting an amputation specimen that featured a rigid clubfoot with missing and reduced midline metatarsals and reduplication of the distal phalanx of the hallux,[6] we found major anomalies of the muscles, tendons, and nerves in the leg and foot, as well as severe reduction of the anterior tibial artery and absence of the dorsalis pedis artery and the plantar arterial arch. We compared the anatomy of this specimen to others featuring a variety of bony malformations of the leg and foot, and discerned a clear and consistent pattern.[15] Abnormalities of the muscles, tendons, and nerves correlated with the bony abnormalities present in each limb, but the abnormalities of the arteries were consistent and did not vary significantly despite the presence of different bony malformations in each limb. Since the arteries appear early in limb development (at about the same time that the cartilaginous models of the bones appear), and since the vast majority of human limbs that present bony malformations also present a consistently abnormal arterial pattern, and since the anatomy of the arterial anomalies stands out from all the other soft tissue anomalies, we conclude that an etiologically significant relationship exists between the development of the bony and arterial abnormalities.

Development of the Normal Arterial Pattern in the Human Leg

The embryonic development of the arteries of the lower limb follows a specific predetermined pattern in humans and other vertebrates[12,20–22] (Figure 1.53A–E). At approximately the 5-mm stage of human development, primitive arteries emerge off the dorsal root of the umbilical artery and traverse each early limb bud as the axis artery. A second artery that develops off the ventral root of the umbilical artery at the same time becomes the external iliac artery and terminates as the embryonic femoral artery.[12] At this early stage of development,



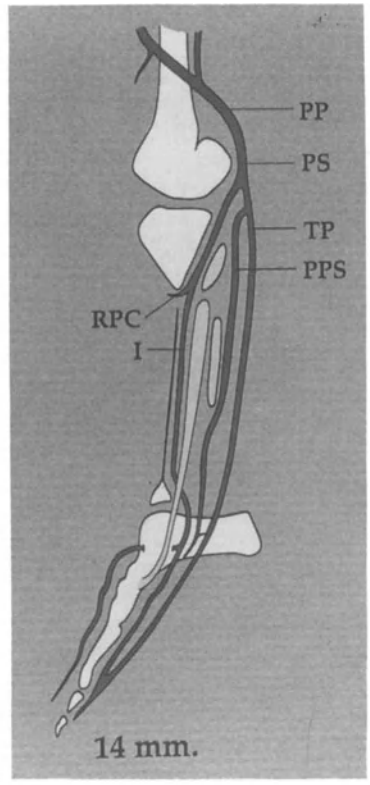
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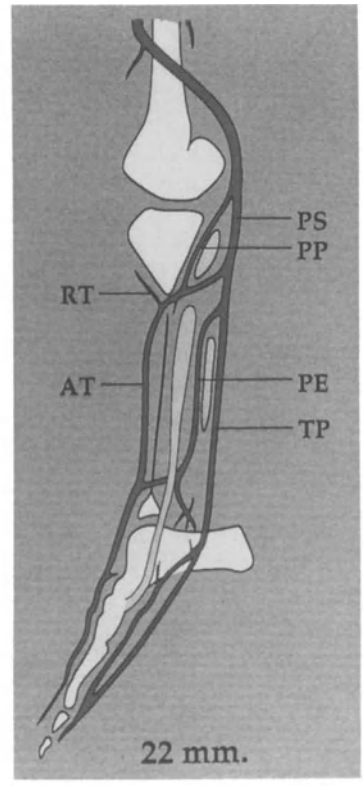
B

FIGURE 1.53. A: Anteroposterior radiograph demonstrating the developing arteries in the body of a 4.5-day chicken embryo (corresponding developmentally to the 8.5-mm human embryo). A, axis artery (lower extremity); a′, axis artery (upper extremity); c, capillary network (proximal); c′, capillary network (distal), p, perforating artery; r, dorsal rete; r′, plantar rete; t, thoracic artery. (Reprinted, with permission, from Levinsohn et al.[12]) B: At the 12-mm stage of development, a single axis artery traverses the lower extremity. C: By 14-mm, two arteries, the tibialis posterior superficialis (TP) and the peronea posterior superficialis (PPS), originate posteriorly. At this time, the ramus perforans cruris (RPC) branches anteriorly off the interossea artery. D: By 18 mm, the anterior tibial (AT) artery develops as the distal continuation of the ramus perforans cruris. A branch, the ramus communicans inferior, develops off the peronea posterior superficialis (PPS) and anastomoses with the interossea (I) artery. Five major vessels now transverse the leg. E: By 22 mm, regression of the distal portion of the peronea posterior superficialis and of the proximal portion of the interossea artery occurs. F: With regression of the poplitea profunda, which occurs at approximately 7 weeks, the mature pattern is established.

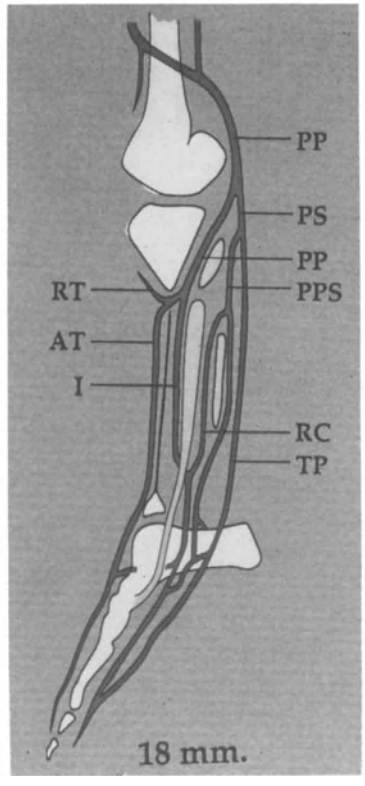
Embryonic arteries: poplitea profunda (PP), poplitea superficialis (PS), peronea posterior superficialis (PPS), interossea (I), ramus communicans inferior (RC), ramus perforans cruris (RPC), ischiatic (IS), tibialis posterior superficialis (TP). Mature arteries: popliteal (P), posterior tibial (PT), peroneal (PE), anterior tibial (AT), recurrent tibial (RT). Muscles: popliteus (MP), tibialis posterior (MTP), flexor hallucis (MFH). (Reprinted, with permission, from Levinsohn et al.[11])


PP
PS
TP
PPS
RPC
I
14 mm.

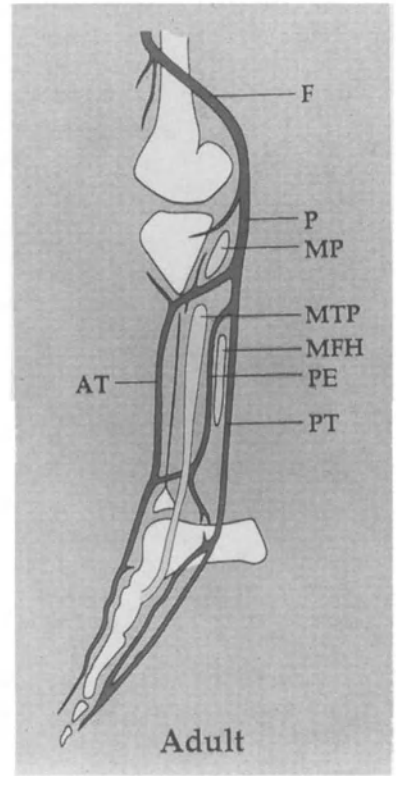
C


PS
PP
RT
AT
PE
TP
22 mm.

E


PP
PS
PP
RT
PPS
AT
I
RC
TP
18 mm.

D


F
P
MP
MTP
MFH
AT
PE
PT
Adult

F

the bones, nerves, and muscles remain undifferentiated.

By approximately 8.5 mm of embryonic development (Figure 1.53A), the axis artery enters the foot as a single discrete vessel, where it branches into dorsal and plantar retia. A single perforating vessel destined to become the embryonic perforating tarsal artery connects the retia (Figure 1.53B).

Between 12 to 14 mm, two distinct arteries descend distally in the limb: the axis and femoral arteries. Subdivisions of the axis artery into three regions above, at, and below the knee are termed the ischiatic, poplitea profunda, and interosseous arteries. The ischiatic artery traverses the thigh undivided. The poplitea profunda develops a distally directed posterior branch, the poplitea superficialis, which lies posterior to the popliteus muscle and runs distally to bifurcate into the peronea posterior superficialis and tibialis posterior superficialis arteries. A branch of the poplitea superficialis, the ramus communicans medius, extends anteriorly to merge with the axis artery just posterior and distal to the developing knee. The poplitea profunda, defined as that portion of the axis artery between the distalmost portion of the ischiatic and the ramus communicans medius arteries, lies anterior to the popliteus muscle. That portion of the axis artery that continues distal to the ramus communicans medius artery is named the interosseous artery.

By the 14-mm stage of embryonic development (Figure 1.53C), a superior communicating branch of the femoral artery anastomoses with the axis artery. At that time, a branch of the poplitea profunda artery, the ramus perforans cruris, moves anteriorly to become part of the future anterior tibial artery. Simultaneously, the distal branch of the tibialis posterior artery enters the foot to anastomose with the plantar rete. Portions of that rete coalesce to form the plantaris medialis artery. A branch of the peronea posterior superficialis anastomoses with the tibialis posterior artery; then it continues on to the plantar surface of the foot in a laterally oblique direction. There it merges with the plantar rete forming the lateral plantar artery and arcus plantaris.

By 18 mm of development, regression of portions of the interosseous artery occurs with the disappearance of the axis arterial supply to the foot. At this stage, the pars distalis of the anterior tibial artery arises and grows rapidly distally, where it sends branches to join the coalescing dorsal rete. This process Leads to the development of the dorsalis pedis artery.

Five major arteries traverse the leg at the 18-mm stage (Figure 1.53D) from anterior to posterior: (a) the anterior tibial artery (pars distalis), (b) interosseous artery (running along the posterior aspect of the interosseous membrane), (c) ramus communicans inferior (a branch off the peronea posterior superficialis), (d) peronea posterior superficialis, and (e) tibialis posterior. The embryonic muscles and nerves now form, having appeared at the 12-mm stage. From 18 to 22 mm of development, further regression of the interosseous artery and of the peronea posterior superficialis artery occurs. By 22 mm, the resulting embryonic pattern closely resembles that seen in the newborn (Figure 1.53E).

Several important features of embryonic development deserve emphasis. The axis artery, including the plantar and dorsal retia and the interconnecting perforating artery directed from the plantar retia to the dorsal retia, is present by the 5-mm stage of fetal development. This pattern remains constant between 5 and 12 mm of fetal development. All of the embryonic arteries in the foot derive from coalescence of capillaries within the plantar and dorsal retia. Ingrowth of the posterior tibial artery feeds the medial plantar artery. Ingrowth of an anastomosing branch from the peronea posterior superficialis to the posterior tibial artery provides the main vascular source for the lateral plantar artery and plantar arch. These events occur at approximately the 14-mm stage of development. The anterior perforans cruris, which is the proximal developing portion of the anterior tibial artery, also develops at this time, begins downward growth, and merges with the dorsalis pedis artery by the 18-mm stage of development. Regression of the interosseous artery is most notable at approximately 18 mm of fetal development. By 22 mm, condensation of a tract between the lateral plantar and dorsalis pedis arteries occurs, leading to the mature pattern (Figures 1.53F and 1.54).

Most investigators believe that arterial variations represent either incomplete development of normal arteries and/or retention of embryonic arteries that normally regress.[2,21,22] In normal populations congenital deficiency of

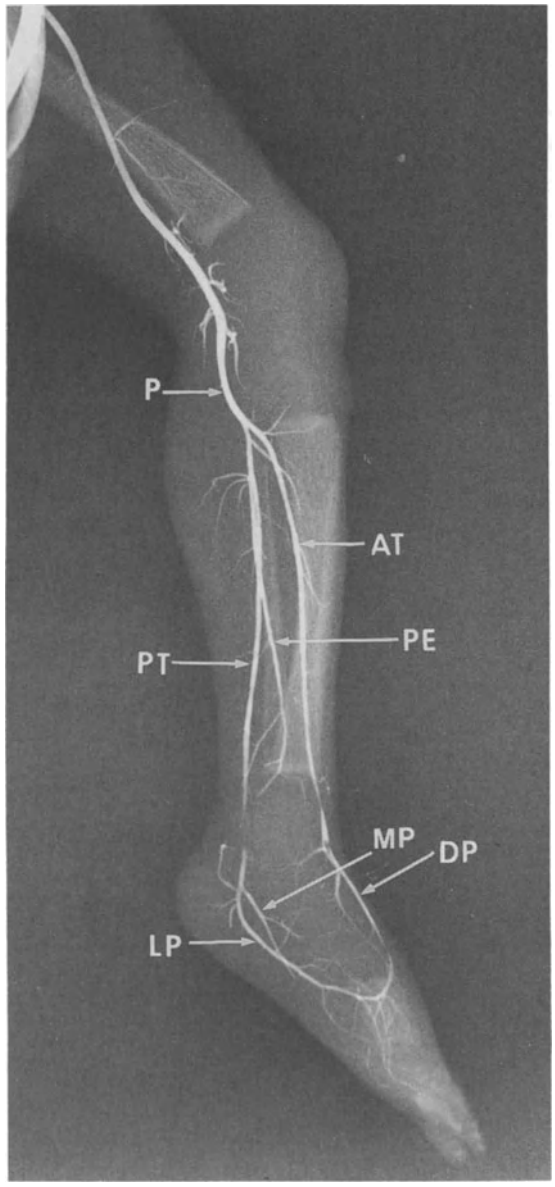


FIGURE 1.54. Lateral radiograph of a 20-week human fetus showing a vascular pattern that corresponds closely to that seen in the newborn and adult. Arteries: popliteal (P), anterior tibial (AT), posterior tibial (PT), peroneal (PE), lateral plantar (LP), medial plantar (MP), dorsalis pedis (DP).

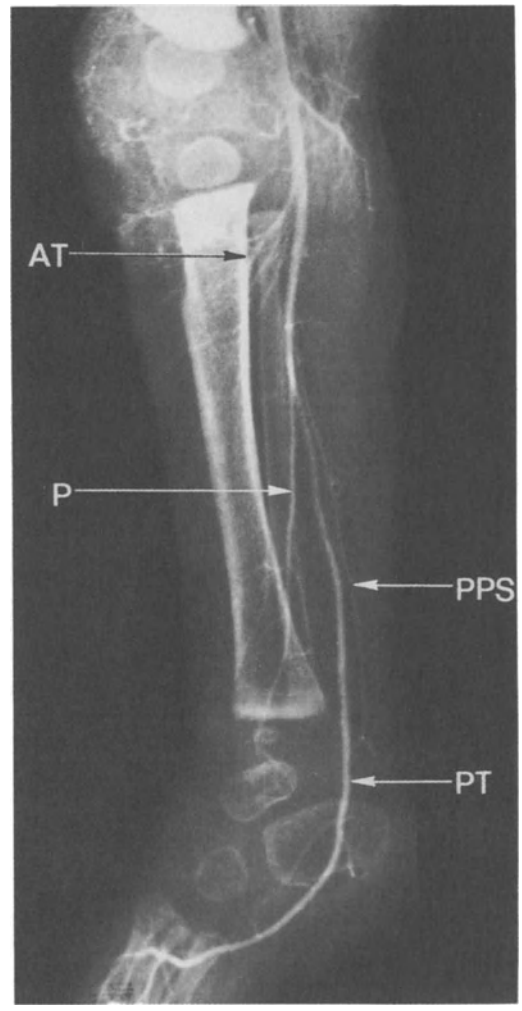
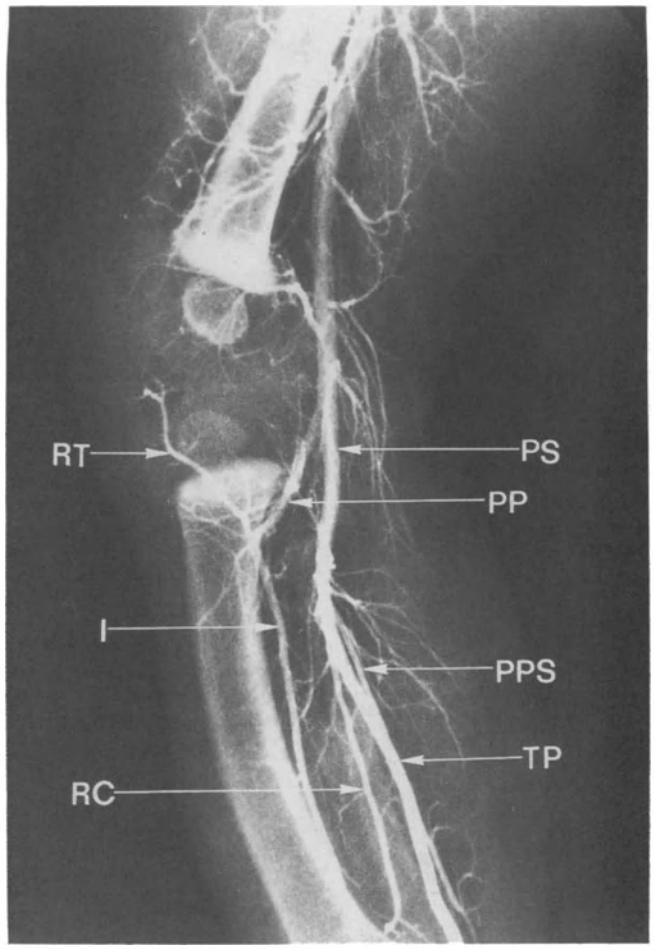


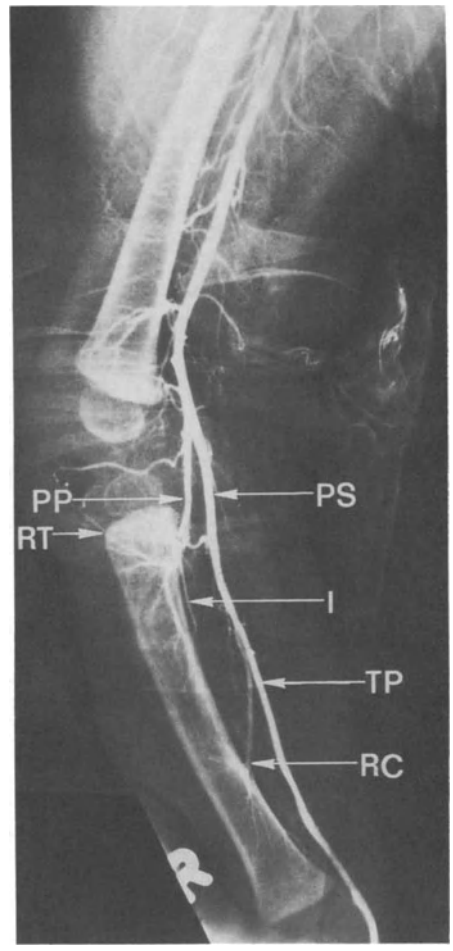
FIGURE 1.55. Lateral arteriogram of the right leg of a patient with CTEV shows a small anterior tibial artery (AT) that terminates proximally in the calf. No dorsalis pedis artery is present. The posterior tibial (PT) and peroneal (P) arteries appear normal. A complete plantar arch is not present. An additional artery, tentatively identified as the remnant of the embryonic peronea posterior superficialis artery (PPS), is present. (Reprinted, with permission, from Hootnick et al.[4])

the anterior tibial artery has a reported incidence of 2.4% to 7.1%. In nearly 90% of patients with clubfoot who have been examined arteriographically (Figure 1.55), researchers have found the absence or severe diminution of the anterior tibial artery and of the dorsalis pedis artery.[24]

The arterial pattern found in most patients with clubfoot and other congenital anomalies of the leg and foot (Figures 1.55 and 1.56) resembles most closely the pattern seen in the embryo between 14 and 18 mm (5.7 to 6.3



A



B

FIGURE 1.56. Lateral arteriogram of the right leg of a patient with fibular shortening and a normal foot demonstrates the absence of the anterior tibial artery. Extra posterior arteries are interpreted to be retained embryonic remnants. B: Lateral arteriogram of the leg of a patient with complete fibular absence and midline metatarsal dysplasia shows a large posterior artery progressing to the foot. There is absence of the anterior tibial artery. Extra posterior vessels are interpreted to be retained embryonic remnants. Arteries: poplitea profunda (PP), poplitea superficialis (PS), peronea posterior superficialis (PPS), interossea (I), ramus communicans inferior (RC), tibialis posterior superficialis (TP), recurrent anterior tibial (RT). (Reprinted, with permission, from Hootnick et al.[3])

weeks) of development. It is at that time that two distinct and anatomically separate vascular events occur:

1. The ramus perforans cruris buds anteriorly off the poplitea profunda artery and becomes the future anterior tibial artery.
2. The condensation of the plantar rete coalesces to form the medial plantar artery, which then accepts a communicating branch from the dorsal rete.

These events are occurring at the time of specification of the distal portion of the lower limb. Whether the failure of normal arterial development represents a primary vascular

event, such as focal rupture of a developing bud, or is a chronologic marker of the teratogenic event, remains to be demonstrated.

An Hypothesis for the Etiology of Clubfoot

The very high association between clubfoot and diminution (or absence) of the anterior tibial and dorsalis pedis arteries might lead to speculation that the loss of these arteries directly causes the bony deformity. Since the major part of the deformity seems to reside in the region of the talus that is supplied by these same vessels, such speculation remains tempting. However, the following observations make this conclusion unlikely: (a) approximately 10% of the limbs with clubfeet have a normal arterial pattern,[24] (b) researchers associate a wide variety of disparate human limb malformations with this same abnormal arterial pattern,[3,7,9] (c) most of the limbs that exhibit the abnormal arterial pattern appear to be normal, and (d) several anecdotal stories report the posterior tibial artery rather than the anterior tibial artery missing in limbs with clubfoot.

We propose that the association between skeletal anomaly and arterial deficiency demonstrates etiologic significance. Specifically, we hypothesize that this abnormal arterial pattern in developing limbs, described above, puts them at risk for subsequent malformation, since it reduces the potential routes for collateral circulation. Conditions that jeopardize blood flow through the remaining arteries may be initiated by the teratogenic event and lead to tissue damage. This tissue damage could, in turn, interfere with the developmental specification or differentiation of limb structures, leading to the bony or soft tissue abnormalities we have observed.

That about 10% of limbs with clubfeet display normal arteries can be explained in two ways. Either the abnormal arteries are occasionally restored following the teratogenic event,[17,18] or these clubfeet may result from a nonvascular teratogenic event. We can attribute the wide variety of limb defects associated with the abnormal arterial pattern to variations in the time in development, location, and severity of the teratogenic event.[25] This idea leads one to a conclusion: although researchers traditionally consider all the defects associated with this arterial pattern to be discrete entities, they may actually constitute different results of the same pathologic process. We may explain why most limbs that exhibit the abnormal arterial pattern described here appear to be normal by hypothesizing that teratogenic damage to those limbs did not occur because blood flow through the remaining vessels was not impaired. In the limbs with clubfeet that lack a posterior, rather than the anterior, tibial artery, we suggest that such a condition also reduces the number of collateral routes for blood flow. Thus, we are suggesting that it is the reduction in the number of vessels supplying the limb that produces the risk of teratogenic damage, rather than the absence of any particular artery.

The hypothesis presented here for the vascular etiology of clubfoot does not suggest a detailed description of the nature of the teratogenic event,[16] other than the suggestion that it results in a decrease in blood flow through the remaining arteries in the embryonic limb. There are other possible explanations. Perhaps a focal vascular teratogenic event[1] results in arrested arterial development. Alternatively, the arrested arterial pattern and the talar deformity may both represent postspecification defects caused by a separate teratogenic event. There is, in fact, a large literature concerning the possible nature of vascular teratogenic events (see Packard, et al.[15] for review). We are currently engaged in an effort to develop an experimental model of vascular teratogenesis in avian embryos.

Summary

The anatomy of the clubfoot deformity [talipes equinovarus (TEV)] suggests that the teratogenic event in clubfoot occurs after the developmental specification of the limb. The majority of limbs with TEV are associated with diminution of the anterior tibial artery and its derivatives, a pattern that resembles most closely that seen in the embryo between 14 and 18 mm (5.7 to 6.3 weeks) of development. We propose that the association between skeletal anomalies and arterial deficiency is etiologically significant.

Specifically, we hypothesize that this abnormal arterial pattern in developing limbs puts

them at risk for subsequent malformation, since it reduces the potential routes for collateral circulation. Conditions that jeopardize blood flow through the remaining arteries may be initiated by the teratogenic event and lead to tissue damage. This tissue damage could, in turn, interfere with the differentiation of limb structures, leading to TEV. Since the anterior tibial artery provides a portion of the blood supply of the talus and the medial part of the foot, and since these sites are commonly believed to be the sites of a major portion of the deformity in TEV, arterial disruptions in those areas may result in medial tethering secondary to scarring or talar anlage dysplasia, thus leading to the TEV.

Acknowledgments. This paper is dedicated to the memory of Mr. George Lloyd-Roberts whose zest for orthopedics remains with us even now. Our thanks to Dr. Lester Friedman for his talented review of this manuscript, to University Orthopedics and Sports Medicine P.C., Syracuse, N.Y., for financial support, and to Ms. Christine Anderson for typing.

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Color Doppler Imaging for Assessment of Arterial Anatomy in Congenital Skeletal Foot Deformity

R.A. Schwartz, D. Kerns, and M. Fillinger

The etiology of congenital skeletal dysplasia remains unknown. There has been speculation that a concurrent relationship exists between the skeletal anomaly and the well-documented coinciding arterial dysgenesis. A previous retrospective review of patients with the talipes equinovarus deformity demonstrated a 93% incidence of dysgenesis of the anterior tibial and medial plantar arteries.[2] Furthermore, Hootnick and his associates[1] have proposed a relationship of arterial dysgenesis and foot necrosis as a result of therapeutic intervention. Consequently, clinical scenarios may arise in which the surgeon may tailor his therapy based on a knowledge of the preexisting arterial anatomy.

Angiography to date has been the only diagnostic imaging modality that provides sufficient anatomic detail to accurately delineate the aberrant lower extremity arterial anatomy in children with skeletal deformity. The logistic difficulties and risks of performing angiography in children has precluded its routine utilization. In contrast, color Doppler ultrasound imaging conceivably would provide a rapid, safe, and potentially accurate method of defining lower limb arterial anatomy prior to therapy for the equinovarus deformity. Therefore, the purpose of this preliminary study was to determine the feasibility of mapping the lower extremity arterial anatomy in infants and children with skeletal dysgenesis.

Materials and Methods

Eight unsedated children (ages 1 to 22 years) with congenital skeletal foot deformity underwent color Doppler ultrasound imaging. Four patients had the study prior to elective repair and 4 were studied following surgical intervention. A 22-year-old patient was included who was severely developmentally delayed and weighed approximately 40 kg.

A Quantum QAD 1 color Doppler ultrasound imaging device (Quantum Medical Systems, Issaquah, Washington) was selected for this feasibility study because of its unique ability to process simultaneously all reflected ultrasound signals for amplitude, phase, and frequency. Since this device does not utilize beam steering technology and wall filtering software, it potentially could detect small, weak echogenic arterial blood flow despite the highly echogenic background of a limb.

A 7.5-MHz linear array transducer was utilized with a standoff that maintained an angle of

ultrasound insonation of 72° to the tissue being examined. Transmission power and amplification were maximized to reflect and receive as much ultrasound as possible from the weak echogenic red blood cell roulettes.

The popliteal and tibioperoneal arteries were examined through the dorsal acoustical window to the popliteal fossa. The posterior tibial artery was identified within the acoustical window medial and posterior to the tibia (Figure 1.57, see color plate 1). The anterior tibial and peroneal arteries could be visualized through the acoustical window lateral to the tibia and medial to the fibula. When the arterial supply appeared absent, system amplification was increased to detect arterial flow as slow as 0.3 cm/sec. Because of the technology utilized, arteries less than 0.5 mm went undetected. When an artery was detected, the diameter, peak systolic velocity, and end diastolic velocity were measured.

Results

Detailed arterial anatomy was depicted in all eight patients studied. No examination required more than 30 min per extremity. Three of the eight patients studied had an absent anterior tibial artery in the distal portion of the afflicted extremity. Three patients had hypoplasia of the anterior tibial artery, which was defined as at least a 50% reduction in luminal diameter as compared to the posterior tibial artery. One patient had absent anterior and posterior tibial arteries with foot perfusion being maintained by a large peroneal artery (Figure 1.58, see color plate 1). The mean anterior tibial artery diameter when present was 1.5 ± 0.61 mm, whereas the mean posterior tibial artery diameter was 1.9 ± 0.86 mm. The mean peak systolic velocity in the anterior tibial artery when present was 76 ± 35 cm/sec with a mean end diastolic velocity of 12 ± 3 cm/sec. In comparison, the mean peak systolic velocity in the posterior tibial artery was 61 ± 22 cm/sec with an end diastolic velocity of 8 ± 2 cm/sec.

Discussion

Color Doppler ultrasound imaging has proven to be a workable alternative to invasive iodinated contrast angiography in children for the depiction of arterial anatomy associated with congenital skeletal deformity. The examination can be completed expeditiously as an outpatient with sufficient resolution to aid the physician in clinical decision-making. Though feasible, the accuracy of the technique remains unknown. A clinical series comparing angiography to color Doppler ultrasound imaging is necessary to quantitate the sensitivity and specificity of the technique. Comparative studies in other clinical circumstances, such as venous disease and carotid occlusive diseases,[3] have proven accurate. Therefore, it is reasonable to anticipate that this application of the technique should prove reliable, provided that high-resolution equipment capable of detecting slow flow and small vessels is available.

The advantages of color Doppler imaging as compared to angiography are obvious. It eliminates the risks of general anesthesia and transarterial injection of iodinated contrast, and outpatient ultrasonography is significantly less expensive than contrast angiography. Hence, ultrasonography meets the criteria for a screening test for arterial dysgenesis in children with skeletal deformity.

Color Doppler imaging also has advantages over a hand-held continuous-wave Doppler device. The continuous-wave Doppler device receives transmitted ultrasound energy from any reflector within the plane of insonated tissue; therefore, any blood flow within a given vector causes a frequency shift that produces an audible signal. Thus, there can be no discrimination as to the depth of the vessel being evaluated at any given location. For instance, when a ventral window above the ankle is utilized, the physician cannot determine whether the returning signal is from the anterior tibial artery or from a terminal branch of the peroneal artery. The frequency shift information obtained from a continuous-wave Doppler device will not indicate the size of the vessel, and the direction of flow is often misinterpreted in tortuous aberrant vessels. Color Doppler, even though more expensive, provides the clinician with data as to vessel size, continuity, direction of flow, and true velocity of flow. Therefore, anatomic localization and identification of the arterial vasculature is possible.

Color Doppler ultrasound imaging does not transmit and process ultrasound uniformly. As noted in the Methods section, there is a high

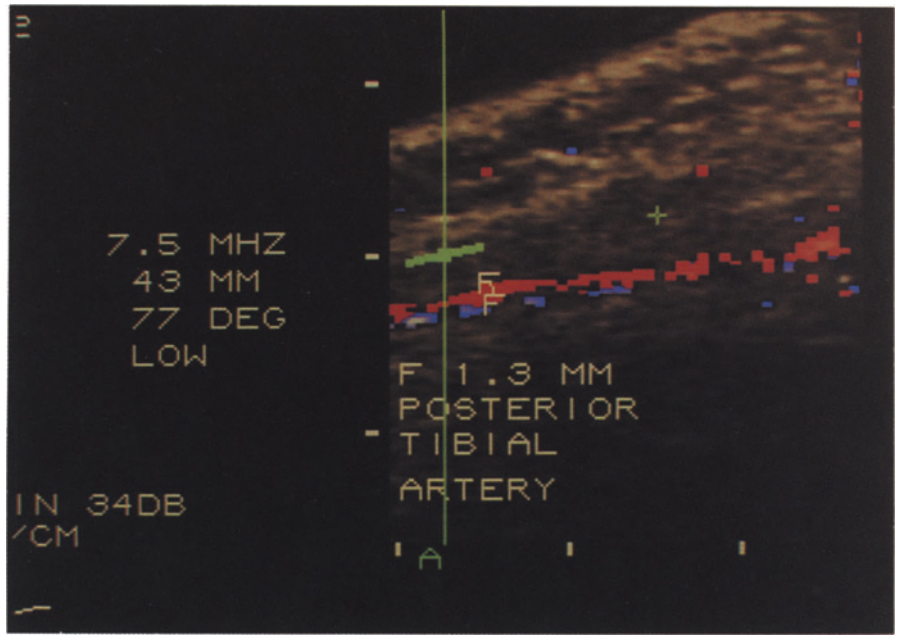


FIGURE 1.57. Color Doppler ultrasound image of the posterior tibial artery in a 1-year-old child.

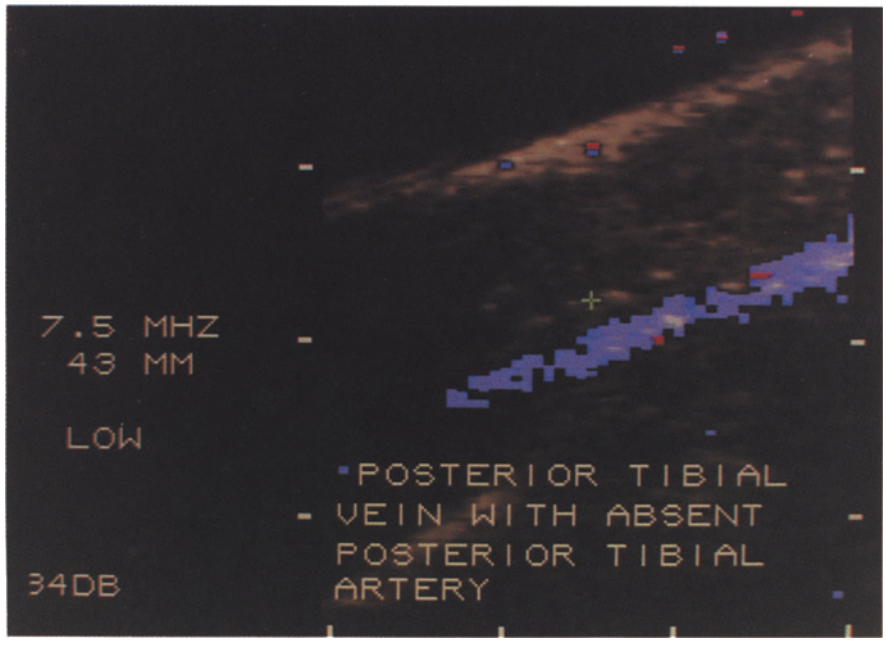


FIGURE 1.58. Color Doppler ultrasound image of a hyperplastic posterior tibial vein in a child with an absent posterior tibial artery.

probability that these results depend on the ultrasound hardware used.

Summary

This early feasibility study suggests that color Doppler ultrasound imaging provides sufficient arterial anatomic detail to replace angiography in children. Sensitivity and specificity studies will be necessary to put this technique in clinical perspective. Color Doppler imaging appears to be acceptable for screening children suspected of having arterial dysgenesis.

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Discussion

Griffin (Charleston): From my observations of the neurological cavovarus deformities, of congenital myopathies, and of peripheral neuropathies, even though the calcaneus is in varus, it does not usually medially rotate as it does in the typical CTEV. How do you explain this phenomenon?

Cummings (Jacksonville): Presumably there is a muscle imbalance, which may cause the particular configuration of deformity that one sees with the clubfoot.

Barnett (Minneapolis): One wonders whether the very strong abductor hallucis, which causes the forefoot to go into adduction, may also cause the hindfoot to go into varus as well as to rotate beneath the calcaneus.

Crawford (Cincinnati): What is the effect of cast immobilization and splinting on the results of the muscle biopsies?

Kojima (Osaka): There are studies that show that the immobilization of splints and casts does not change the fiber type.

Handelsman (New Hyde Park, New York): We did a similar study immobilizing six young baboons, which have musculature similar to that of humans. The results of these studies did not show any major differences.

Catterall (London): At the time of surgery, one observes that the Achilles tendon and the tibialis posterior do not have the ability to stretch. That is, if one pulls on the end of one of these muscles, the muscle does not give; however, the long toe flexor and the common toe flexors will commonly stretch without any trouble at all. Thus, it appears that the ability of these muscles to respond to manipulation or stretching is entirely different.

Tachdjian (Chicago): Has anyone performed fetal muscle biopsies in clubfeet? [The panel's answer was no.—ED]

Watts (Los Angeles): If the etiology of typical clubfeet is neurologic, as you believe, Dr. Handelsman, why don't patients with peripheral neuropathies and myopathies like Charcot-Marie-Tooth and patients with spina bifida all have clubfeet? They have the same muscle pattern histologically.

Handelsman: I don't know; however, if this is of central neuromuscular origin, why is it limited to muscles below the knee; that is, why don't we see this in a more global pattern? It may be related to the location of the lesion within the anterior horn cells.

Porat (Jerusalem): After reconstruction of the foot, the peroneal nerve apparently resumes

functioning in most of these feet. In view of the initial deficiency in innervation, how does one explain this recovery? Is this due to reinnervation?

Handelsman: I think there are two factors. First, the muscle is overstretched and doesn't function very well until the foot becomes realigned after redevelopment of the normal anatomy. Then these muscles shorten and power returns. We also looked at the peroneal muscles and found that they are not normal, but they are not as abnormal [as the plantar flexors]. We did not find the same number or the same magnitude of changes in the peroneal muscles as we did in the others. However, they are actually affected as well.

Shimizu (Osaka): In one case that I showed, there was a normal histochemical pattern present, although the child clinically had peroneal nerve palsy, so I don't know the exact cause of this difference between the clinical and histochemical findings.

Griffin: I have stimulated the peroneal muscle in newborn babies with clubfeet. It's very difficult to get the peroneal muscle to contract sufficiently, even to twitch the foot. Therefore, I have used peroneal stimulation in my postsurgical treatment over the last several years. I have also shortened the peroneus brevis in some feet. If I get good peroneal muscle function following surgery, I usually get a good result in my clubfoot.

Coleman (Salt Lake City): You demonstrated that the arterial patterns of a clubfoot are frequently abnormal and seem to have a certain pattern. How does this apply to your assessment of the vascularity prior to, during, and after clubfoot surgery? That is, how does it influence what you do when you determine the particular circulation pattern? [Dr. Hootnick referred the question to Dr. Turco.—Ed.]

Turco (Hartford): The foot with severe equinus in which the calcaneus is almost vertical is the type of foot that I become concerned about as far as postoperative vascular complications. Before the wound is closed, with the neurovascular bundle in direct view, I dorsiflex the foot to a right angle and notice the amount of tension on the neurovascular bundle. If there is any tightness, that foot should be immobilized in equinus. The correction is maintained with K wires, and postoperative manipulations are performed at 1-week intervals. Gradually the foot is brought up into dorsiflexion. I think this is the way to avoid vascular complications.

Goldner (Durham): I think the use of the color Doppler may be an extremely important contribution. I think that all of Dr. Hootnick's cases have been operated on previously. This may be a factor as complications occurred with secondary surgery and, therefore, I give special attention to previously operated feet as far as possible vascular compromise is concerned. First, I use a Doppler, then obliterate the posterior tibial artery with my thumb, obliterate the anterior tibial artery with my thumb, and then take the tourniquet down. If the foot is white, then you've got a problem. If you take the tourniquet down and the foot pinks up slowly, you may or may not have a problem. Then you treat it as is necessary. Now, when you take the tourniquet down and the foot is white, one may have to put vein grafts in the posterior tibial artery. The point I'm making is that one has to determine the vascularity intraoperatively, and immediately postoperatively and if it's not all right, then a decision should be made at that time. We have never lost a foot and have never done arteriograms in any of our feet. We have used the continuous-wave Doppler, but I think the color Doppler will certainly help.

Hootnick (Syracuse): Unfortunately, the complications didn't arise immediately postoperatively. As a matter of fact, in one foot the child's parents noticed on the 7th postoperative day that the toes were turning blue. Prior to this the toes had looked normal; the child's splint was removed in the emergency room and the foot looked normal; however, the following day the child was brought back and the great toe was necrotic. Thus, I think that necrosis in this case may not have had anything to do with damage to the artery specifically. It may be due more to the oxygen demands of wound healing because there is a diminished blood supply.

Goldner: I think that there was something present in the first 24 hours, either slow blanching of the toes or some other clinical sign was present that should have been a tip-off.

Zimbler (Boston): Is there an increased flow in the posterior tibial artery? As there is a

decreased flow in the anterior tibial artery, is there compensatory increased blood flow through the posterior tibial artery by color Doppler assessment?

Hootnick: I'm not certain but I suspect that there is a decreased flow. Dr. Schwartz, do you agree?

Schwartz (Syracuse): We've studied eight limbs, three of which had a normal contralateral limb. The velocity of flow in the afflicted limb was identical to the velocity of flow in the contralateral, normal limb. It does not appear to me that there is a compensatory hyperplasia of the posterior tibial artery in those patients that have an absent anterior tibial artery, or if there is, the compensatory increase is of such a small magnitude that it's unmeasurable.

Marcus (Detroit): Can you tie together the neurogenic and vascular etiologies? Which is primary and which is secondary?

Packard (Syracuse): In the experimental chicken model, we see both spina bifida and severe limb defects. Sometimes we see something that resembles a clubfoot, but I'm not sure in the chicken's model that this really is a clubfoot. Certainly all sorts of severe limb defects are seen and it suggests that it's possible that there are two defects occurring simultaneously for a similar reason. We see hematomas in both the cord and lower extremity; thus, it suggests to us the possibility that hematomas are involved in the etiology of both the spine and limb defects rather than one defect causing the other, but we really can't be certain.

Barnett (Minneapolis): Does there appear to be a vascular etiology for the loss of contractibility or elasticity in the contracted muscles?

Hootnick: In the development of the limb, the bones and arteries develop simultaneously. I think the musculature develops later. In the teratologic specimens, if the bones are abnormal, the muscles will attach to whatever bones are present. So if the bones are misshapened or in any way absent, the muscles find other places to attach. Therefore, I believe that changes in the muscles are really a secondary phenomenon.

On the other hand, in Sodre's patient, there was an anomalous muscle present. When the muscle was released, the foot deformity corrected easily. So this must obviously be a different problem in which the muscle was the primary etiologic factor.

Editor's Comments

Mellerowicz et al., using morphometric studies, concluded that type 1 fiber predominance is probably related to the etiology of clubfeet. **Kojima et al.,** using histochemical studies, concluded that the etiology of clubfeet is perhaps due to defective neuronal influences (i.e., recovery from temporary denervation during the early fetal period or anomalous innervation to developing muscles causing abnormal muscle development and maturation). **Shimizu et al.** concluded that CTEV is due to neuromuscular dysfunction with a spectrum of severity of neurological findings ranging from partial loss of innervation with reinnervation in the case of CTEV, to partial loss of innervation and no reinnervation in patients with constriction band syndrome with TEV, to total loss of innervation with no reinnervation in a patient with sacral agenesis. In the first group, the anterior tibial muscles and peroneal muscles were normal by histochemical studies; in the second group, the anterior tibial muscle was normal but the peroneal muscles were atrophic by histochemical studies; and finally, in the third group the anterior tibial muscles, peroneals, and the toe extensors were all abnormal by histochemical studies. Thus, there was a spectrum of neurological abnormalities, as well as a spectrum of muscular abnormalities of the anterior lateral ankle muscles and nerves that correlated with one another. **Handelsman** and **Glasser** concluded that an increase in the number and grouping of type 1 muscle fibers suggested a neurogenic etiology based on the

findings of denervation and reinnervation in CTEV. They also observed similar findings in patients with other lower motor neuron lesions. Furthermore, it has been shown that muscle integrity is dependent upon normal neuronal input. They postulated that, when nerve input is lacking, muscular abnormalities in early fetal life may occur with fixed peripheral deformities present by the time of birth.

Therefore, in conclusion: (a) type 1 fiber predominance and grouping is present in CTEV (Mellerowicz, Kojima, and Handelsman); (b) changes characteristic of denervation and reinnervation are present in CTEV (Shimizu and Handelsman); (c) these changes may be due to an abnormality occurring in the early fetal period with partial recovery by the time of birth (Kojima); (d) lesions similar to CTEV have been observed in other lower motor neuron diseases (Handelsman); (e) the findings in CTEV are at the mild end of the spectrum of lower motor neuron lesions (Shimizu); (f) a spectrum of neurogenic, as well as muscular, abnormalities has been seen in different types of TEV—primary CTEV, constriction band syndrome with TEV, and sacral agenesis with TEV (Shimizu); (g) thus, neurogenic abnormalities that present in early fetal life may result in denervation followed by reinnervation without complete recovery and the persistence of a mild, fixed deformity at the time of birth (Kojima and Handelsman).

In an EMG study, **Martin et al.** attempted to prove a neuropathic etiology of CTEV. They studied motor unit counts in the abductor hallucis and the extensor digitorum brevis muscles, innervated, respectively, by the posterior tibial and the common peroneal nerves. They demonstrated a reduced motor unit count in the extensor digitorum brevis, but the motor unit counts were normal in the abductor hallucis.

They were unable to explain why, although the extensor digitorum brevis (EDB) had reduced motor unit counts, the abductor hallucis did not show reduced motor unit counts despite the fact that there was a gross reduction in the size of the muscle innervated. They were also unable to demonstrate the level and nature of the neuropathy (if this is a neuropathy).

Sodre et al. point out that, when present, an anomalous muscle may well be the major (or only) etiologic factor in the development of a particular clubfoot. However, because of the relatively infrequent occurrence of these muscles, they would have to be considered as a rare cause in a wide spectrum of etiologic factors.

Hootnick et al. report that the cost of the color Doppler equipment is approximately $200,000. A color Doppler exam costs between $200 and $250. It cannot be performed in the office or in the operating room. It must be performed in a laboratory because of the bulk of the equipment and requires a trained technician.

Indications for color Doppler examination appear to be:

1. reoperation on a previously operated clubfoot; or
2. the second foot in which the contralateral, previously operated foot had an abnormal vessel(s), especially a congenitally absent posterior tibial artery.

Therefore, the routine use of the color Doppler is not indicated but, when it is indicated, it should be obtained if the equipment is available.

Continuous-wave Doppler (as opposed to color Doppler) cannot tell the depth of the vessel by quantified blood flow. For this reason, **Hootnick's** group stopped using the continuous-wave Doppler in favor of the color Doppler.

In my experience, veins have always accompanied the artery in normal feet; however, in an anomalous situation, this may not always be the case (as in Schwartz's patient, see page 61, Figure 1.58). If veins can occur without an accompanying artery, this may be of considerable clinical significance. In the case that I report in Chapter 5, the posterior tibial artery was absent as were the veins; the absence of the veins alerted me to the fact that there was a congenital anomaly present in the vessels. If the veins had been present without the artery, I would not have recognized this as an anomalous absence of the artery, and would probably have incised the deep peroneal artery during the routine dissection.

2
Laboratory and Nonclinical Evaluations: Neuropsychiatric Evaluation, Pathomechanics, Magnetic Resonance Imaging, Gait Analysis

Introduction

This chapter deals with various laboratory and other nonclinical techniques for the evaluation of the child with congenital talipes equinovarus (CTEV). In the first paper by **Motta** and **Merello**, the author reports the results of the evaluation of 20 postoperative clubfoot patients who had surgery between birth and 1 year of age. These evaluations consisted of a routine neurological examination, a psychiatric interview, the Brunet-Lezine test, and the SCENO test.

Rab, in a cleverly designed three-dimensional computerized geometric model, attempted to evaluate which ligaments were contracted in CTEV. He thereby was able to predict which ligaments needed to be released. In addition, the model was used to simulate various strategies during the ligamentous releases.

Turco describes a rare type of clubfoot that appears to have the usual clubfoot characteristics without any evidence of neurological or genetic syndromes. However, the response of this atypical CTEV to serial casts is unlike the response of the typical idiopathic type of clubfoot. Furthermore, results with early soft tissue surgery are unpredictable and often include a grotesque overcorrection resulting in a severe flat foot. Turco identifies the clinical characteristics and x-ray findings that suggest the presence of this type of foot. He concludes by presenting his suggestions for managing these feet.

In one of the first magnetic resonance imaging (MRI) studies of CTEV, **Downey**, **Drennan**, and **Garcia** evaluate the in vivo anatomic relationships in CTEV. MRI provides superior imaging of the cartilaginous and other soft tissue structures in both the normal and abnormal infant's foot. MRI is ideal for studying TEV feet, which are largely cartilaginous at birth.

Campos da Paz et al. evaluate the child's self-image and opinion of his own gait (presence or absence of a limp). These impressions are compared with those of the surgeon. In addition, the authors differentiate between function and performance, and stress that the latter should be incorporated into the child's evaluation.

Neuropsychiatric Assessment of Infants Treated Surgically for Congenital Clubfoot During the First Year of Life

F. Motta and S. Merello

Prolonged orthopedic treatment, especially treatment involving daily physiotherapy, casts, or surgery may have a negative influence on a child's neuropsychiatric development.[3,4] The usefulness of a neuropsychiatric evaluation as a factor in the selection of appropriate orthopedic treatment in patients with clubfeet has not been previously evaluated. The purpose of this study, therefore, is to evaluate the usefulness of neuropsychiatric assessment as part of the evaluation of the results of treatment of CTEV.

Methods

Twenty children between 24 and 30 months of age treated for clubfoot during the first year of life were assessed by a neuropsychiatrist (Merello). Orthopedic treatment (Motta) consisted of cast applications for 3 months starting from the first days of life. This was followed by 2 months of daily physiotherapy. At 5 months of age, the children underwent clinical and radiographic examinations, and the decision was made whether to surgically correct the residual deformity. Once surgery was chosen, McKay's[5] operation was employed. All children were cured by the age of 1 year, and the malformation was well corrected. Neuropsychiatric evaluation started with an interview with each child's pediatrician to obtain information about the pregnancy, childbirth, first acts of life (crying, cardiorespiratory conditions, icterus, sucking, body development, sleep-waking rhythm), the child's psychomotor stages, and any diseases. The child's mother was then interviewed to obtain information about her mood during pregnancy—her fears, desires, and general feeling about the unborn baby.

The children then underwent a neurological examination followed by the Brunet-Lezine test,[1,2] which assesses motor, verbal, and social development, and how the child acts with objects; this permits an assessment of the real mental age. The children were then observed through the SCENO test,[6] which is a diagnostic and therapeutic tool for sensing the child's innermost attitudes toward people and things. It includes toys, puppets, and animals with which the child can represent a story, invented by himself, which is related to his affective and emotional life. As a rule, very young children build up a scene without planning, tending to line up similar objects, showing that they have learned the relationship between them.

Results

From the interviews with the pediatricians, it appeared that the children had no fetal or perinatal problems. All of their first acts of life were normal, and they attained the various psychomotor developmental stages within the normal intervals. None of the children had any significant disease. All of their mothers had wanted a child during pregnancy and their mood had generally been good. No sad events had occurred in this period and all husband-wife relationships were satisfactory. Neurological examination of the children indicated normal neurological development with no disorders of the brain or muscles. The Brunet-Lezine test indicated that their mental development and age coincided with their chronological age. They could all observe and handle toys and puppets with dexterity, and the older children were able to play symbolically. Therefore, their development was considered normal.

Conclusion

The purpose of this study was to determine the usefulness of neuropsychiatric assessment in

the evaluation of the results of orthopedic treatment for major clubfoot pathology. The tests employed for assessing the outcomes of young children surgically treated for clubfoot proved valuable and confirmed the validity of the orthopedic protocol we use. Its basic aim, i.e., the clinical cure within the first year of life, was achieved, and the children appeared to have normal motor and neuropsychiatric development.

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A Mathematical Model of Congenital Clubfoot

G.T. Rab

The treatment of congenital clubfoot has generally followed empiric lines: clubfoot deformities are initially manipulated and casts applied. At some point, a subjective judgment is made whether surgical treatment should be instituted. However, once a decision to operate is made, there is no standard agreement about the exact surgical procedure to be performed. Some surgeons advocate posterior release and continuation of cast treatment of the midfoot deformity, whereas others recommend tibiotalar release.[2] In North America, complete subtalar release is commonly performed,[6] whereas a fourth approach includes specific attention to the calcaneocuboid joint.[1] The mathematical model described in this paper was designed to help understand the three-dimensional mechanics of the clubfoot deformity and its correction. The model was designed to specifically answer the following questions: (a) How does ligament length change from normal in the congenital clubfoot? (b) How does release of specific ligaments effect the correction of the deformity? (c) Can joint incongruency be quantitated? and (d) Can spurious correction by incomplete or inappropriate surgery be predicted by ligament geometry?

Methods

A three-dimensional geometric computer model was created using a combination of anatomic measurements from photographs, measurements from skeletal models, and standard anatomy textbooks. The model consists of bones that are mathematically modeled as geometric solids, with three-dimensional inelastic linkages to serve as joints. These linkages were designed to simulate, as nearly as practical, the observed motion of individual joints. For example, the talonavicular joint was modeled as a spherically mobile joint with a center of rotation near the midportion of the talar neck, whereas the subtalar joint was modeled with movement around an oblique axis as described by Inman et al.[4] Ligaments were modeled as straight lines connecting origins and insertions on individual bones, with the segmental attachments mobile with the individual bone to which

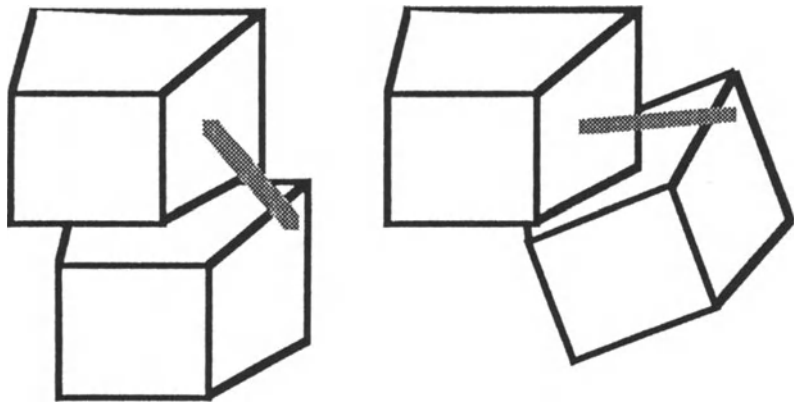


FIGURE 2.1. The basic "building blocks" of the clubfoot model. Bones are modeled as geometric solids, free to move in three-dimensional space. Ligaments are modeled as straight lines connecting fixed origin and insertion points on the mobile bones; the ligament length is calculated by the three-dimensional distance between origin and insertion after the bones are positioned as described in the text.

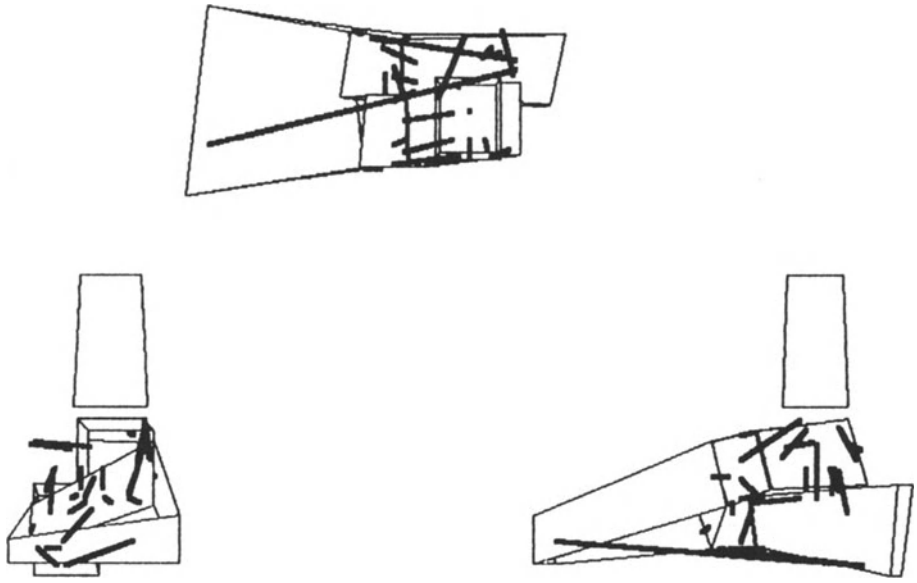


FIGURE 2.2. Anterior (left), superior (center), and medial (right) views of the bones and ligaments in the clubfoot model described in this paper. The bones have been made transparent to show the ligaments from all views. The specific ligaments are described in Table 2.1.

they were connected. A basic conceptual diagram of the model is shown in Figure 2.1.

Six bones and 22 ligaments were modeled (Table 2.1 and Figure 2.2). The entire distal foot (cuneiform bones, metatarsals, and phalanges) were modeled as a single bone because the primary interest of this study was in the midfoot and hindfoot region. The three-dimensional model was programmed in BASIC on a Macintosh SE computer. The programming allowed free manipulation of individual bone and joint positions, so that the foot and ankle could be put into both normal and deformed positions to allow circulation of the length of individual ligaments. This allowed simulation of the normal physiological move-

TABLE 2.1. The 6 bones and 22 ligaments that were modeled in the study.

Bones
Tibia
Talus
Calcaneus
Navicular
Cuboid
Distal foot
Ligaments
Anterior tibiotalar
Tibiocalcaneal
Posterior tibiotalar
Tibionavicular
Posterior talofibular
Anterior talofibular
Talonavicular
Medial talocalcaneal
Lateral talocalcaneal
Medial interosseous talocalcaneal
Lateral interosseous talocalcaneal
Calcaneonavicular—bifurcate
Calcaneocuboid—bifurcate
Medial plantar calcaneonavicular
Calcaneofibular
Plantar calcaneocuboid
Plantar fascia
Long plantar
Dorsal cubonavicular
Plantar cubonavicular
Naviculofoot
Cubofoot

ment of the foot as well as the abnormal position of the bones seen in clubfoot.

Results

Normal Foot

The movement of the normal foot and ankle was modeled throughout their physiological range of plantar flexion and dorsiflexion, including "coupling" of the subtalar and talonavicular joints (Figure 2.3).[7] The length of each ligament during these motions was calculated as above, and a range of physiological ligament excursion (equal to the change in distance between origin and insertion during full ankle and foot motion) was calculated. Next, the length variation for each ligament was calculated during *uncoupled* motion (i.e., full inversion-eversion *without* ankle motion). For example, Figure 2.4 shows the variation in length of the calcaneofibular ligament during full ankle dorsiflexion and plantar flexion, and subtalar eversion and inversion. The gray region on these graphs indicates the expected variation in range during normal plantar flexion and dorsiflexion of the foot, and takes into

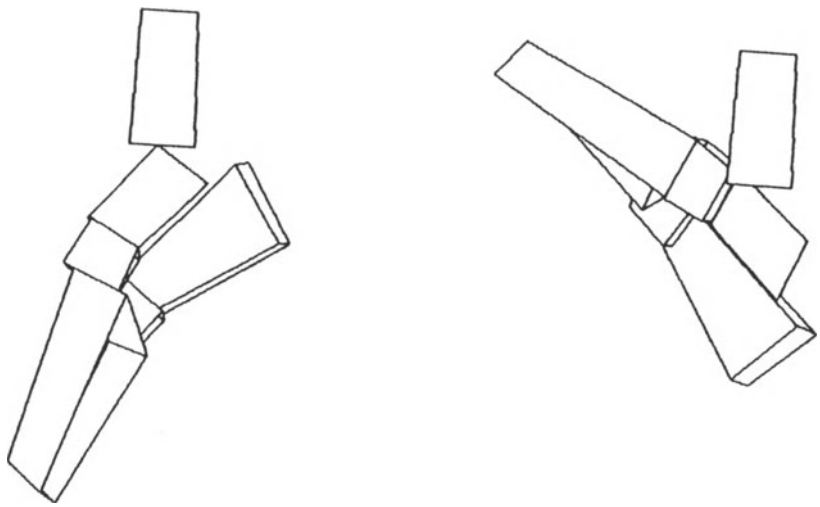


FIGURE 2.3. Modeled physiological range of plantar flexion and dorsiflexion used to calculate physiological ligament excursion. There is coupled motion, with mild inversion of the subtalar joint and adduction (medial rotation) at the midtarsal joints during plantar flexion (left) and corresponding opposite movements during dorsiflexion (right).

account the mild inversion of the hindfoot during plantar flexion, and eversion/abduction of the hindfoot and midfoot during dorsiflexion. The gray area on the graphs also represents a minimal variation in range of ligament length that could be expected to allow fairly normal function of the foot and ankle. It can be seen that severe eversion and inversion (Figure 2.4B) cause a greater change in ligament length than one would normally see during simple plantar flexion and dorsiflexion of the foot and ankle complex.

Clubfoot Deformity

There is very little specific information about the actual geometry of the clubfoot deformity. I chose to model the basic clubfoot based on information from Herzenberg et al.[3] as shown in Table 2.2. Even that particular reference does not mention the talonavicular deviation; this had to be estimated from the figures in the article. The modeled clubfoot bony deformity appears in Figure 2.5, and it can be seen that the appearance is fairly typical of the clinical

TABLE 2.2. Three-dimensional angular deformities used to generate the computer model of the deformed clubfoot.

40° equinus of talus
15° varus of calcaneus
80° medial talonavicular deviation
55° medial calcaneocuboid deviation

Derived from the data of Herzenberg et al.[3]

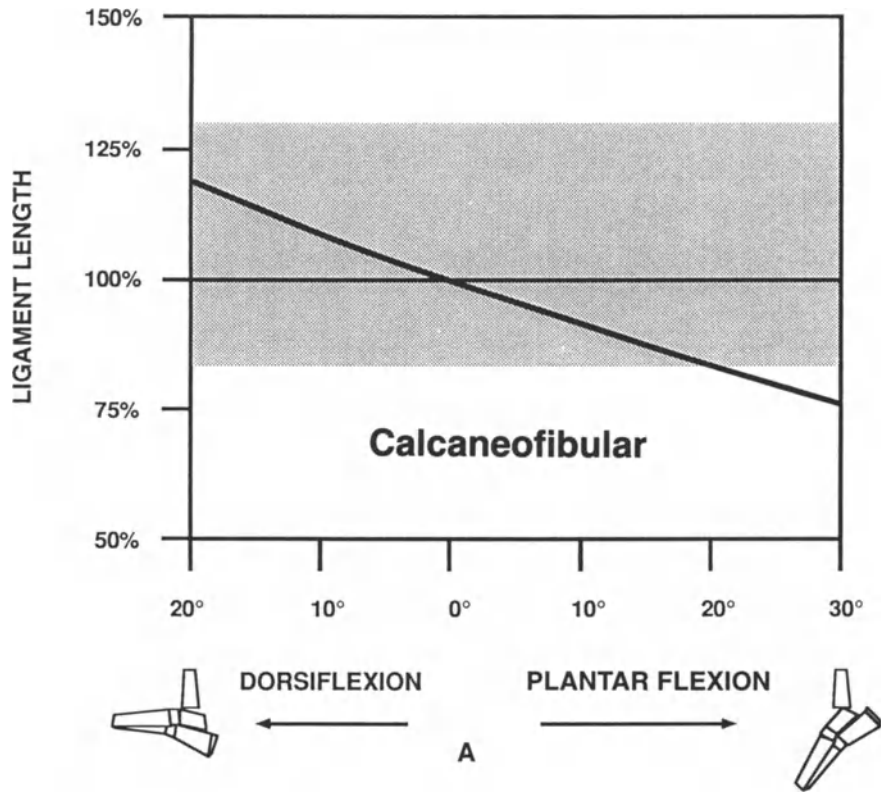


FIGURE 2.4. A: Variation in length calculated for the calcaneofibular ligament during dorsiflexion and plantar flexion. The gray area corresponds to the "physiological" range of motion calculated during the movements described in Figure 2.3. B (page 72): Variation in calcaneofibular ligament during eversion and inversion without other coupled motions. The gray area represents the physiological variation as noted above.

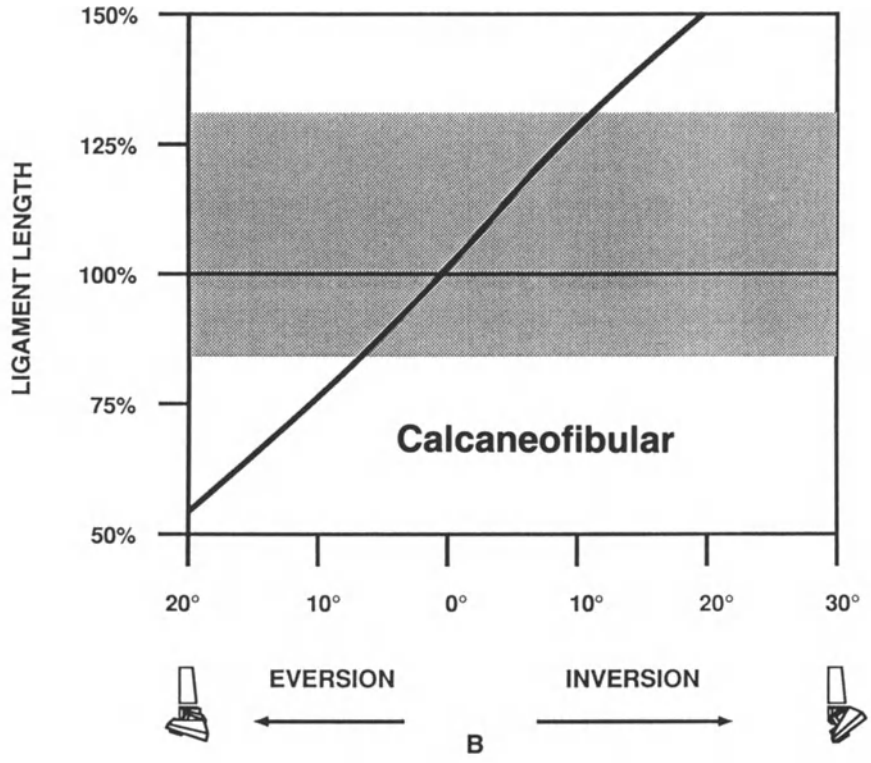
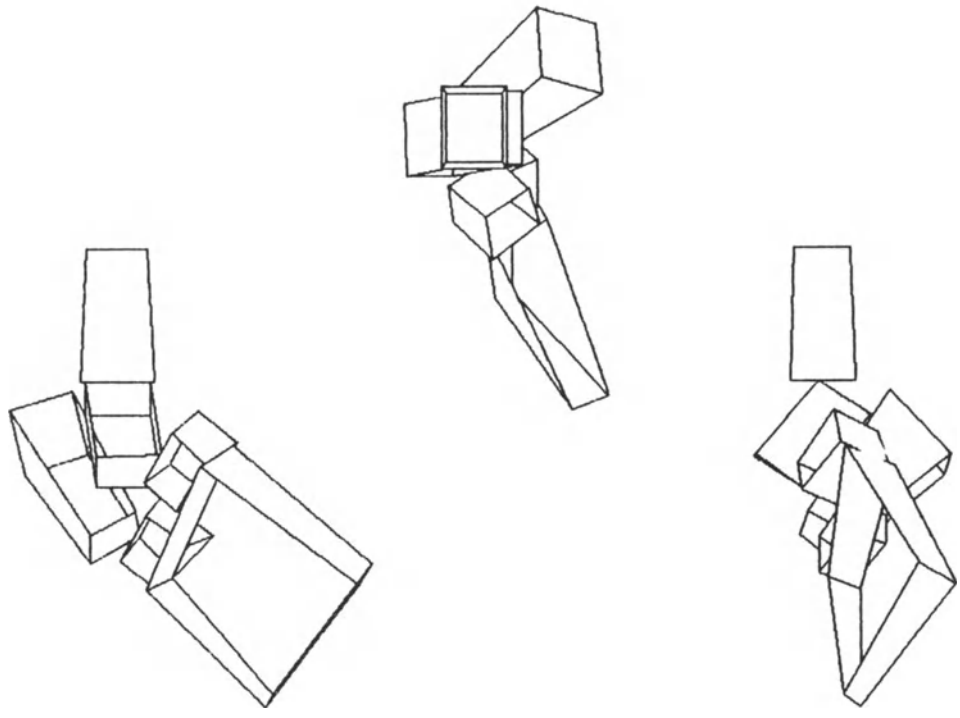


FIGURE 2.4 (cont.)



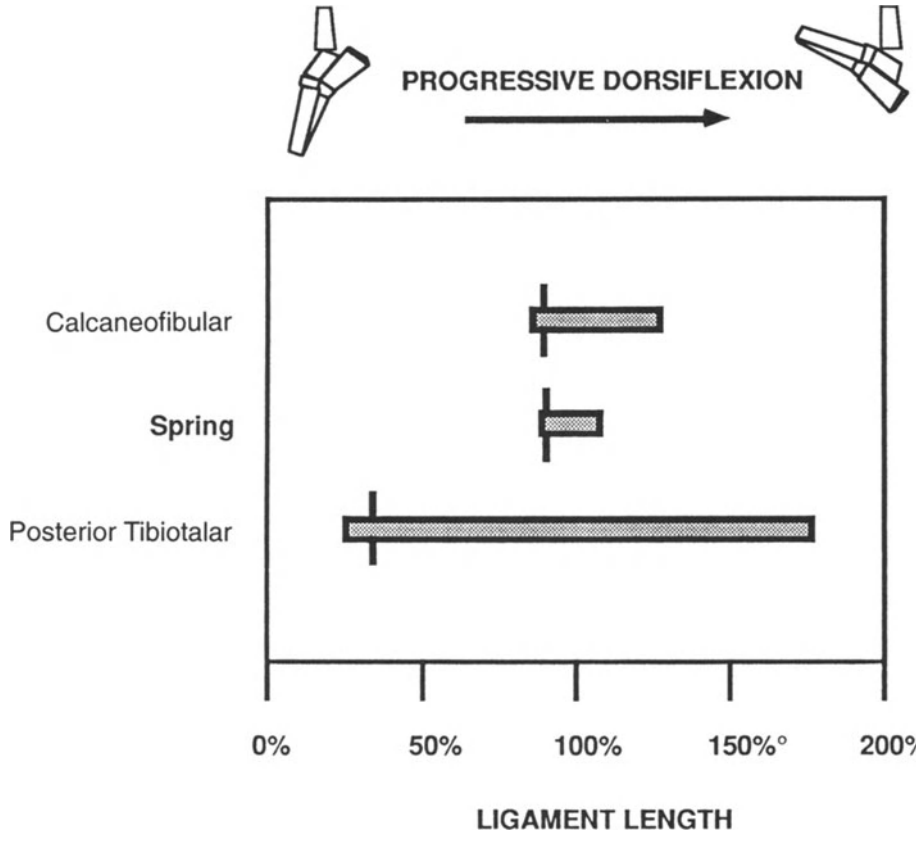


FIGURE 2.6. Graph of the length of three ligaments in the deformed clubfoot position, represented by the vertical black line. The range of "physiological" excursion necessary for normal plantar flexion and dorsiflexion (see text) is indicated by the gray bars. One hundred percent ligament length corresponds to resting length with the foot and ankle in neutral position.

appearance of true clubfoot. Note the marked supination of the forefoot as well as inversion and internal rotation of the subtalar joint.

After generation of the deformed clubfoot model, the length of various ligaments was compared to the variation in ligament length which is necessary for normal function of the foot and ankle. This is shown in Figure 2.6, where the calcaneofibular, spring, and posterior tibiotalar ligaments can be seen to be at the very shortest length encountered during normal motion. This would imply that correc-

TABLE 2.3. Ligaments that were found to be short relative to their physiological range in the deformed clubfoot model (corresponding to the clinical presence of contracture).

Tibiocalcaneal (part of deltoid)
Posterior tibiotalar
Calcaneonavicular (medial half of bifurcate)
Plantar calcaneonavicular "spring"
Calcaneofibular
Plantar calcaneocuboid (short plantar)
Plantar fascia
Long plantar

FIGURE 2.5. Three-dimensional representation of an uncorrected congenital clubfoot. The ligaments are not shown. The views follow the same format as Figure 2.2 (anterior, superior, and medial views). Note the marked subluxation of both talonavicular and calcaneocuboid joints, as well as supination of the forefoot and internal rotation of the subtalar joint.

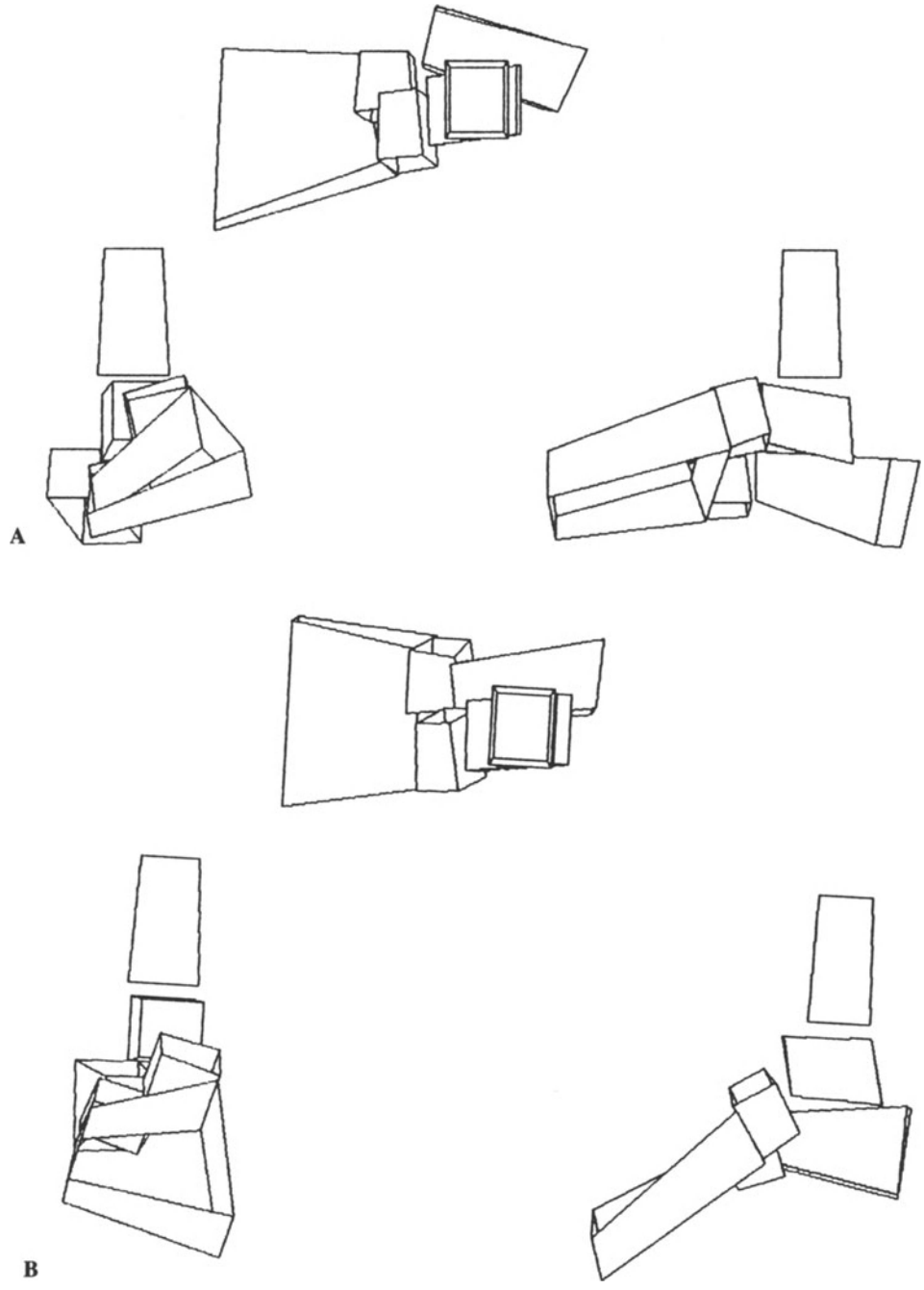


FIGURE 2.7. A: Attempted three-dimensional correction of a clubfoot while maintaining contracture of the ligaments of the calcaneocuboid complex. Note the external rotation of the subtalar joint and residual midfoot subluxation. B: Attempted correction of the deformed clubfoot model derived from moving bony elements while maintaining contracture of the calcaneofibular ligament complex. Note the residual internal rotation of the subtalar joint as well as rotational malalignment in the midtarsal joints.

tion of clubfoot must involve either stretching or release of these ligaments, or physiological motion could never be obtained. Numerous ligaments were found to be particularly tight (short) with the deformed clubfoot modeled, and they are listed in Table 2.3. Note that each of these is addressed by some of the surgical procedures described for clubfoot, but the entire group of ligaments is never released in any of the recommended methods.

Once the deformity was modeled, an attempt was made to "correct" the deformity by allowing the modeled joints to return to normal position, with the exception that certain ligaments were left tight to impede joint mobility. Two cases are shown in Figure 2.7. In Figure 2.7A, the calcaneocuboid structures were left tight and, although the foot appears to have returned to a fairly normal position, there is still residual subluxation of the calcaneocuboid joint and forced external rotation of the subtalar joint. In addition, there is a significant amount of forefoot supination. In Figure 2.7B, the calcaneofibular ligament complex was left tight. Although the forefoot has come into abduction, the hindfoot is still severely internally rotated at the subtalar joint with residual cavus and medial subluxation of the talonavicular joint. Both of these deformities are commonly seen in congenital clubfoot that has undergone surgery with incomplete ligamentous release.

Discussion

Congenital clubfoot is a complex three-dimensional congenital deformity that defies easy classification. In the described model, it must be noted that geometric information was derived from normal anatomy and did not take into account deviations of the talar neck, shortening of the bones, and other dysplastic features that are known to exist in clubfoot.[5] In addition, this is a first-generation model; the articular surfaces have been modeled very simply, without the ability to move relative to each other except as prescribed by the center or axis of rotation, which was arbitrarily selected.

A second obvious limitation of a model such as this is the source of geometric data for both the physiologically normal range of motion of the foot and the abnormal bone positions seen in clubfoot. There have been very few studies of the three-dimensional geometry of clubfoot and there is probably a wide variation that is not adequately expressed by a single selected position.

Nevertheless, modeling such as this can be very valuable when trying to understand the complex three-dimensional changes that can occur both with clubfoot itself and its correction. For instance, it seems obvious that there must be release of the posterolateral subtalar structures (calcaneofibular ligament) or subtalar internal rotation will not be corrected. In addition, by "tethering" the calcaneocuboid joint in its medially subluxated position, one can model the three-dimensional problems in the subtalar joint that occur as the talonavicular joint is reduced. These findings have been demonstrated clinically, and a parametric ligament model such as described here can be of great help in trying to decide how best to design one's surgical release to achieve anatomic correction of the deformity.

Finally, a review of the ligaments that were found to be tight in the clubfoot shows that all of the various eclectic surgical approaches to clubfoot address at least some of the tight ligaments, but none addresses all of the tight structures. Whether it is logical to proceed with more aggressive surgical releases or whether that is unnecessary is a critical question in clubfoot surgery at the present time. Future modeling to include pathological bone shape, joint contact motion coupling, muscle-tendon units, and viscoelastic properties of normal and abnormal ligaments might help in achieving a better understanding of the role of surgical correction in this complex congenital disorder.

Summary

A three-dimensional model of the bones and ligaments of the foot and ankle was created to better understand the role of ligament tightness in clubfoot deformity and its surgical correction. The model allows prediction of the correction of clubfoot after ligament release and specifically clarifies the three-dimensional residual deformities that can occur when partial ligament release has been performed.

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Recognition and Management of the Atypical Idiopathic Clubfoot

V. Turco

The purpose of this paper is to call attention to a type of CTEV that I call the "atypical idiopathic clubfoot," which occurs in a very small percentage of congenital clubfeet. At birth, it appears to be a typical clubfoot with no associated abnormalities and without any stigmata of neurological or genetic syndromes. The main difference is that it responds altogether differently to both operative and nonoperative treatment. Results with early soft tissue surgery are unpredictable and, unlike the more common typical idiopathic clubfoot, early surgery usually results in a grotesque, overcorrected severe flatfoot.

Clinical Findings

I have identified 37 patients suspected of having atypical idiopathic clubfoot. Nonoperative treatment was used in 35 cases; two had limited surgical releases at 5 and $5\frac{1}{2}$ years of age.

The following are some of the characteristic clinical findings that I have observed in a retrospective study (these were present in most of the cases studied):

1. In the typical clubfoot the Achilles tendon insertion is more medial and forward than normal. In the atypical idiopathic clubfoot, the heel cord invariably inserts more laterally.
2. In the typical clubfoot there are never skin creases in the area of the Achilles insertion, whereas fine transverse creases may be found in this area in the atypical idiopathic clubfoot.
3. Contralateral deformities, e.g., calcaneal valgus or metatarsus adductus point to the possibility of an atypical idiopathic clubfoot.
4. Most of these feet are likely to be longer and more flexible than the typical clubfoot.
5. Rocker-bottom deformity occurred in many cases.

Overcorrection seemed to be more common when early surgery was performed. Thus, the earlier the surgery, the greater the overcorrection.

Radiographic Findings

The radiographic findings were as follows: (a) dorsal subluxation of the navicular, (b) plantar flexed talus, (c) severe calcaneovalgus, (d) de-

formities of the big toe, and (e) painful arthritis in the metatarsophalangeal (MTP) joint.

Treatment

When I suspect an atypical idiopathic clubfoot, I treat the foot conservatively and reevaluate the child at 3 months of age (especially when rocker-bottom is present and the heel cord inserts laterally). I discontinue serial manipulations and cast applications in favor of a Denis Browne bar. When the child starts to walk, an orthosis is used and early surgery is avoided.

Conclusion

The clinical and radiographic findings of an unusual type of clubfoot are described. If treated as a typical clubfoot, severe valgus occurs. However, these feet usually respond to conservative treatment. The early recognition of these feet is imperative.

Magnetic Resonance Imaging in Congenital Talipes Equinovarus

D. Downey, J. Drennan, and J. Garcia

Congenital talipes equinovarus (CTEV) is characterized by osseous deformities in the midfoot and hindfoot, which remain only partly understood. Anatomic dissections disrupt the relationships they seek to demonstrate, and routine radiographs yield truncated information in that the infant foot bones are only partly ossified. A recent advance has been seen in the computerized three-dimensional reconstruction of histologic sections from the clubfoot of a stillborn child. This technique generated in situ bony relationships.[1] Magnetic resonance imaging (MRI) offers a further advance through its potential for studying in vivo anatomic relationships in the clubfoot. The present study was undertaken to explore this modality's value in imaging cartilaginous, osseous, and soft tissue structures in both the normal and abnormal infant hindfoot.

Materials and Methods

Eight patients, age 4 months to 15 months, were included in this study. The patients all had undergone serial cast applications for CTEV and had their MRI performed 1 day prior to surgical correction. Five patients had unilateral and three had bilateral involvement. Chloral hydrate was used for sedation and a rigid plastic lower-extremity cradle was utilized to hold the tibiae horizontal and parallel to each other and to maintain the ankles in a near-neutral position.

The first four studies were obtained utilizing a Diasonics 0.064-tesla MR machine with a head coil. The second four images were obtained utilizing a General Electric 1.5 tesla machine with a knee coil. The change in machines was made to obtain greater resolution. Images were obtained with a 3-mm slice in the standard anatomic sagittal, transverse, and coronal planes.

Images in normal and abnormal feet were studied for both gross and quantitative differences in hindfoot bone alignment. The cut most clearly demonstrating the anatomy was chosen for measurement in each case. In the sagittal cuts, lines were drawn through the long axes of the entire ossified and cartilaginous talus and calcaneus (Figure 2.8). By maintaining a common reference window when measuring these axes on the appropriate cuts, a sagittal talocalcaneal angle could be generated.

In the transverse cuts, a line was drawn through the transmalleolar axis (Figure 2.9), which has been previously described by Jakob and colleagues.[2] A second line was drawn

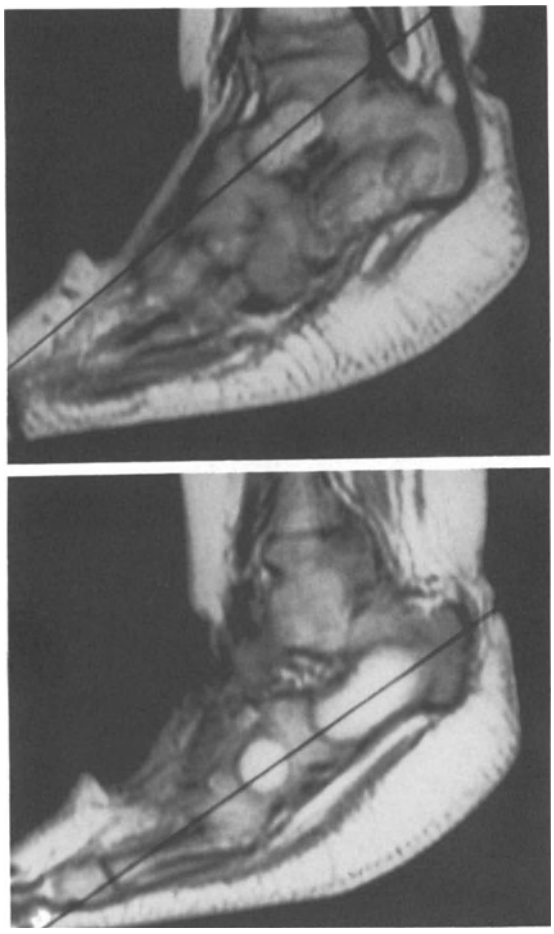


FIGURE 2.8. This composite reveals sagittal slices with lines drawn through the long axis of the talus and calcaneus. The sagittal talocalcaneal angle is derived by superimposing a common reference window on the two slices for comparison of the two axes.

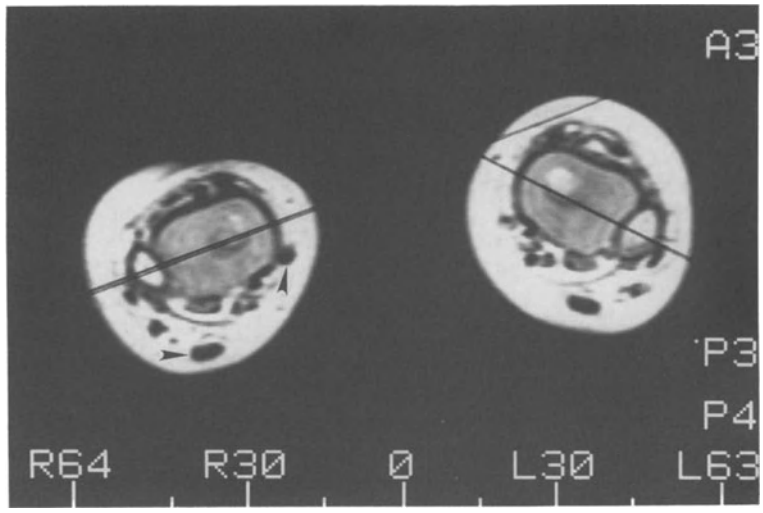


FIGURE 2.9. Intermediate density transverse section at the level of the mortise in a patient with bilateral clubfeet. Lines through the tansmalleolar axis are drawn. The Achilles tendon and posterior tibial tendon are easily visualized (arrows on the left).

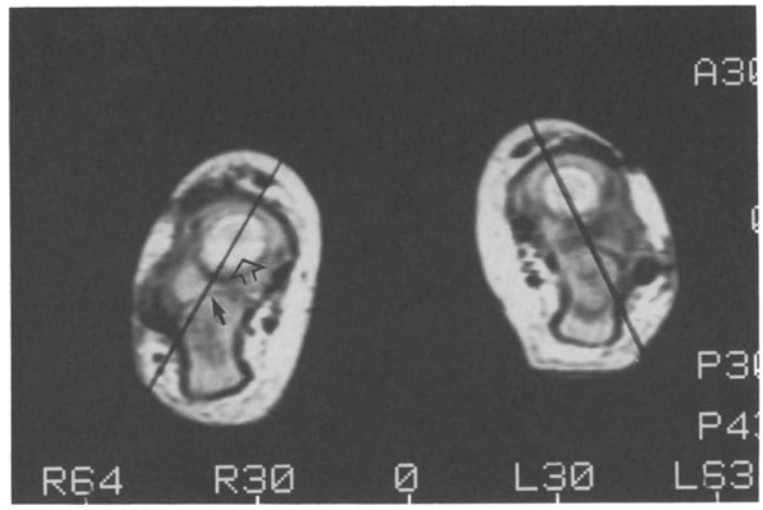


FIGURE 2.10. Transverse section at the level of the talar neck and head. The axis of the talar neck and head is drawn bilaterally. The talar ossific nucleus (open arrow), the subtalar joint (closed arrow), and the posterior calcaneus can be appreciated.

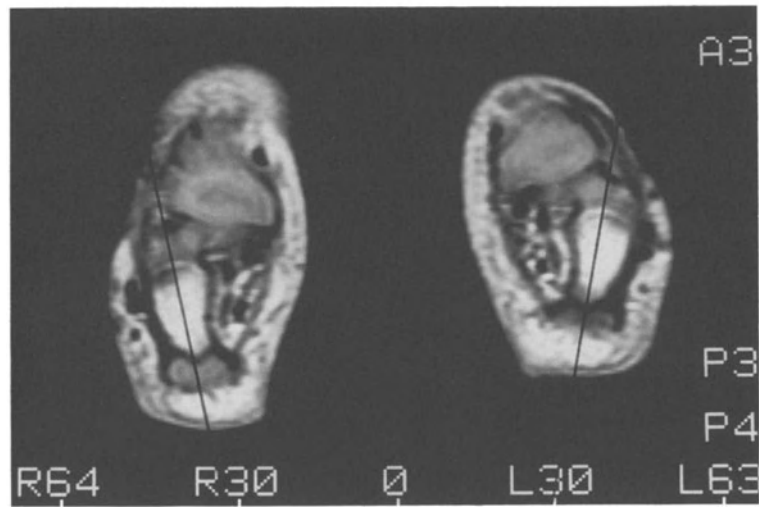


FIGURE 2.11. Transverse section at the level of the calcaneus. The axis of the calcaneus is shown. The ossific center and cartilaginous anlage of the calcaneus as well as the more medial navicular and right cuneiforms can be appreciated.

through the neck and head of the talus using the outlines of the neck and the articular surface of the head for reference (Figure 2.10). A third line was drawn through the long axis of the entire calcaneus (Figure 2.11). A line perpendicular to the transmalleolar axis was considered as the longitudinal axis of the talar body and this line was used for reference in defining the talar head and neck and calcaneal axis in the transverse plane. The individual axes described were on different cuts; by maintaining a common reference window, these axes could be compared with each other.

Results

Although images obtained on the low-field MR machine (0.064 tesla) were acceptable for alignment measurements, the resolution was suboptimal. The higher-field MR machine (1.5 tesla) gave better resolution (Figures 2.8–2.11). It was found that an intermediate imagining sequence (TR = 2,000, TE = 25) gave the best overall definition of cartilaginous structures but a T2 sequence (TR = 2,000, TE = 80) was most helpful in defining articular locations.

General observations included the following: (a) the talar body was similar in the normal and abnormal feet with the anterior articular surface of the talar dome consistently parallel to the transmalleolar axis in the transverse plane; (b) the navicular, which could be identified by the insertion of the posterior tibial tendon, was dislocated medially relative to the talar head in 3 of the 13 abnormal feet; and (c) in the coronal plane, the calcaneus could be seen to be displaced medially to lie beneath the talus in the abnormal feet.

Quantitative comparisons between normal and abnormal feet were based on the five patients with unilateral clubfoot. The abnormal feet showed a mean sagittal (lateral) talocalcaneal angle of $7° \pm 10°$, as opposed to $27° \pm 6°$ in the normal feet. In the transverse cuts, the axis of the talar head and neck with respect to the talar body was more internally rotated in the abnormal feet, $56° \pm 6°$, than in the normal feet, $39° \pm 6°$. The axis of the calcaneus followed suit: the abnormal foot mean calcaneal axis was $11° \pm 14°$ internally rotated relative to the talar body, and the normal foot mean calcaneal axis was $1° \pm 8°$ internally rotated. In the abnormal foot, the mean transverse (anteroposterior) talar head and neck calcaneal angle was $44° \pm 10°$ versus a normal foot mean transverse talar head and neck calcaneal angle of $38° \pm 5°$.

Discussion

The objectives of this study were to determine the qualitative and quantitative efficacy of magnetic resonance imaging in the infant clubfoot. Qualitatively, MRI has been shown to be helpful, and clearly superior to plain radiography. An intermediate imaging sequence between T1 and T2 gave the best overall image for appreciating details in growth cartilage and ossification center outlines, whereas T2 gave a better delineation of articular surfaces. In addition to the mineralized ossific centers that can be seen on plain films, cartilaginous anlages, articular surfaces, and tendons can be visualized.

Quantitatively, we have been able to demonstrate transverse and sagittal plane findings in clubfoot based on measurement of hindfoot alignment. The deformity in the transverse plane was consistently found to be a medial deviation of the talar neck and head, along with the calcaneus, relative to the mortise and talar body. This has been previously reported by Shapiro and Glimcher.[3] We were not able to identify a deformity of the talar body relative to the mortise. Dislocation of the talonavicular joint was an occasional, but not consistent, finding. In the sagittal plane, the clubfoot deformity was localized between the talus and calcaneus with a parallelism between their longitudinal bone axes that has long been appreciated between ossific centers on plain radiographs.

As a preliminary report, it is beyond the scope of this paper to interpret the place of our findings among the many previous anatomic studies of clubfoot. Rather, we wish to provide details of the imaging technique that has been optimal for us and point to the direction provided by these imaging studies in understanding clubfoot pathoanatomy.

Summary

The feet of eight infants with congenital talipes equinovarus (CTEV) were studied by magnetic resonance imaging. The images obtained using an intermediate density and T2 sequence have been found most useful. In the transverse plane the primary osseous defect appears to be localized in a medial deviation of the talar neck, whereas in the sagittal plane it appears to lie in the subtalar relationship. Additional imaging and analysis with consideration of three-dimensional reconstructions will be necessary for more definitive findings.

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Gait Analysis in Clubfeet: An Experimental Study

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The grading of treatment results in clubfeet has always been under criticism due to the subjectiveness entailed when one judges morphology and function and to the causes of error when goniometric measurements are performed.[9,10,12] The functional rating systems developed by Laaveg and Ponseti[9] and by McKay[10] have added greater accuracy to the judgment of morphology and function. Furthermore, several objective techniques including assessment of body image and self-esteem have recently been developed, making it theoretically possible to correlate these psychological variables with the orthopedic evaluation.[2,3,5,6,14]

Over the last 20 years, 1,394 children with 2,007 clubfeet were treated at the National Institute for Medicine of the Locomotor System at Brasilia, Brazil. The difficulties confronted in evaluation, the frequency of unexpected results, the complexity of the pathomechanics, and the broad range of secondary adaptations created the need for a more comprehensive evaluation.[10,11]

Materials and Methods

In this preliminary study, 17 children, previously treated, with ages ranging from 6 years to 11 years, were evaluated according to sex, topography, pain, the child's judgment of his own gait, orthopedic and clinical evaluation, gait analysis, McKay's rating, body image, and self-esteem.

In evaluating gait and pain, the children were asked specifically whether they felt that they had a limp and whether it was affected by pain. Clinical and radiographic evaluation was followed by orthopedic evaluation. Results were graded as excellent, fair, or poor.[9,10,12] Gait was classified as normal or almost normal according to clinical criteria.

In the gait evaluation, the linear parameters of double-support duration, single stance, and swing were the basic criteria.[7,13] With these criteria, a limping index (L.I.) was devised using this formula:

$$\text{L.I.} = \frac{\text{Initial double support} + \text{stance}}{\text{Second double support} + \text{swing}} \times 100$$

A clinical trial showed that limping could be clearly perceived by orthopedic surgeons when an index below 80% was present. At the gait laboratory, a randomized group of hospital personnel were studied as a control group with results of 5% variation. Consequently, in each case in which an index below 95% was demonstrated, limping was considered to be present.

Table 2.4 shows the technique used in obtaining a kinematic index, considering foot movements in the frontal and sagittal planes. Different gradings were established for each abnormality according to its relevance in relation to morphology and function. The presence of one abnormality proved to be sufficient to trigger off an abnormal gait. Therefore, an abnormality was considered to be present whenever a kinematic index below 90% was obtained.

Using McKay's grading system, children with results of over 160 were considered normal (page 117, Chapter 3).[10] In children with bilateral clubfeet, only the foot with the worse result was considered for analysis.

TABLE 2.4. Kinematic index (subtracted from 100).

Changes at initial double support		
toe strike (equinus)		−10
inversion		−10
Changes at single stance		
(Overcorrection)	increased dorsiflexion	−10
	increased eversion	−10
(Relapse)	increased plantar flexion	−20
	increased inversion	−20
Changes at second double support		
(Overcorrection)	decreased plantar flexion	−10
Changes at swing		
(Relapse)	plantar flexion	−20
	inversion	−10

TABLE 2.5. Patient's self-evaluation × Surgeon's gait evaluation.

	Gait self-evaluation		
Surgeon	Normal	Abnormal	Total
Normal	6	2	8
Abnormal	4	5	9
Total	10	7	17

Fisher's Exact Test = .21781

TABLE 2.6. Surgeon's gait evaluation × McKay's rating.

	Surgeon's gait evaluation		
McKay	Normal	Abnormal	Total
Excellent/good	5	1	6
Fair/poor	3	8	11
Total	8	9	17

Fisher's Evaluation Test = .04299

Body image and self-esteem were evaluated by the "house-tree-person" test.

All results were submitted to statistical analysis. Because of the small sample, Fisher's Exact Test was used.*[1]

Results

Of the 17 children, 7 believed that they had an abnormal gait. Of these, two were judged by the surgeon to have a normal gait. Ten children said that their gait was normal, whereas four of them were judged by the surgeon as being abnormal (Table 2.5).

In nine children, gait was considered as abnormal in the surgeon's evaluation. Comparing this observation with McKay's rating, a statistically significant result was obtained (Table 2.6).

In contrast, when the surgeon's evaluation was compared with the children's opinion and the gait analysis, there was no statistical significance. In other words, children judged by the surgeon as having an abnormal gait, a poor orthopedic result, or a low McKay's rating, considered their gait as normal or presented a gait analysis without relevant changes.

The limping index was found to have a significant correlation with McKay's index and the body image (Table 2.7). A significant correlation was observed between topography and body image. We found that children with bilateral clubfeet generally reported a normal body image, whereas those with unilateral involvement did not (Table 2.8). Gait self-evaluation when positive for limping was related to pain and a low self-esteem (Tables 2.9 and 2.10).

TABLE 2.7. McKay's rating × Limping index.

	Limping index		
McKay	Normal	Abnormal	Total
Excellent/good	5	1	6
Fair/poor	2	9	11
Total	7	10	17

Fisher's Exact Test = .0173

TABLE 2.8. Body image × Topography.

	Topography		
Body image	Unilateral	Bilateral	Total
Normal	1	7	8
Distorted	6	3	9
Total	7	10	17

Fisher's Exact Test = .03640

Discussion

There are studies showing that the reality of a deformity and its perception are unrelated.[4,8] That the deformity was corrected by anatomical, goniometric, and radiographic criteria did not imply that the child was free from having a

*Fisher's Exact Test is used when the expected frequencies are small (>5) because, in this case, the sampling distribution of χ^2 is not approximated by the χ^2 distribution. A new, reduced contingency table can be constructed by combining any two or more adjacent rows and/or any two or more adjacent columns, such that the expected frequency of each cell of this new table is at least 5. The statistic χ^2 is then considered for this new table.

TABLE 2.9. Pain × Evaluation of gait by patient.

	Gait self-evaluation		
Pain	Normal	Abnormal	Total
Absent	9	1	10
Present	1	6	7
Total	10	7	17

Fisher's Exact Test = .00365

TABLE 2.10. Self esteem × Evaluation of gait by patient.

	Gait self-evaluation		
Self-esteem	Normal	Abnormal	Total
Normal	7	1	8
Abnormal	3	6	9
Total	10	7	17

Fisher's Exact Test = .03640

disturbance in body image and a low self-esteem. There is also a direct relationship between pain, abnormal gait, and self-esteem.

The correlation demonstrated between McKay's grading, the limping index, and the surgeons' and children's evaluation suggests that the performance in gait is the main element in classifying the results. These findings lead us to question the validity of isolated clinical and radiographic protocols and indicate the need to assess *performance*, finding our judgment in conflict with the children's.

According to Webster's dictionary, *function* is "the action for which a person or thing is specially fitted" and *performance* is "the execution of an action." An approach toward performance will bring us closer to the child's judgment, thus increasing our accuracy in grading results.

Conclusions

The most relevant findings in this study were as follows: (a) there is disagreement between the child's and the surgeon's judgment in relation to limping; (b) limping induces disturbances in the child's body image and creates low self-esteem; and (c) if we include in our assessment McKay's rating system and gait analysis, we will be closer to the child's own feeling of how he walks.

Summary

The methods used for the evaluation of results of treatment of clubfeet are frequently the objects of criticism due to the subjectiveness in judging morphology and function and to the causes of error when clinical and radiographic measurements are performed.

Three different parameters—gait analysis, McKay's grading system, and the child's own judgment—were evaluated in this study.

Goniometric evaluation of gait in the lateral plane confirmed McKay's functional rating. Limping, at levels difficult to be perceived by surgeons, were reported by the children and confirmed by gait analysis. Due to these findings, it is suggested that gait analysis should be considered with functional ratings when evaluating CTEV.

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Discussion

Schoenecker (St. Louis): Dr. Motta, did you study any of the children who had surgery after 1 year of age?

Motta (Milan): I saw four children who were treated later than 1 year of age; two had abnormal psychiatric evaluations, and the other two had learning disabilities and socializing problems. I feel that it is important to obtain neuropsychological evaluations to try to find the best time for surgery for these children.

Schoenecker: Dr. Rab, has your model influenced your surgical approach for the treatment of clubfeet?

Rab (Sacramento): No. Although one interesting finding is that the interosseous talocalcaneal ligament is very difficult to make tight using a model like this. It parallels the clinical finding that you often don't need to incise the whole ligament.

Schoenecker: Dr. Drennan, are you routinely doing MRIs now or is this just an investigational study to identify anatomy?

Drennan (Albuquerque, New Mexico): Currently we're doing it for informational purposes.

Ryoppy (Helsinki): Dr. Drennan, have your studies with the MRI shown any evidence of remodeling of the bones in response to manipulation and/or casting?

Drennan: I'm a great believer in the Hueter-Volkman law. This is one of the reasons we are undertaking this study. I don't have any long-term follow-ups. The longest in the study is only 6 months, but I expect to see some changes in the midfoot on the medial column perhaps in a period of 2 to 3 years.

Weiner (Akron): Dr. Turco, I'm not certain about some of your cases that you call "atypical" clubfeet. They appear to be cases of congenital vertical talus on x-ray.

Turco (Hartford): That's the point that I am trying to make. These children all started off as typical talipes equinovarus, and they were altogether different than the congenital vertical talus that one sees in a newborn nursery. None of these children had any of the clinical or x-ray findings of congenital vertical talus until about 3 months and then they developed it.

Coleman (Salt Lake City): Dr. Campos da Paz, did your gait analysis and your subjective/objective studies influence your prognosis or treatment of your clubfeet?

Campos da Paz (Brasilia): It has not changed our surgical technique but has changed our timing of surgery. We are no longer operating in the neonatal age period but only after 4 months of age.

Stark (Minneapolis): Dr. Campos da Paz, what success have you had with treatment of psychological problems or problems with the child's self image?

Campos da Paz: From the psychological aspect, the child is destined to have problems because of the calf atrophy. We have to clarify one point about psychiatric and psychological evaluation of the children. This is different

from the child's own judgment, which can complement the psychiatric and psychological evaluation. The child's own judgment only becomes valid (according to Piaget and Freud) between 8 and 12 years, as that is the age of "concrete judgment" as stated by Piaget in his studies on the biology of intelligence. This is why we selected children in this age group to perform the study. This is only a preliminary report. I can affirm that there is a correlation between gait, pain, and the child's own judgment. There was no correlation between the psychological evaluation and the foot evaluation.

Editor's Comments

Motta and **Merello** conclude from their study on the neuropsychiatric development of children following successful clubfoot surgery (performed in the first year of life) that these children had normal motor and neuropsychiatric development. Apparently, only patients were studied who had a "cure" following their first operative procedure. It would be interesting if the authors would study patients who had not achieved satisfactory results with their first surgery and patients who have had multiple surgical procedures performed. Certainly, their findings in "cured" children are in contrast to those of Campos da Paz et al., who showed that "uncured" children with a residual limp have problems with self esteem.

Rab's paper presents a three-dimensional model of the bones and ligaments of the foot and ankle specifically to demonstrate the role of ligament contractures in the clubfoot and the surgical treatment that is required to correct the various deformities.

Despite several limitations of his geometric model, the model proved to be very valuable as far as understanding the complex three-dimensional changes that take place in a clubfoot. Furthermore, he was able to point out some of the shortcomings of various surgical procedures that are limited in scope and, therefore, inevitably lead to lack of full correction.

Rab beautifully demonstrates, in two different situations, deformities that persist when inadequate releases are performed. In one of these the calcaneofibular ligament complex was left contracted and severe internal rotation of the calcaneus remained along with residual cavus and medial subluxation of the talonavicular joint. These are the same changes that are often seen following conventional posteromedial release. In the second case, the calcaneocuboid structures were left contracted and residual subluxation of the calcaneocuboid joint was seen with forced external rotation of the calcaneus at the subtalar joint, i.e., valgus of the heel. This latter situation is described in the paper by Thometz and Simons,[2] in which valgus of the hindfoot resulted from incomplete correction of the calcaneocuboid subluxation. **Rab's** model therefore verified two of the most common situations that result in undercorrection of the clubfoot.

Rab cites eight ligaments that must be released in order to completely correct the fully deformed clubfoot. He states that none of the conventional operative techniques currently in use recommends release of all eight of these ligaments. In reviewing these ligaments carefully, I came to the conclusion that, in the very severe clubfoot, I would release all of these ligaments.

Finally, **Rab** excluded the interosseous talocalcaneal ligament (ITCL) from his list of eight essential ligaments. Release of this ligament, either in part or completely, is a very controversial issue in pediatric orthopedics at this time. I prefer to release it in all cases so that I can achieve proper realignment of the bones. It is my feeling that releasing this ligament only rarely leads to overcorrection. Usually the overcorrection seen following release of this ligament is due to pinning of the foot in the overcorrected position at the time of surgery. In those cases in which the ligament is released and the foot gradually drifts into valgus deformity, this is usually due to generalized ligamentous laxity. Further proof of the con-

cept that release of the ITCL does not, in itself, lead to overcorrection is the fact that most children have very limited range of motion following surgery at the subtalar joint rather than excessive motion.

In my opinion, this is one of the most important papers presented at the congress. For the first time a careful modeling study confirms which ligaments are contracted and which ligaments require release.

When this model has been refined to incorporate the deformation of each bone that is involved as well as the other improvements that **Rab** mentioned, the use of computer graphics may well prove to be an ideal way to approach the correction of deformities of the clubfoot.

One wonders if **Turco's** atypical clubfeet are, in fact, patients who have excessive ligamentous laxity. This is often very difficult to detect at the early age when surgery is required as infants normally have more laxity than older children. One of two situations may occur: the patients develop either (a) overcorrection, i.e., marked calcaneovalgus, or (b) an excellent range of motion at the ankle and subtalar joint without deformity. Thus, ligamentous laxity may be either beneficial or detrimental.

At the time of initial evaluation, I usually examine both parents for ligamentous hyperelasticity. If it is present in both, I am much more cautious about proceeding with surgery. When operating on these feet, I use special care not to pin the navicular in an overcorrected position.

Further evidence for ligamentous laxity as the culprit in **Turco's** atypical feet was provided by a patient of a colleague whose clubfoot was treated by conservative measures alone. He had significant ligamentous laxity and developed a 4+ lateral subluxation of the navicular.

One also wonders if the patients that **Turco** described as having calcaneovalgus deformity of the hindfoot have either of the two deformities that often accompany it: (a) lateral talonavicular subluxation, or (b) a significant degree of calcaneocuboid subluxation. As the former is frequently associated with ligamentous laxity whereas the latter is not, I would suspect that the cases he described have a significant incidence of associated lateral talonavicular subluxation.

Although **Turco** alluded to the fact that his treatment for these various overcorrections included first metatarsal base osteotomy and fusion of the MTP joint, one is curious as to how he treated the dorsal talonavicular subluxation, the calcaneovalgus deformities, and the plantar flexed talus, which he apparently regards as a secondary form of congenital vertical talus. However, I have tried to replace the navicular on the talar head in several patients with excessive laxity, including one with previous bilateral Turco-type posteromedial releases. Unfortunately, this patient's feet again drifted into valgus following surgery. Therefore, a second soft-tissue procedure on the talonavicular joint for lateral subluxation of the navicular cannot be recommended when there is evidence of excessive ligamentous laxity.

In a very fine article by **Downey**, **Drennan**, and **Garcia**, a "trial run" was made using MRI to evaluate CTEV. Valuable preliminary technical data about MRI as well as basic anatomical information were obtained.

The finding that the talar body is parallel to the transmalleolar axis in the transverse plane is evidence of the absence of rotation of the talar body in the mortise. This contrasts with the findings of Herzenberg et al.,[1] who used computerized three-dimensional reconstruction of the stillborn clubfoot. Most observers hold that the talus is located within the mortise without rotation. Further MRI studies as well as computerized three-dimensional reconstructions are needed to clarify this point, which represents one of the basic issues of controversy about the anatomy of the hindfoot of CTEV.

Another finding was that only 3 of 16 patients showed evidence of talonavicular subluxation. This, no doubt, was due to the fact that the patients had previous cast treatment, which resulted in partial or complete correction of the talonavicular subluxations. In the future, this study should be repeated on untreated patients.

Clearly, MRI opens a new vista for the exploration of cartilaginous and anatomical relationships heretofore unavailable. This work must be expanded to include the completely untreated clubfoot as well as the exploration of various articular relationships such as the calcaneocuboid joint. It should be especially interesting to study the changes occurring in the subtalar joint following its reduction. Whether or not the articular facets will show development

normally, and if so, the time involved in this process and the age by which reconstruction must take place would add greatly to our knowledge of these feet.

In the paper by **Campos da Paz et al.** children were studied from the standpoint of their own perception of their gait disturbance. They occasionally perceived a gait disturbance that was verified by gait analysis but was not observed by the surgeon. The authors learned that limping significantly disturbs the child's body image and self-esteem.

They recommended that McKay's rating system (which correlated closely with their limping index, and the surgeon's and child's evaluation) and gait analysis be included with the routine clinical and radiographic parameters when evaluating patients with CTEV.

They pointed out that the definition of *function* is the action for which a person is specifically fitted, whereas *performance* is the execution of that action. They suggested that performance in gait should be the main element in classifying the results. Focusing on performance over morphology and function will bring us closer to the child's own opinion of his result. Any future attempts to develop classification and evaluation systems must include these parameters described by **Campos da Paz**.

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3
Classification and Evaluation

Introduction

Simons describes his method of classification and method of evaluation of congenital talipes equinovarus. He stresses the importance of differentiating between classification and evaluation and describes how these two techniques differ.

Pandey and **Pandey** present a classification of severity and evaluation for which they use clinical criteria as well as the patient's response to treatment.

Dimeglio combines classification with evaluation. The group to which the foot is assigned is determined by motion, or rather, the lack of it, and treatment is determined on the basis of the group to which the foot is assigned.

Catterall describes a "link mechanism" between the medial and lateral rays. If certain portions of the mechanism become contracted, the foot will become deformed. Correcting each component is necessary for the correction of CTEV. He describes three patterns of deformity that may be appreciated on clinical grounds alone, but, in addition, he also uses stress films for their evaluation. These three types consist of the functional (resolving) pattern, and the typical (joint contracture) types, plus a third intermediate type (tendon contracture).

Carroll uses a relatively simple 10-point scoring system for the preoperative evaluation, which consists of 10 anatomic criteria. The obvious advantage of this system is its simplicity.

Stevens and **Meyer** introduce a "CTEV severity grading scale," based on the clinical assessment of equinus deformity prior to surgery. This grading system is compared with a conventional grading system (based on a 1 to 100 point scale), which uses clinical, radiographic, and functional criteria. Their goal is to determine if this simple severity grading system is more practical, but yet as accurate, as a conventional grading system.

Barnett's interoperative evaluation form is an excellent checklist that helps prevent the accidental omission of any step of the procedure. During follow-up visits it also serves as a quick reference as to what was done at the time of surgery.

In an excellent paper by **Cummings et al.**, a pilot study has been performed to evaluate 36 clinical, radiographic, and functional criteria, with additional criteria for the interobserver error. Excluding Watts'[1] recent paper, which deals with radiographic criteria only (without using standardized methods for obtaining radiographs), this is the first study to report on the interobserver error of clinical, radiographic, and functional criteria.

Lehman et al. present their rating system for postoperative evaluation of CTEV. They use subjective and objective clinical criteria, functional parameters, and a limited radiographic assessment.

Barnett has contributed his postoperative evaluation forms and **McKay** his postoperative rating scale, the latter has been used by several participants in the congress for evaluation of their results.

Goldner and **Fitch** in an excellent and extensive paper describe their classification and method of evaluating CTEV and their radiographic technique. They explain their pathoanatomic concept of rotation at the ankle joint. Finally, they report the results of their prosective study of 100 CTEV cases followed for 15 years. In these patients a "four-quadrant" approach was used in which the subtalar joint was essentially left intact.

Reference

1. Watts, H.: Reproducibility of reading clubfoot x-rays. *Ortho. Trans.*, 15(1):105, Spring 1991.

CLASSIFICATION

Classification Versus Evaluation of Congenital Talipes Equinovarus

George W. Simons

Classification and *evaluation* are different entities and must not be confused with one another (Table 3.1). Their purposes are different, they are performed at different times, and the criteria for establishing each are different.

TABLE 3.1. Differences between classification and evaluation.

	Classification	Evaluation
Synonyms	Categories Groups	Assessment Grades
Purpose	Prognosis	Treatment Results
When done	Birth Recurrence	During conservative treatment, and pre-, intra-, and post-operatively
Criteria	Clinical	Clinical Functional X-ray

TABLE 3.2. Classification of congenital talipes equinovarus (CTEV).

Congenital	Developmental
Functional	Guillain-Barré
Typical	Cerebral palsy
Neuromuscular	Intraspinal tumors
Associated with other deformities	Diastematomyelia
Part of a syndrome	Poliomyelitis
	Charcot-Marie-Tooth

Classification

Purposes and Timing of Classification

Classification applies only to the examination made at birth to establish the prognosis and to the reexamination following recurrence of the deformity to reestablish a new prognosis (Table 3.2).

At birth, an examination for classification—not for evaluation—separates the true clubfoot from other types of clubfeet. (This is important for valid comparative and end-result studies.)

At the time of recurrence, a reexamination for classification rules out any underlying neurological or muscular cause not apparent on the examination at birth.

Evaluation

Purpose and Timing of Evaluation

Evaluation applies strictly to treatment phases to determine the specific treatment to be undertaken and to monitor the results (Table 3.3).

During conservative treatment, an examination for evaluation is made to determine if correction is occurring and to diagnose early overcorrection in order that it may be minimized or reversed.

Preoperatively, an evaluation detects the

TABLE 3.3. Evaluation of CTEV.

Clinical	Functional	X-ray
Deformity	Gait	Anteroposterior
Motion	Shoe wear	Lateral:
Strength	Pain	(DF + PF)

DF, dorsiflexion; PF, plantar flexion.

presence and extent of various deformities and determines the type of surgical treatment needed, e.g., posterior release (partial subtalar release), complete subtalar release, complete calcaneocuboid release, plantar release, etc.

Intraoperatively, an evaluation determines the completeness of the surgery, diagnoses potential overcorrection, and establishes a baseline to compare early and late follow-up exams. This baseline clarifies the difference between persistent and recurrent deformity and (together with a postoperative evaluation) determines if overcorrection is progressive or static.

Postoperatively, an evaluation compares the findings with other postoperative exams to detect loss of correction and increasing overcorrection.

Criteria

A classification may be made on the basis of clinical criteria (parameters) alone, e.g., deformity, motion, and muscle strength (if the patient is old enough), whereas an evaluation should be made on the basis of clinical, functional, and x-ray criteria (Table 3.4). In the papers in this chapter, the authors have used as few as one, i.e., motion (Dimeglio), to as many as 35 criteria (Cummings), while most authors use about 10.

About the Papers in this Chapter

If the reader agrees that our definitions of the terms *classification* and *evaluation* are valid, then these terms will appear to be used improperly in some manuscripts in this chapter.* The reader should keep this in mind and make a mental adjustment when the improper terms are observed.

*In other manuscripts the editor has taken the prerogative of interchanging these terms; when this has been done the author's term appears in parentheses.

Most of the papers in this chapter deal with evaluation rather than classification, although Dimeglio's may be considered to deal with either, and Pandey and Pandey's deals with both.

Five papers deal with preoperative evaluation (Dimeglio, Catterall, Carroll, Pandey and Pandey, and Stevens and Meyer), four deal with postoperative evaluation (McKay, Lehman et al., Barnett, Cummings et al.), and one deals with both (Goldner and Fitch). None of the papers in this section deals with deformities due to overcorrection postoperatively.

Finally, some deformities must be evaluated by clinical means (such as supination), whereas other deformities (especially complications) can only be evaluated by x-ray, e.g., avascular necrosis of the talus, flattop talus, etc.

Fallacious results may occur if an evaluation is made between two feet having a different classification or if an evaluation is made of a postoperative foot without taking the preoperative evaluation into consideration.

TABLE 3.4. Criteria used for evaluation.

Clinical	Functional	X-ray
Undercorrected deformities	Gait	AP view
Equinus	Shoe wear	APTC angle—varus or valgus (rotary or hinge)
Varus	Pain	APTC divergence—valgus (translation)
Uncorrected calcaneal rotation		AP talar axis–1st metatarsal base—medial or lateral TNS
Medial TNS		CC alignment—calcaneocuboid subluxation
CCS		
Cavus		
Supination		
FFA		
Overcorrected deformities		Lateral view
Calcaneus		Lateral talocaneal angle—equinus, calcaneus
Valgus		Lateral talar axis–1st metatarsal base—dorsal, volar TNS
Overcorrected calcaneal rotation		Lateral talar–1st metatarsal angle—cavus
Dorsal TNS		
Lateral TNS		
Dorsal bunion		
Motion		
Strength		

AP, anteroposterior; APTC, anteroposterior talocalcaneal; CC, calcaneocuboid; CCS, calcaneocuboid subluxation; FFA, forefoot adduction; TNS, talonavicular subluxation.

Clinical Classification of Congenital Clubfeet

S. Pandey and A.K. Pandey

The persistent fetal position of the foot following birth may appear to be a typical clubfoot. However, this "postural clubfoot" even with gentle manipulation can be manually corrected beyond the neutral position. On the other hand, the clubfoot associated with arthrogryposis multiplex congenita, neurologic disorders, and other generalized systemic disorders cannot be classified along with the classical idiopathic clubfoot because of their severity and other problems that are more important than the foot deformities.

The quantification of the clubfoot deformities on a mathematical scale is impossible.

TABLE 3.5. Clinical evaluation (classification) of clubfoot.

Clinical findings	Mild	Moderate	Severe	Very severe
Skin condition	Normal	Almost normal	Superolateral aspect stretched; crowded skin creases on posteromedial aspect; congenital grooves on inferomedial aspect of foot, rarely in lower leg; thin callousities on dorsolateral aspect	Atrophied skin, congenital groove always present in inferomedial aspect of foot; thick callousities on lower leg
Attitude of foot	Mild equinovarus	Equinus more dominant than varus; associated with forefoot adduction	Varus, adduction of forefoot, equinus and cavus, in that order	Inverted foot; equinus comparatively less, foot turns inward at right angle to leg, marked cavus
Stretchability of deformity	Fully correctable on passive stretching	50–75% correctable on passive stretching	25–50% correctable on passive stretching	Less than 25% correctable on passive stretching
Heel	Almost normal	Comparatively smaller	Small, moderate heel varus	Small, severe heel varus
Calf	Normal	Almost normal	Tendency to become tapering and cylindrical	Almost cylindrical (peg-like)
Feel of calf	Normal	Almost normal	Firm	Markedly firm, thin end presents feel of soft tissue fixation
Varied	Manipulative massage and maintenance with orthotics	Manipulative massage, serial taping, serial plaster cast, maintenance orthotics; resistant cases require posteroinferomedial soft tissue release with or without tendon transfer	Trial of serial plaster casts; soft tissue releases required	Soft tissue release, maintenance with orthotics, regular stretching and physiotherapy; recurrence common

For neglected, resistant, and relapsed clubfoot presenting beyond 3 years of age, bony operations are usually needed for satisfactory correction.

However, the well-planned clinical classification of clubfoot will be a definite guideline for the surgeons to declare its prognosis.

The clinical evaluation presented here (Table 3.5) has been used in evaluating 1,117 idiopathic clubfeet in 767 patients since 1963 for assessment of the clubfoot. It has been useful for planning the management and evaluating the results. It has also been used in teaching programs of the undergraduate medical students, postgraduate trainees, and registrars.

Basing the observations on overall look, feel, skin, magnitude of the components of the deformity, possibility of passive correction, effect of stretching of the deformities on the vascularity of the toes, and the look and feel of the heel and calf, the clubfeet have been graded: mild (grade I), moderate (grade II), severe (grade III), and very severe (grade IV).

The observations made while analyzing the patients' records and examining 917 treated feet (in 566 patients) helped us to deduce the possible bony changes, the approximate prognosis of each grade, and the mode of treatment.

Classification of Talipes Equinovarus

A. Dimeglio

The various types of talipes equinovarus (TEV) must be classified in order to objectively compare the effectiveness of the various forms of treatment. However, no ideal classification has been found as yet, and each practitioner has his own method of classifying TEV. I have attempted to standardize and precisely define the scope of the four basic categories of CTEV as follows: (1) stiff (irreducible), (2) severe (slightly reducible), (3) mild (partially reducible), and (4) postural (totally reducible). The amount of reducibility is therefore more significant than the deformity itself. This assessment involved 384 clubfeet of children seen during the first few weeks of life.

The degrees of deformity (equinus, varus, adduction, and supination) were measured. The skin creases in the posterior and medial regions of the foot were also taken into account. Thus a dynamic study of these feet was possible.

Four Groups of Clubfeet

1. *Stiff = stiff feet**: Also called teratologic clubfeet, stiff-stiff feet make up 9% of all cases. The foot is generally short and stiff. Reducibility in the horizontal and sagittal planes does not exceed 20%. The equinus deformity is severe, and the varus deviation of the calcaneus exceeds 45°. Posterior, medial, and plantar retraction is often observed.

   These feet are often regarded as bordering on arthrogryposis. This type of clubfoot is often bilateral. A unilateral clubfoot is always highly suspicious and requires an investigation to detect dysraphism. In these severe feet, early surgery performed between the third and fifth month is essential. Nonorthopedic management is absolutely ineffective. The operation procedure is extensive. All areas of retraction must be dealt with, and almost all tendons, not only the Achilles tendon but also the tibialis posterior tendon, must be lengthened. This category yields the poorest results and further surgery is required in 40% of cases. Good results were obtained in only 50% of all cases.
2. *Stiff > soft feet*: This category is by far the most common type, accounting for 61% of our patients. These feet have a reducibility rate by conservative treatment of less than 50%. The foot is resistant but partially reducible in both the horizontal and the sagittal planes. Surgery is indicated, but properly performed, well-understood

*The author's terminology applies to the initial response of the foot to passive movement, and then to the eventual response following a period of manipulation or physical therapy.—Ed.

orthopedic management by means of initial casts or physiotherapy can take advantage of partial reducibility.

The most appropriate surgery is tailored to the circumstances of each foot. However, these feet usually require a posteromedial, posterolateral, or subtalar release until reduction is achieved. An additional release on the lateral aspect of the foot is sometimes needed, as well as a plantar release. Thus, specific releases are essential in each case.

3. *Soft > stiff feet*: These feet represent 30% of cases. Reducibility is considerable and exceeds 50% in the horizontal and sagittal planes. The varus angle is smaller than 20°. The foot is generally long. Orthopedic management seems to be effective during the first months of life. During the seventh or eighth month, however, it becomes clear that total reduction of the foot has not been achieved and defects are still seen on the radiographs. Surgery then becomes necessary and must be performed with great caution as overcorrection is a major risk. This category includes the highest percentage of very good or excellent results, which is often as high as 95%.
4. *Soft = soft feet*: These may also be called postural or resolving feet. They do not require surgery. Casts or physiotherapy is effective.

EVALUATION

Preoperative Evaluation

Clinical Assessment of Clubfoot Deformity

A. Catterall

The results of treatment of children with clubfeet remain unpredictable. The results of primary conservative treatment cannot be predicted in the neonatal period. This may reflect the inadequacies of primary assessment. A clinical assessment has been developed that can identify three types of deformity in the neonatal period. There is a *postural* or *resolving type* in which there is no fixed deformity but dorsiflexion above the right angle is not necessarily present. There is a *tendon contracture type* in which the tight structures are mainly posterior with no fixed deformity in the midtarsal or forefoot. Finally, there is a *joint contrac-*

TABLE 3.6. Catterall's clinical types of congenital talipes equinovarus (CTEV).

Type	Resolving pattern	Tendon contracture	Joint contracture	False correction
Other names	Postural/soft foot	Fibrous foot	Stiff foot	
Hindfoot				
Lateral malleolus	Mobile	Posterior	Posterior	Posterior
Equinus	No	Yes	Yes	Yes
Creases				
Medial	No	No	Yes	No
Posterior	No	Yes	Yes	Yes
Anterior	Yes	No	No	Yes
Forefoot				
Lateral border	Straigh	Straight	Curved	Straight
Mobile	Yes	Yes	No	Yes
Cavus	±	±	±	No
Supination	No	No	Yes	No

ture type in which there is fixed deformity in both the hindfoot and the forefoot in the neonatal period (Table 3.6).

The Dynamic Concept of the Foot

Although the foot consists of a number of bones, from a functional and dynamic aspect it consists of a medial and lateral ray together with a tethering link mechanism. The two rays lie one above the other posteriorly but are at the same level anteriorly with the foot in the position of weight bearing. The link mechanism joins the two rays and is formed by the interosseous ligament posteriorly, the remaining tarsal bones in the midfoot, and the transverse metatarsal ligament anteriorly. The movements of inversion, eversion, pronation, and supination consist of rotary movements of the medial and lateral rays in which the limitations are imposed by the elasticity of the link mechanism. These are the joint capsule, the short plantar ligaments, and the distal attachment of the tibialis posterior.

The Rays of the Foot

In terms of the dynamic concept of the foot there are two rays: medial and lateral. The medial ray consists of the talus, navicular, medial cuneiform, and first metatarsal. The lateral ray consists of the calcaneus, cuboid, and fifth metatarsal. They are joined by the link mechanism.

The Link Mechanism

The link mechanism forms a partly bony, partly ligamentous link between the medial and lateral rays. It is formed by the interosseous ligament posteriorly, the remaining tarsal bones (intermediate and lateral cuneiform), and the second, third, and fourth metatarsals together with the transverse metatarsal ligament.

The Concept of Tethers

The movement of dorsiflexion may be prevented by tethers occurring posterolaterally between the lateral malleolus, talus, and calcaneus; medially between the medial malleolus and navicular; inferiorly and anterolaterally in relation to the link mechanism. The inferior structures that prevent movement are the short plantar ligaments and the distal tendon of the tibialis posterior. Anterolateral structures limiting movement are the ligaments between the lateral aspect of the navicular, calcaneus, and cuboid. All of these tethers need to be released if normal dorsiflexion is to occur.

Clinical Assessment (Tables 3.7 and 3.8)

The tethers will produce fixed deformities in the intact foot. Assessment, therefore, must be an analysis of these fixed deformities and the range of movement that is present from this fixed point. To do this, there must be a method of examination. This will identify the orientation of the tibia and hindfoot, give an assessment of forefoot-hindfoot relationship and mobility, observe the process of dorsiflexion, and finally, identify the presence or absence of supination or cavus.

Orientation of the Tibia and Hindfoot

This is best assessed with the knee flexed. The tibial tubercle and medial and lateral malleoli are identified, together with the position of the head of the talus. This relationship with the posterior aspect of the calcaneus identifies fixed equinus.

Forefoot-Hindfoot Alignment

Once the hindfoot is oriented, the forefoot is examined from below. A curved lateral border is commonly noted. Attempting to straighten the lateral border by manipulation with the foot in equinus should result in the head of the talus becoming covered by the navicular, a palpable gap appearing between the navicular and medial malleolus, and the lateral border changing from curved to straight. If these three observations are present, the midtarsal area of the link mechanism is considered mobile and correctable.

TABLE 3.7. Clubfoot assessment form 1.

Name Initials Hospital no. Research no.

ADDRESS Date of birth Consultant

Position in family Sex M F Side R L Bilateral

F.H. of CTEV Y/N Other deformties (state)

PREGNANCY DETAILS

Duration weeks Complication Y/N (state)

Delivery Vertex/Breech Caesarian section Y/N Birth weight lbs ozs or kg

Neonatal period normal Y/N If no, state why.

PRIMARY EXAMINATION

Date / /8 Facial molding Y/N Plagiocephaly Y/N

Upper limbs Normal/abnormal

Spine normal Y/N If no state why.

Hips Right: Stable Y/N Abduction-in-flexion 1/4 1/2 3/4 full
Left: Stable Y/N Abduction-in-flexion 1/4 1/2 3/4 full

Knees normal Y/N

NEUROLOGICAL EXAMINATION Normal Y/N If no, state why.

EXAMINATION OF FEET

General appearance Normal R/L Long and thin R/L Short and fat R/L Trophic changes Y/N

CALF	RIGHT	LEFT
Tibial torsion (degrees)		
Max calf measurement (cm)		
HINDFOOT		
Equinus (degrees)		
Lateral malleolus posterior (Y/N)		
FOREFOOT		
Lateral border of foot		
straight/curved (degrees)		
corrects in equinus		
Creases		
posterior/medial/both		
anterior		
Presence of: cavus		
supination		

Radiographs taken Y/N If yes, result.

PRIMARY TREATMENT

No treatment

Serial plasters—frequency of reapplication/week

Manipulation only number of times per day/week

Manipulation + strapping number of times per day/week

OTHERS (please specify details)

TABLE 3.8. Clubfoot assessment form 2.

Name	Initials	Hospital No.	Consultant	Date of Birth
	Date / /	Date / /	Date / /	Date / /
	Right Left	Right Left	Right Left	Right Left
Length of foot (cm)				
HINDFOOT				
Dorsiflexion/plantar flexion				
Lateral malleolus posterior (Y/N)				
FOREFOOT				
Lateral border of foot				
straight/curved (degrees)				
corrects in equinus Y/N				
Creases				
Posterior/anterior/medial				
both				
Presence of: cavus				
: supination				

RADIOGRAPHS	
Date / /	Result

RESULT OF TREATMENT			
If treatment successful, was position maintained by splints	Y/N	Type of splint	
Date of stopping conservative treatment / /	Duration	weeks	

OPERATION	
Date / /	Nature (Posterior only/posterior and medial)
Date / /	Nature (Posterior only/posterior and medial)
Date / /	Nature (Posterior only/posterior and medial)

The Process of Dorsiflexion

As the normal foot dorsiflexes from the position of equinovarus three observations are noted: (a) the lateral malleolus moves forward in relation to the posterior aspect of the calcaneus; (b) the posterior borders of the tibia and heel become straight and the posterior crease is obliterated, and (c) a crease appears anteriorly over the ankle joint. Overall, the forefoot externally rotates in relationship to the tibia. The point at which this process fails to occur is noted.

The Presence of Cavus and Supination

Supination is best observed by bringing the heel to the neutral position in relation to the tibia and assessing the position of the heads of the first and fifth metatarsals. Cavus is best observed from the medial side by noting tightness of the plantar fascia and whether the line between the medial malleolus and head of the first metatarsal is straight or curved.

Radiological Assessment

Plain radiographs show only the position in which the foot lies. Stress radiographs identify fixed deformity. Two radiographs are of value. A lateral x-ray in dorsiflexion reveals whether the lateral malleolus is opposite the tibia. The forefoot is seen in lateral projection. Breaching of the calcaneocuboid or cuboid metatarsal joints implies a false correction with a rocker-bottom foot.

A stress anteroposterior radiograph with the foot in eversion reveals the alignment of the calcaneocuboid joint and whether there is divergence between the talus and calcaneus.

On the basis of this clinical and radiographic method of examination, the four types of feet may be identified.

Preoperative Clinical Assessment of Clubfoot

N.C. Carroll

The author recommends that all newborns with clubfeet have an ultrasound of the lumbosacral spine to make sure that there is not an intraspinal anomaly producing the deformity.

There are five parts to the preoperative assessment:

1. The "bird's-eye view" of the entire child and his deformity.
2. A detailed neurological examination.
3. Doppler examination of the foot.
4. Roentgenographic assessment.
5. The specific clinical assessment.

In the bird's-eye view, one needs to make sure that one is not dealing with a syndrome complex such as Freeman-Sheldon syndrome, Larsen's syndrome, Pierre Robin syndrome, Goldenhar's syndrome, Smith-Lemli-Opitz syndrome, or diastrophic dwarfism. The child needs to be examined prone to make certain that the spine is normal.

One needs to perform a careful neurological assessment of the motor and sensory function in the limb, especially the peroneal muscles and the tibialis anterior muscle.

The Doppler examination is used to assess the arterial supply to the foot. If the child does not have a tibialis anterior artery it is helpful to be aware of this fact before surgery.

Roentgenographic assessment of the foot has been described in detail by other authors in this book.

The specific clinical assessment consists of inspection, palpation, and manipulation. One inspects the leg and foot for:

1. calf atrophy
2. posterior displacement of the lateral malleolus (assessed with the patient prone and the knee flexed to 90°)
3. medial and/or posterior skin creases
4. curved lateral border
5. cavus.

One palpates the foot to see if:

6. the navicular is fixed to the medial malleolus
7. the calcaneus is fixed to the fibula.

The foot is then manipulated to see if there is:

8. fixed equinus
9. fixed adductus
10. fixed forefoot supination.

Assessment Criteria*

The foot is graded with one point assigned for each criterion present. A severely deformed foot with all of the criteria listed would score 10, whereas a well-corrected foot would score 0.

Summary of the Clinical Criteria

Calf atrophy
Posterior fibula
Creases
Curved lateral border
Cavus
Navicular fixed to medial malleolus
Calcaneus fixed to fibula
Fixed equinus
Fixed adductus
Fixed forefoot supination

Examples of the Grading System (Table 3.9)

Case A demonstrates a child with calf atrophy, a posterior fibula, creases, curved lateral border, cavus, navicular fixed to the medial malleolus, calcaneus fixed to the fibula, fixed equinus, fixed adductus, and fixed supination. This foot would score 10 on the severity scale and would obviously require a complete plantar, lateral, medial, and posterior release to achieve correction.

In case B, with the manipulation and casting, the deep creases have disappeared. The lateral border of the foot is no longer curved. There is some midtarsal mobility and no fixed forefoot supination. This foot scores 6 points. The anterior posterior radiograph demonstrates that the cuboid is no longer subluxated medially; therefore, this foot would require a plantar,

*Developed with A. Catterall and B. Yoneda.

TABLE 3.9. Scoring system for clubfoot.

Assessment criteria	Cases				
	A	B	C	D	E
Calf atrophy	1	1	1	1	0
Posterior fibula	1	1	1	1	0
Creases	1	0	0	0	0
Curved lateral border	1	0	0	0	0
Cavus	1	1	0	0	0
Navicular fixed to medial malleolus	1	1	1	0	0
Calcaneus fixed to fibula	1	1	1	1	0
Fixed equinus	1	1	1	1	1
Fixed adductus	1	0	0	0	0
Fixed forefoot supination	1	0	0	0	0
Total	10	6	5	4	1

medial, and posterior release but not a lateral release.

In case C, the manipulation and casting applications have eliminated the creases, the lateral border of the foot is no longer curved, a cavus deformity no longer exists, there is midtarsal mobility, and the forefoot supination has been corrected. This foot will require a medial and posterior release only. The plantar and lateral release would not be required.

In case D, the initial manipulation and casting have removed the creases, the lateral border is straight, there is no cavus, the navicular is not fixed to the medial malleolus, there is midtarsal mobility, and the forefoot supination has been corrected. This foot would require only a posterior release. Included in the posterior release is a division of the calcaneofibular and talofibular ligaments.

Case E resembles a clubfoot. The foot is held in equinus and varus. On examination, the only fixed component of the deformity is the equinus. The foot is quite mobile and the heel is not tethered to the lateral malleolus. With further casting, this foot is likely to correct completely and surgery will not be required.

These cases demonstrate that one must assess each foot individually and plan the surgery accordingly. The purpose of the surgery is to restore the bony architecture to normal and to balance the muscle forces. A total plantar, lateral, medial, and posterior release is not required for every foot.

Reference

1. Morrissy, R.T. (ed.): Clubfoot. In *Lovell and Winter's pediatric orthopaedics*, 3rd ed., vol II. Philadelphia: J.B. Lippincott, 1990.

CTEV Equinus Severity Grading Scale

D. Stevens and S. Meyer

At the Lexington unit of the Shriner's Hospitals for Crippled Children, analysis of results of posterior releases done prior to 1971 reveals generally a 50% failure rate. That is, half of the children operated upon required further operative procedures. After the introduction of the posteromedial release, popularized by Turco[6] in the early 1970s, the failure rate dropped to 20%. It has remained constant over the last 20 years, based on long-term follow-up reports. The failures appear to be due to both undercorrection and now increasingly recognized overcorrection. Both have occurred early and late after surgery in some cases and their genesis remains obscure. Inexplicably in otherwise normal children, two separate clubfeet of similar appearance on clinical and x-ray examination have responded differently to a similar operation by the same surgeon. The pathology of CTEV appears to be similar, varying only in degrees of severity.

A grading scale, based on the degree of severity, would be useful in classifying clubfeet into various groups. This scale could be applied to the various types of clubfeet, such as congenital or idiopathic, and those associated with

arthrogryposis, myelodysplasia, congenital constriction band syndrome, and other etiologies. Retrospective correlation of the degree of severity with other operative techniques and surgical results might help select the best operation for each patient.

Also, a convenient severity grading scale, if reproducible, could be used at multiple centers to compare the results following the various treatments. That is, if feet could be classified at a specific grade and selected by severity, the results of the series in different centers could be more accurately compared than is done at present.

Methods

The ideal grading on a severity scale would involve reproducible clinical measurements. It should be easy to learn. It would need to be correlated with treatment to determine if it had prognostic or therapeutic value. It should be applicable to all forms of clubfeet, that is, idiopathic as well as secondary forms. It should not be related to the age of the patient, e.g., standing x-rays that require weight bearing are, therefore, not applicable to infants. If possible, it should be recoverable from retrospective record review.

After complete correction of varus deformity by conservative treatment, our custom has been to measure the residual equinus deformity in the operating room after anesthetic induction but before the incision is made. This measurement has been added to the criteria to be evaluated in all clubfeet at clinical presentation and throughout treatment.

Technique

The foot is gently held by the examiner with as much correction as possible. Varus of the foot is gently stretched (Figure 3.1). After passive correction of varus and equinus to whatever extent possible, a goniometer is placed along the axis of the tibia and along the plantar surface of the foot measuring the angle between the tibia and the plantar surface of the foot (Figure 3.2). This is defined as residual equinus and is applied to a scale of 0 to 5. This scale is inter-



FIGURE 3.1. The residual varus and equinus are present despite passive stretching.

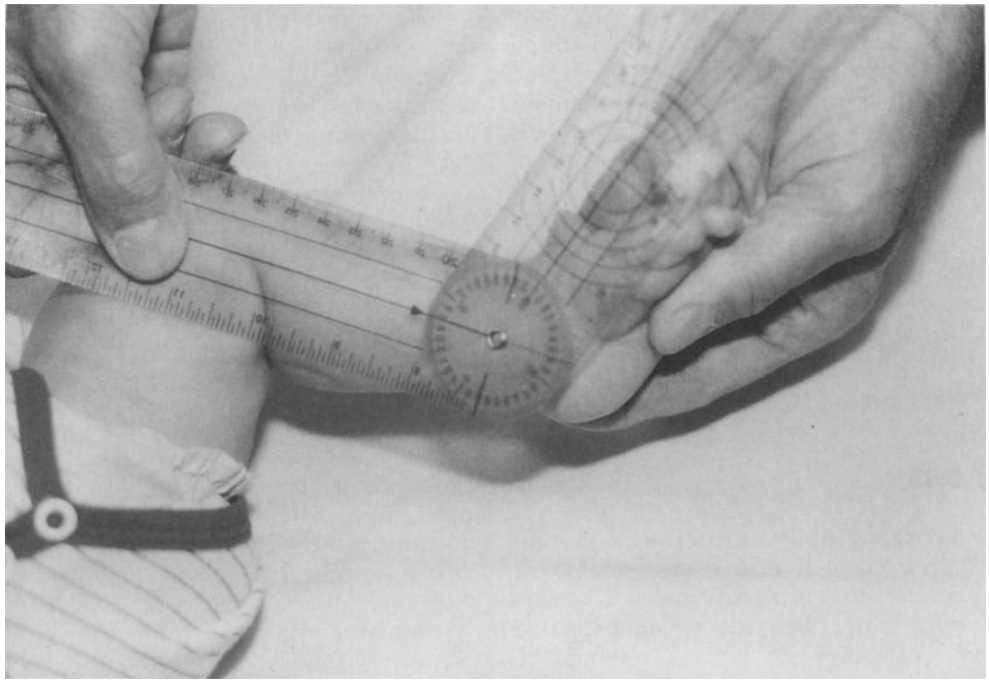


FIGURE 3.2. Measuring residual equinus with a goniometer.

preted as the "Clubfoot Equinus Severity Grading Scale" and is defined as follows:

Grade
0: full dorsiflexion
1: dorsiflexion above neutral but not full range
2: 0° of residual dorsiflexion
3: 1°–30° of retained residual equinus or plantar flexion
4: 31°–50° of equinus
5: over 50° of equinus

Alternatives and Preferences

At the recent International Congress on Clubfeet, a severity scale was introduced by Goldner.[2] His comprehensive and thorough scale requires clinical examination as well as radiographic evaluation. These x-rays probably need to be obtained by a physician or with a physician's direct supervision. At the same congress, Carroll[1] described an intriguing system of clinical evaluation based on a scale of 1 to 10. He assigned one point each for the presence of a specific physical finding.

Simons[5] has used radiographic parameters for indicating the various deformities and their severity. Kumar[4] reported an interesting application of footprints in an attempt to quantify the variation of severity.

Most authors in the past have used the terms *mild*, *moderate*, and *severe* in describing their preoperative cases, though few, if any, have delineated the specifics by which they were able to apply these adjectives. Harold and Walker[3], however, did use a severity scale based on residual equinus and varus after passive correction.

Our attempts with cineradiography, arthrograms, computed tomography (CT) scans, and standard x-rays have not served to differentiate the various feet. As it has not been our custom to hold the foot during the x-ray examination, the images have not been as reliable an indicator as the clinician's measurement of equinus. On several occasions, multiple examiners were asked to examine the same feet without knowledge of the others' measurements. This generally has resulted in a variation of 10° or so between examiners in their estimation of equinus. It appears that the more severe deformities with over 30° of equinus have the greatest error.

TABLE 3.10. Postoperative rating scale.

		Points
Subjective (15)		
Pain (5)	No pain	(5)
	Pain with activity only	(3)
	Pain regardless of activity	(0)
Function (5)	Fully active with no or minimal limitation, including athletics	(5)
	Some limits on activity, athletics	(3)
	Severe limitations, including walking	(0)
Cosmesis (5)	Satisfied with appearance	(5)
	Mildly dissatisfied	(3)
	Very dissatisfied	(0)
Objective (60)		
Gait (20)		
Strike (10)	Heel to toe	(10)
	Flatfoot (plantigrade)	(5)
	Toe-toe or calcaneus	(0)
Push-off (10)	Good push-off (can tiptoe)	(10)
	Weak but present (no tiptoe)	(5)
	No push-off	(0)
Braces required for gait		(−10)
Motion (30)		
Dorsiflexion (10)	>10°	(10)
	0–10°	(5)
	1–20° equinus	(0)
	>20° equinus	(−5)
Plantar flexion (10)	>30°	(−10)
	10–30°	(5)
	<10°	(0)
Eversion (5)	Full	(5)
	Half	(3)
	None	(0)
Inversion (5)	Full	(5)
	Half	(3)
	None	(0)
Static deformity (10) (includes varus/valgus, cavus, adductus, serpentine)	No significant deformity	(10)
	Residual but acceptable deformity	(5)
	Unacceptable deformity	(0)
Radiographic (25)		
Lateral talocalcaneal angle (15)	>20°	(15)
	10–20°	(10)
	<10°	(0)
Talonavicular relationship (5)	No displacement or malshaped navicular	(5)
	Mild displacement or deformity of navicular	(3)
	Significant displacement or deformity of navicular	(0)
Foot alignment (5) (talus to 1st MT angle)		
	<10°	(5)
	10–20°	(3)
	>20°	(0)

MT, metatarsal.

Results

All patients were operated on at the Shriner's Hospital for Crippled Children, Lexington unit, and all were followed at that institution. The operation performed was a posteromedial release with no attempt to align the calcaneocuboid joint. The technique described by Turco[6] was used, although some surgeons excised and others repaired the posterior tibial tendon.

In addition to the clinical measurement of

TABLE 3.11. Preoperative grade versus outcome.

Preoperative grade*	Good result	Poor result	Reoperation	<80 Assess	Number of feet
2	10 (90.9%)	1 (9.1%)	1	0	11
3	63 (65.6%)	33 (34.4%)	15	18	96
4	40 (61.5%)	25 (38.5%)	14	11	65
5	6 (85.7%)	1 (14.3%)	0	1	7
Number of feet	119	60	30	30	179

* Clubfoot Equinus Severity Grading Scale.

equinus, the other data related to the postoperative evaluation are also included. These data are based on a rating scale of 100 for a normal foot, minus a variable number of points based on the symptoms, physical examination, x-ray findings, as well as the functional capacity (Table 3.10).

An attempt was made to determine if there was a correlation between the preoperative evaluation using the clubfoot equinus grading scale and the results as determined by this point rating scale. There were 179 feet available with a recording of the preoperative grade and final grade. The final assessment was performed at least 2 years after operation using both clinical and radiographic examinations. The feet were rated on a scale of 1 to 100 (Table 3.10). All final assessments were based on repeat, current examinations (Table 3.11).

It would appear, on initial analysis, that there was no clear definition between grades 3, 4, and 5 based on these results. Statistical correlation shows that the percentages vary significantly between grades 2, 3, 4, and 5, but there was no statistically significant variation between those grades. The distinction that Harold and Walker[3] were able to show in their survey between their grades of 1, 2, and 3 did not appear to be duplicated in this study. The operative treatment required did not appear to be related to the severity. Intraobserver and interobserver correlation appears to be adequate to establish it as a reproducible clinical measurement. Many of those who had a rating of less than 80 were considered to have an acceptable, though not good, result. It is planned to further analyze the good and poor results as based on under- and overcorrection.

Conclusion

Analysis of these results suggests this CTEV Severity Grading Scale may provide a system of grading talipes equinovarus at birth and throughout the presurgical period.

References

1. Carroll, N.: Presentation at the First International Congress on Clubfeet. Milwaukee, Wisconsin, September 6, 1990.
2. Goldner, J.L.: Presentation at the First International Congress on Clubfeet. Milwaukee, Wisconsin, September 6, 1990.
3. Harold, A.J., Walker, C.J.: Treatment and prognosis in congenital club foot. *J. Bone Joint Surg.*, 65–B:8–11, 1983.
4. Kumar, K.: The role of footprints in management of clubfeet. *Clin. Orthop.*, 140:32–36, 1979.
5. Simons, G.W.: A standardized method for the radiographic assessment of clubfeet. *Clin. Orthop.*, 135:107–118, 1978.
6. Turco, V.: Surgical correction of the resistant clubfoot: one-stage posteromedial release with internal fixation: A preliminary report. *J. Bone Joint Surg.*, 53–A:447–497, 1971.

Intraoperative Evaluation

Intraoperative Evaluation Form (Checklist)

R.M. Barnett, Sr.

Date of surgery _____

Right _____ **Left** _____

Virgin _____ **Redo** _____

Staff doctor _____

Clubfoot Surgery Worksheet

A. INCISION
- 1. Medial _____
- 2. Plantar _____
- 3. Lateral _____
- 4. Cincinnati _____

B. CAPSULOTOMY
- 1. Talonavicular _____
- 2. Calcaneocuboid _____
- 3. Talocalcaneal _____
  - a. Total _____
  - b. Partial _____
- 4. Talotibial _____

C. TENDONS
- 1. Posterior tibialis
  - a. Distal release _____
  - b. Z-lengthening _____
- 2. Flexor digitorum longus tendon
  - a. Lengthen _____
  - b. 0 _____
- 3. Flexor hallux longus
  - a. Lengthen _____
  - b. 0 _____
- 4. Tendo Achilles
  - a. Lengthen _____
  - b. 0 _____
- 5. Abductor hallux
  - a. Lengthen _____
  - b. 0 _____
- 6. Anterior tibialis
  - a. Lengthen _____
  - b. Transfer _____
  - c. 0 _____

D. LIGAMENT
- 1. Deltoid, deep
  - a. Total _____
  - b. Posterior _____
- 2. Plantar fascia _____
- 3. Interosseous _____
- 4. Calcaneofibular _____

E. PINS
- 1. Talonavicular _____
- 2. Calcaneocuboid _____
- 3. Talocalcaneal _____
- 4. Talotibial _____

F. SUTURE
- 1. Sustentaculum _____
- 2. Calcaneocuboid _____
- 3. Talonavicular _____
- 4. Posterior subtalar _____

G. DORSIFLEXION OF ANKLE POSTOPERATIVE
- 1. Neutral _____
- 2. −10% _____
- 3. +10% _____

H. POSTOPERATIVE
- 1. Cotton splint _____
- 2. Short leg cast _____
- 3. Long leg cast _____

I. OSTEOTOMY
- 1. Cuboid _____
- 2. Calcaneus _____
- 3. Cuneiform _____
- 4. Talus _____

J. PULSES DETECTABLE WITH DOPPLER
- 1. Posterior tibial _____
- 2. Dorsalis pedis _____

Postoperative Evaluation

Can Clubfeet Be Evaluated Accurately and Reproducibly?

R.J. Cummings, R.M. Hay, W.P. McCluskey, J.M. Mazur, and W.W. Lovell

The purpose of this study was to determine the interobserver error in evaluating the parameters commonly used to measure the results of clubfoot treatment.

The literature contains many articles written on the pathologic anatomy of the congenital clubfoot deformity. Not surprisingly, these articles have either been accompanied by, or resulted in, a number of therapeutic approaches to this condition. Unfortunately, evaluation of these approaches and the validity of their underlying concepts has been hindered by the lack of a universally accepted method of evaluating the severity of involvement prior to treatment and the improvement after treatment.

Until there is an accurate, reliable, sensitive, and specific method of evaluating clubfeet, one cannot prove that one method of treatment is superior to another.

This study was conducted, as the first step, to develop a system for the evaluation of clubfeet that ideally should be:

1. accurate in determining to what degree the feet are normal or abnormal;
2. reproducible between observers;
3. useful for evaluating clubfeet preoperatively and postoperatively;
4. useful for determining which feet may be difficult or easy to treat, and therefore, predictive of the long-term prognosis;
5. useful for comparing one treatment method to another; and
6. useful for helping make treatment recommendations.

Materials and Methods

A review of the English literature from 1966 to 1990[1–59] produced 46 articles that reported results of clubfoot surgery. These authors used 85 different parameters* to evaluate their results of treatment. We divided these parameters into history items, physical examination items, and radiographic items (Table 3.12).

Of these 85 parameters, 37 were selected for this study (Table 3.13). Parameters like marital status were deleted because they were felt to be subject to too many factors other than the status of the subjects' feet or were inappropriate for children. Other parameters were combined; for example, absent heel strike, simultaneous heel-toe, and absent toe-off could all be described as "abnormal gait." Many parameters too general to be useful were eliminated. The authors met, reviewed, and agreed on how each of the 37 parameters would be assessed and recorded.

Twenty-nine clubfeet in 20 patients (15 boys and 5 girls) were then evaluated, utilizing the 37 preselected parameters in the predetermined fashion. The evaluations included a history, physical examination, and radiographs (AP, lateral dorsiflexion, and lateral plantar flexion views). Figures 3.3 to 3.6 describe the radiographic grading systems used (Simons[48]). The other radiographic measurements were all angular measurements.

The average age at the time of evaluation was 64 months (range 16 to 156 months). The affected feet were all treated surgically by three different surgeons using various techniques. The evaluations were performed an average of 45 months (range 16 to 150 months) after the surgery. Twenty-six feet were examined by three examiners, and three feet were examined by two examiners, giving a total of 84 clubfeet ratings. The examiners were three orthopedic surgeons with fellowship training in, and practices limited to, children. One examiner was a

*Tables list the same parameter more than once when varus values are used by more authors than valgus values and with gait relative to shoes.

TABLE 3.12. Parameters to evaluate clubfeet.

	Parameter	Number of authors using		Parameter	Number of authors using
History:	ankle pain	15		angle bimalleolar to longitudinal foot axis	2
	subtalar pain	15		centerline of foot through 2nd or 3rd toe	2
	sports participation	11		circulatory disturbance	2
	pain and fatigue/walking endurance	10		footprint	2
	normal shoes	8		recurrence of deformity	2
	need for further procedure	8		retained arch	1
	patient satisfaction	6		tibial torsion	1
	difficulty with uneven surfaces	4		"residual deformity"	1
	difficulty with stairs	4		foot-knee alignment	1
	limited activity	4	Radiographs:	talocalcaneal angle lateral	17
	career choice	2		talocalcaneal divergence angle AP	16
	military service	1		talocalcaneal index	10
	marital status	1		navicular displacement AP and lateral	10
Physical examination:	heel hindfoot varus	40		"normal appearance"	8
	ankle dorsiflexion	39		talar 1st MT angle	5
	heel hindfoot valgus	39		dorsiflexion on stress lateral	3
	forefoot adduction	37		plantar angle	3
	subtalar stiffness/ROM	29		navicular 1st MT angle	3
	ankle plantar flexion	27		plantar deviation talonavicular joint	3
	equinus	27		medial deviation talonavicular joint	3
	forefoot abduction	23		talocalcaneal overlap	3
	normal gait	17		"Y" angle of Kite	3
	foot shape	16		tibiocalcaneal angle in DF	2
	plantigrade foot	15		flattop talus	2
	cavus	13		forefoot adduction	2
	midtarsal joint ROM	13		talocalcaneal angle in DF	2
	planovalgus foot	12		calcaneus 1st MT angle	2
	gait with/without shoes	12		talonavicular angle	2
	active eversion	8		talar beaking	2
	toe walking	7		calcaneocuboid joint space	2
	appearance of scars	7		tibiotalar angle	1
	calf size	7		hindfoot varus	1
	forefoot varus	7		tibiotalar angle DF	1
	heel walking	6		R/L ratio	1
	absent heel strike	6		central angle of talar curvature	1
	abnormal toe-off	6		1st–5th MT angle lateral	1
	foot length	5		calcaneus 5th MT angle AP	1
	supination	4		deformed navicular	1
	calluses	3		closed sinus tarsi	1
	forefoot valgus	3		rotation of fibula	1
	leg length	3		tibiotalar angle PF	1
	plantar flexion strength	3		calcaneus 2nd MT AP angle	1
	simultaneous heel-toe strike	3			
	shoe deformation	3			
	running	3			
	strength of muscle transfer	3			
	FHL function	2			
	genu recurvatum	2			

AP, anteroposterior; DF, dorsiflexion; MT, metatarsal; PF, plantar flexion; ROM, range of motion.

TABLE 3.13. Parameters studied to determine interobserver error.

	% Agreement (left)	% Agreement (right)	% Average agreement
History			
Shoes	91	94	92.5
Activities	82	89	85.5
Pain/fatigue	91	89	90.0
Uneven surfaces	55	78	66.5
Stairs	73	78	75.5
Other procedures	55	56	55.5
Satisfaction	82	83	82.5
Physical examination			
Normal gait	55	39	47.0
Toe walk	55	61	58.0
Heel walk	64	72	68.0
Run	55	61	58.0
Ankle tenderness	91	100	95.5
Subtalar tenderness	91	94	92.5
Calluses	73	83	78.0
Thigh-foot axis	55	50	52.5
Calcaneal bimalleolar axis	72	45	58.5
Arch	64	72	68.0
Plantigrade foot	91	83	87.0
Hindfoot alignment	91	94	92.5
Forefoot alignment	100	89	94.5
Subtalar ROM			
Active Inv.	73	72	72.5
Passive Inv.	64	61	62.5
Subtalar ROM			
Active Ev.	72	83	77.5
Passive Ev.	73	61	67.0
Ankle ROM			
Active DF	27	45	36.0
Active PF	36	39	37.5
Passive DF	54	55	54.5
Passive PF	54	50	52.0
Midfoot ROM			
Dorsiflex	82	72	77.0
Plantarflex	73	56	64.5
Adduction	82	56	69.0
Abduction	91	77	84.0
Radiographs			
AP talocalcaneal angle	63	83	73.0
AP calcaneo–5th metatarsal angle	91	94	92.5
Lateral talocalcaneal angle	73	90	81.5
Dorsilateral tibiotalar angle	63	89	76.0
Plantar lateral tibiotalar angle	73	89	81.0
Dorsilateral tibiocalcaneal angle	73	83	78.0
Plantar lateral tibiocalcaneal angle	73	94	83.5
Lateral calcaneo–1st metatarsal angle	63	78	70.5
Dorsilateral foot tibial angle	73	79	76.0
Plantar lateral foot tibial angle	91	67	79.0
AP talocalcaneal overlap	54	61	57.5
AP navicular displacement	72	83	77.5
Lateral navicular displacement	72	83	77.5

resident who completed 4 months of training with the three pediatric orthopedists.

The percentage of agreement for each parameter was determined and recorded. To be in agreement, we arbitrarily decided that each rater had to be within 10° of the other raters for all angles and within one grade for displacement of bones as seen on the radiographs.

The ideal parameter would yield 100% agreement between raters, but as there are various reasons for measurement errors, we would anticipate less than 100% agreement.

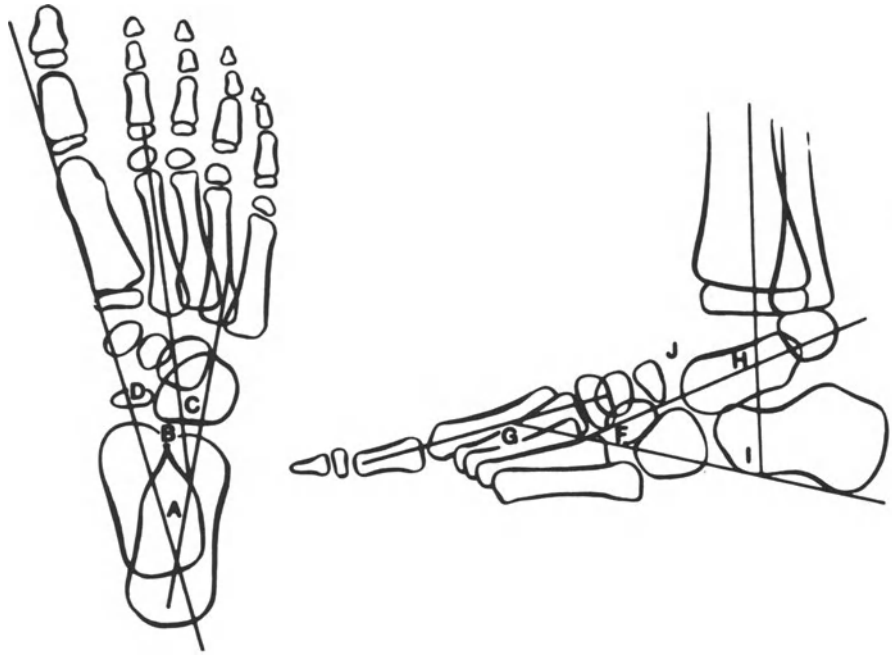


FIGURE 3.3. Radiographic measurements with normal values for the foot of a child who is less than 5 years old. On the anteroposterior radiograph: A, the anteroposterior talocalcaneal angle (20° to 40°); B, the talocalcaneal divergence (zero to +1) (also see Figure 3.4); C, the calcaneal-second metatarsal angle (15° to 20°); D, navicular in central position (also see Figure 3.5). On the lateral radiograph: F, the lateral talocalcaneal angle (35° to 50°); G, the calcaneal–first metatarsal angle (140° to 180°); H, the tibiotalar angle (dorsiflexion, 70° to 100°; plantar flexion, 120° to 180°); I, the tibiocalcaneal angle (dorsiflexion, 25° to 60°); J, the navicular at the same level as the talus (also see Figure 3.6). (Reprinted with permission from Simons.[48])

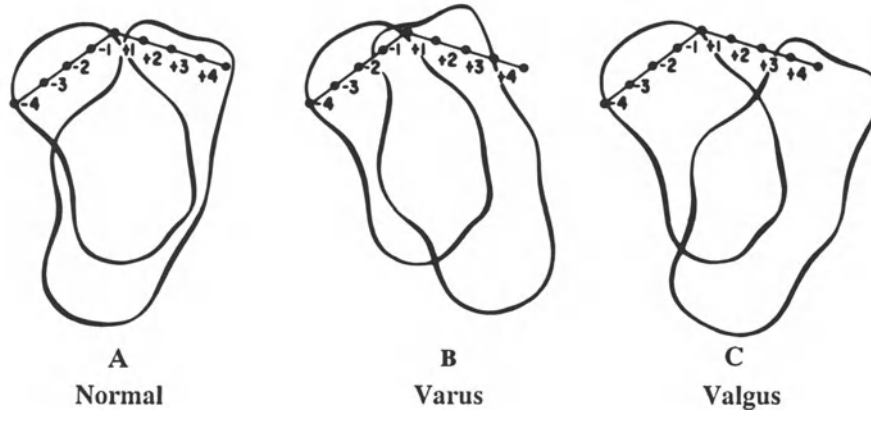


FIGURE 3.4. Talocalcaneal divergence. Divergence of the anterior ends of the talus and calcaneus is normal in children who are less than 5 years old; that is, a cleft exists at the anterior ends. Overlap is measured in one-quarter increments of the talar head (−1 to −4); separation or divergence is designated as +1 to +4. (Reprinted with permission from Simons.[48])

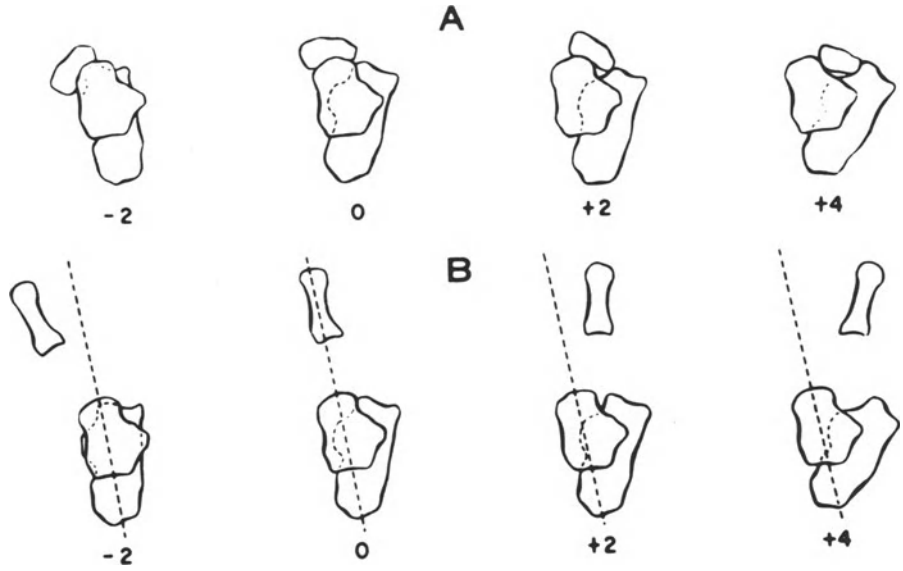


FIGURE 3.5. Navicular position on the anteroposterior radiograph. A: The method of determining the navicular position after ossification has occurred. The position of the navicular is graded as zero if the navicular is positioned centrally on the distal end of the talus. If it is laterally or medially displaced by one-half of the diameter of the talar head, a grade of +2 or −2 is given. Similarly, grades of 3 and 4 are given for displacement of three-quarters and complete displacement of the navicular from the talar head, respectively. On the anteroposterior radiograph, the central position of the navicular with respect to the talar head is the normal position. Mild and moderate lateral deviation are seen in hypermobile flatfeet; this condition is usually asymptomatic and is compatible with good function. Thus, a grade of +1 or +2 is satisfactory but is considered overcorrection, whereas a grade of +3 or +4 represents marked overcorrection and, therefore, a complication. A grade of −1 represents incomplete correction but is considered satisfactory, whereas −2 and −3 are unsatisfactory and, therefore, are considered to represent a major complication. B: The method of determining the navicular position before ossification has occurred. When the talar axis passes through the base of the first metatarsal, the navicular is in normal alignment with the talus and the navicular position is then rated zero. When it passes medial or lateral to the base of the first metatarsal by one-half of the width of the base of the first metatarsal, a grade of −1 or +1, respectively, is given. When it passes medially or laterally the full width of the base of the first metatarsal by one-half of the width of the base of the first metatarsal, a grade of −2 or +2, respectively, is given, and so on. Grades of +1, +2, −1, and −2 are considered satisfactory, whereas ratings greater than this are considered to represent a major complication. (Reprinted with permission from Simons.[48])

We considered an 80% agreement to be good and worthwhile to include in a rating system. Several parameters measure the same characteristic of feet; an attempt was made to choose the best parameter for each characteristic. For example, forefoot alignment could be determined by both physical examination and by radiographs. We attempted to determine which method, physical examination or radiographs, would be better. The percentages of agreement were compared between parameters to determine which gave the most reproducible result.

Results

The history items gave the highest total average percentage of agreement (78%), followed by radiographic items (77%), and physical examination items (68%) (Table 3.13). These overall disappointing results clearly showed some items to be more reproducible than others. Using the 80% agreement level as a cutoff, we found the history items of shoes, activities, pain/fatigue, and parental satisfaction to have acceptable interrater agreement. Physical ex-

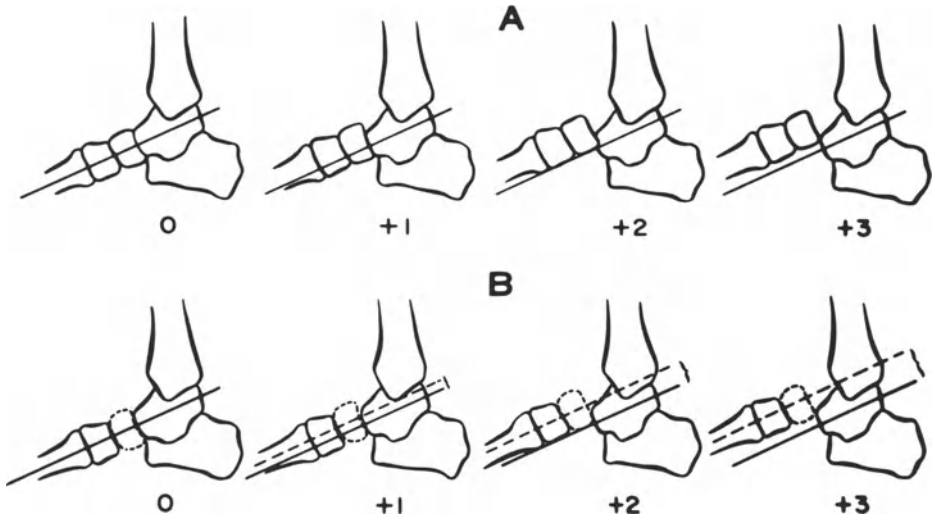


FIGURE 3.6. Navicular position on the lateral radiograph. A: The method of determining the presence or absence of dorsal subluxation of the navicular after ossification has occurred. On the lateral radiograph, the navicular is normally not displaced dorsally with respect to the talus. This normal position is graded as zero. Superior displacement of approximately one-third or less of the height of the ossified navicular head is graded +1, superior displacement of between one- and two-thirds is graded +2, and superior displacement of more than two-thirds is graded +3. A grade of +1 is considered satisfactory (but overcorrected), whereas grades of +2 and +3 are considered unsatisfactory and indicative of a major complication. B: The method of determining the presence or absence of dorsal subluxation of the navicular before ossification has occurred. When a line is drawn through the talar axis and another line is drawn through the first metatarsal axis, the distance between these two parallel lines represents the distance that the navicular is dorsally subluxated. Grades are determined by comparing the distance between the two lines to the height of the talar head; that is, zero to one-third, +1; one-third to two-thirds, +2; and two-thirds to one, +3. Occasionally the overlap of the metatarsals makes identification of the first metatarsal impossible. In that case, a line along the superior surface of the most dorsal metatarsal may be used. If it passes above the talar head, the navicular is dorsally subluxated. Normal position is graded zero; +1, satisfactory; and more than +1, unsatisfactory. In the presence of a cavus deformity, this measurement is unreliable. (Reprinted with permission from Simons.[48])

amination items of ankle tenderness, subtalar tenderness, plantar grade foot, hindfoot alignment, forefoot alignment, and midfoot range of motion were acceptable. Of the radiographic items, the AP calcaneo–fifth metatarsal, lateral talocalcaneal, plantar lateral tibiotalar, and plantar lateral tibiocalcaneal angles yielded reproducible results. Table 3.14 lists the most reproducible items, the clubfoot characteristic for which the items test, and the normal values for each item. The interobserver errors were not affected by the level of training or experience of the observers.

Looking at various items that measure the same clubfoot characteristics, it was noted that physical examinations and x-rays are equally accurate and reproducible for measuring forefoot alignment and arch, whereas radiographs are superior to physical examinations for measuring plantar flexion.

Discussion

Based on the findings, it appears that, in general, radiographic angle measurements are more reproducible than physical examination angular measurements. History items and radiographic items appear to have a similar average percentage of agreement, and both have a better rate of agreement, on average, than physical examination items.

The relatively high total percentage of agreement on history items (78%) is not unex-

TABLE 3.14. Summary of parameters with 80% or greater interrater agreement.

	% Agreement	Clubfoot characteristic	Normal criteria
History			
Shoes	92.5	Shape of foot	Regular shoe
Activities	85.5	Functional status	Full activity for age
Pain/fatigue	90.0	Arthritis/callosities	Absence
Satisfaction	82.5	Subjective functional status	Parents pleased
Physical examination			
Ankle tenderness	95.5	Arthritis	Absence
Subtalar tenderness	92.5	Arthritis	Absence
Plantigrade foot	87.0	Shape of foot	No callosities
Hindfoot alignment	92.5	Heel varus/valgus	10° to 15° valgus
Forefoot alignment	94.5	Residual forefoot deformities	Neutral
Radiographs			
AP Calcaneo–5th metatarsal	92.5	Forefoot varus/valgus	0° to 10°
Lateral talocalcaneal	81.5	Hindfoot alignment	35° to 50°
Plantar lateral tibiocalcaneal	83.5	Plantar flexion	25° to 60°

pected. The lower percentage of agreement with respect to ability to manage stairs and uneven surfaces may reflect difficulty in answering questions about these abilities in younger children. We were surprised by the lack of historical agreement on "other procedures." We feel that referring to records rather than depending on family recall should improve agreement on this parameter.

The difficulty in evaluating many of the physical examination items (e.g., heel walking, toe walking, running, and gait) in younger children may explain the high rate of interobserver disagreement for these items. The younger child's lack of cooperation also seemed a frequent source of difficulty in determining ranges of motion and rotational alignment. On the other hand, the percentage of agreement on static alignment was considerably better.

Many of the physical examination items found to yield unreliable results have been used in the past to determine the success rate of various surgical procedures. For example, we agreed only 45% of the time on the clinical assessment of active dorsiflexion and 55% of the time on assessment of passive dorsiflexion; yet 39 of the 46 articles reviewed used these items as criteria to document the success of their treatment protocols. Ankle range of motion is difficult to measure because observers can confuse subtalar, midtarsal, and tarsal-metatarsal motion for tibiotalar motion. The percentage of interobserver agreement was particularly poor with the clinical evaluation of gait (47%).

Even some of the classic radiographic parameters were found to have an unacceptably high rate of interobserver error. Historically, Kite's angle, the anteroposterior talocalcaneal angle, has been used in almost every article and textbook chapter written on clubfeet. Kite's angle is measured on an AP radiograph by drawing lines through the long axis of the calcaneus and the talus. The line through the talus should coincide with the first metatarsal, and the line drawn through the calcaneus should coincide with the fifth metatarsal. An angle greater than 35° indicates valgus, and less than 20° indicates hindfoot varus. We could not agree within the limits of $\pm 10°$ more than 73% of the time.

It is difficult to draw the lines that make Kite's angle, since the feet in question are usually in skeletally immature children; therefore, the talus and calcaneus appear only as ossific nuclei, which tend to be round. Drawing a line along the long axis of a round structure will inherently create errors in measurement. We therefore agree with Watts,[58] who concluded that "x-rays to compare results of clubfoot treatment pre- and postoperatively, or to compare treatment techniques, should be used with marked caution."

On the other hand, we found the lateral talocalcaneal angle to be reproducible. Watts[58] found this measurement to be reliable at the 95% confidence level. Therefore, this item could be used to evaluate the success rate of clubfoot surgery. As noted above, differences in the level of training and experience of examiners had no effect on interobserver error;

TABLE 3.15. Components of clubfoot deformity.

Component	Deformity	Subject to correction
Forefoot	Adduction and supination	+
Hindfoot	Varus	+
Ankle	Equinus	+
Rotation	Medial spin	+
Stiffness	—	+/–
Foot size	Small	–
Calf atrophy	—	–

we agree with Watts that "there was no difference between the measuring skills of the residents, fellows, or pediatric orthopaedists."

Table 3.15 lists the commonly accepted components of the clubfoot deformity. We were particularly interested in evaluating these parameters since they quantified the components that we felt were the most subject to the influence of our treatment. Comparison of Tables 3.14 and 3.15 reveals acceptably reproducible measurements for forefoot and hindfoot deformity. Measurements of equinus and stiffness in plantar flexion were also acceptably reproducible. The amount of stiffness in dorsiflexion, as measured by the lateral tibiocalcaneal angle, almost reached acceptable reproducibility at an average rate of agreement of 78%.

The only component of deformity not reproducibly measured in this study was the rotational component; there was a 52.5% average rate of agreement for the thigh-foot axis and 58.5% for the calcaneal bimalleolar axis. This is in good agreement with Watts,[58] who found the interobserver error for these two measurements to be ± 19° and ± 18°, respectively. In this study we were able to agree on the direction of the foot's deviation relative to the thigh (i.e., the positive thigh-foot angle versus the negative thigh-foot angle) 75% of the time.

It is hoped that the etiology of clubfeet will be discovered and prevention will be possible. Until this occurs, we will continue to treat clubfeet orthopedically with varying results. It is clear that, although our efforts can make feet functional, they cannot make these feet normal. For this reason, we must continue to strive for better results and be able to evaluate these results with a reliable, accurate, and reproducible rating system that is universally acceptable.

We feel that the final selection of parameters for a universal system should be a two-phase process. First, we must define through studies such as this which parameters can be measured in a reproducible manner. Next, we must determine which of these is significant. This will require correlation of pain, function, and satisfaction with such things as deformity and motion. It is also desirable to choose parameters that can be used both before and after treatment.

Summary

The lack of a universally accepted rating system for assessment of results after clubfoot surgery hinders comparison of various treatment regimens. A review of the English literature from 1966 to 1990 produced 46 articles that reported results of clubfoot surgery. Almost every one described a different rating system for the evaluation of postoperative results, for a total of 85 different parameters.

We divided these 85 parameters into historical, physical examination, and radiographic items. The frequency of use for each was determined. Three examiners then studied a group of 20 clubfoot patients (29 feet) using 37 parameters distilled from the initial groupings. After evaluating each parameter for the interobserver error inherent in its measurement, only 12 of the 37 were found to be reproducible at the 80% level of interobserver agreement.

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Functional Rating System for Evaluation of Long-Term Results of Clubfoot Surgery

W.B. Lehman, D. Atar, A.D. Grant, and A.M. Strongwater

The current concept of treatment for clubfoot deformity is initial manipulations and serial cast applications; when these are inadequate, surgery is required.[6] About 30% to 50% of these feet will not be corrected and will require surgical release.[7,11,12,20,25,27] An average of 25% of the operated feet will have poor results and will need additional surgical intervention.[8,9,15,28] What are the criteria for good results or failure? We have designed a simple and objective rating system by which failures as well as good results can be easily defined.

Materials and Methods

During the period 1985 to 1986, 32 patients (45 clubfeet) have had a complete soft tissue clubfoot release through a posteromedial incision and additional lateral release if necessary through a separate incision. (Patients with clubfeet who had had previous surgery were excluded.) There were 11 females and 21 males. Thirteen patients has bilateral clubfoot deformity. The age range was from 24 months to 33 months (average 11 months). Follow-up evaluation ranged from 24 months to 33 months (average 24.8 months). All were private patients operated upon by the senior author (W.B.L.), who used the same approach and postoperative care. Follow-up was also performed personally by the senior author.

Results

A functional rating system was designed to evaluate the results of the operated clubfeet. The rating system combined subjective and objective clinical assessment and radiographic

TABLE 3.16. Hospital for Joint Diseases Orthopedic Institute functional rating system for clubfoot surgery.

Category	Points	Category	Points
1. Ankle dorsiflexion (passive motion)		6. Radiographic measurements	
More than 90°	15	T-C index*	
90°	5	40° or more	5
Less than 90°	0	Less than 40°	0
2. Subtalar joint motion (passive motion)		Talar–1st metatarsal angle	
More than 10°	0	10° or less	5
Less than 10°	5	15° or more	10
Stiff	0	7. Shoes	
3. Position of heel when standing		Regular—no complaints	5
0°–5° valgus	10	Regular with complaints	2
More than 5° valgus	5	Orthopedic shoe inserts, braces	0
Varus	0	8. Function	
4. Forefoot (appearance)		No limit	15
Neutral	10	Occasionally limited	8
Less than 50° adduction/abduction	5	Usually limited	0
More than 50° adduction/abduction	0	9. Pain	
5. Gait		Never	10
Normal heel/toe gait	10	Occasionally	5
Cannot heel walk	−2	Usually	0
Cannot toe walk	−2	10. Flexor tendons	
Flatfoot gait	−4	Full function	5
		Partial function	3
		No function	0

*The talocalcaneal index (T-C) is the sum of the talocalcaneal angles measured on lateral and anteroposterior radiographs.

TABLE 3.17. Results of clubfoot surgery according to the functional rating system.

1	2	3	4	5	6	7	8	9	10	Score	Age at intervention, in months
15	10	0	0	10	5	5	15	10	5	75	6
5	5	10	5	10	10	5	15	10	5	80	7
5	10	10	5	4	5	5	15	10	5	84	8
15	10	10	5	10	10	5	15	10	5	95	5
15	10	10	5	10	0	5	15	10	5	85	4
15	10	10	10	10	5	5	15	10	5	95	18
15	10	10	10	10	5	5	15	10	5	95	
5	5	0	0	4	5	0	15	10	0	44	6
5	5	0	0	6	0	0	15	10	0	41	
5	10	0	10	10	10	5	15	10	5	80	12
15	10	10	5	10	10	5	15	10	5	95	12
15	10	10	0	10	5	0	15	10	5	80	7
15	10	10	10	10	5	5	15	10	5	95	6
15	10	10	10	8	0	5	15	10	5	88	7
5	10	10	5	10	10	5	15	10	5	85	12
15	10	10	10	10	10	5	15	10	5	100	13
15	10	10	10	10	10	5	15	10	5	100	
15	10	10	5	10	5	0	15	10	5	85	5
15	10	10	0	6	0	5	8	5	3	62	10
15	10	10	0	6	0	5	8	5	3	62	
15	10	10	5	10	5	5	15	5	5	85	48
15	10	10	5	8	0	0	8	5	3	64	24
15	10	0	0	8	0	0	8	5	0	46	
15	5	10	5	10	10	5	8	10	3	81	5
15	5	10	5	10	10	5	8	10	5	83	
15	10	10	5	6	10	5	15	10	5	91	5
15	10	10	10	4	5	5	15	10	5	89	8
15	10	10	10	8	5	5	15	10	5	93	
15	10	10	5	10	10	5	15	10	5	95	6
15	10	10	5	10	10	5	15	10	5	95	
15	10	10	5	10	10	5	15	10	5	95	8
15	10	10	5	10	10	5	15	10	5	95	
15	10	10	10	4	5	5	15	10	5	89	6
15	10	10	5	10	0	5	15	10	5	85	36
15	10	10	5	10	10	5	15	10	5	95	
5	5	10	0	6	0	5	15	10	3	63	8
15	10	0	10	10	10	5	15	10	5	90	10
15	0	10	0	6	5	5	15	10	5	65	6
5	0	10	0	6	5	5	15	10	3	63	
5	10	5	0	10	5	5	15	10	5	70	7
5	5	10	5	10	5	5	15	10	5	75	30
5	5	0	5	10	5	5	15	10	5	65	20
5	5	0	5	10	5	5	15	10	5	65	
15	10	5	5	10	5	5	15	10	5	95	12
15	10	0	5	10	5	5	15	10	5	90	

criteria (Table 3.16). A total score of 100 points indicates a normal foot. This includes a maximum score of 15 points for ankle range of motion and function, 10 points each for subtalar motion, position of the heel when standing, appearance of the forefoot in gait, pain, and radiographic correction, and 5 points each for the type of shoes and flexor tendon function. An evaluation of excellent would be 85 to 100 points, good would be 70 to 84 points, fair would be 60 to 69 points, and poor would be less than 60 points. As can be seen from Table 3.17, we had 23 excellent results (51%), 11 good results (24%), 8 fair (18%), and 3 poor (7%).

Discussion

The optimal age for surgical correction of clubfoot is regarded by some authors as the neonatal period,[17,19,22] as 6 months to 2 years,[26] 3

to 4 years;[14] or even 6 years.[23] But most authors think that 3 to 6 months is the best time.[2,18,21,24] Our study did not show significantly better results in any age group. Our overall excellent and good results compare favorably with the literature. For evaluation of the results of clubfoot surgery, most authors use subjective criteria such as appearance, motion, gait, and pain.[4,9,10,13,15,27,28] Some add radiographic criteria as well.[3,5,16,18,21,26] Our system has been found to be reliable and easy to use for the assessment of the long-term results of clubfoot and revision clubfoot surgery.[1]

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Postoperative Rating System For Clubfeet

Douglas McKay

Category and Point Values (Subtract from 180 points)

1. Ankle motion				
	More than 90°	Less than 90°	Total	
	10°	40°	50°	0
	10°	30°	40°	−10
	10°	25°	35°	−20
	Less than 10°	Less than 25°	Less than 35°	−30
2. Angle of bimalleolar plane to longitudinal plane of foot				
	83° to 90°			0
	76° to 82°			−10
	50° to 75°			−20
3. Strength of tricep surae				
	Weight supported on toes, one foot only			0
	Weight supported on toes, both feet			−10
	Weight not supported on toes			−20
4. Heel				
	0° to 5° valgus			0
	5° to 10° valgus			−5
	More than 10° valgus			−10
	Varus			−10
5. Forefoot				
	Neutral			0
	To 5° adduction or abduction			−5
	Over			−10
6. Flexor hallucis longus				
	Functional			0
	Nonfunctional			−10
7. Ankle pain				
	Constantly disabling			−30
	Tolerable during daily activities			−20
	Limping at end of day			−10
	Interferes only with running			−5
8. Subtalar pain				
	Constantly disabling			−20
	Tolerable during daily activities			−15
	Limping at end of day			−10
	Interferes only with running			−5
9. Shoe wear				
	Stylish shoes foregone option			−5
	Foot deforms shoes			−10
	Shoes do not fit			−15
10. Sports				
	Competitive			0
	Noncompetitive because of foot			−15

Surgical Follow-Up: Talipes Equinovarus

R.M. Barnett, Sr., J.G. Stark, J.E. Johanson, and J. Drogt

Side: Right/Left
Name

Date _____
Chart # _____
Pre-op cast # _____
Post-op cast — Wks. _____

I. Clinical appearance

Sinus tarsi
0) NORMAL
1) ABSENT
2) SHALLOW
3) EXCESS

Medial border
0) STRAIGHT
1) CURVED

Lateral border
0) STRAIGHT
1) CURVED

Heel
0) NORMAL
1) SEVERE VALGUS
2) VARUS
3) SEVERE VARUS
REQUIRES
REOPERATION

Arch
0) NORMAL
1) FLAT
2) HIGH

Calf atrophy
0) NORMAL
1) ATROPHY
2) OBVIOUS SEVERE
QUANTIFY
GREATEST DIMENSION _____
CONTROL _____

II. Function

Gait: Great toe flexion strength
0) NORMAL
1) ABSENT
2) <GRAVITY
3) ANTIGRAVITY

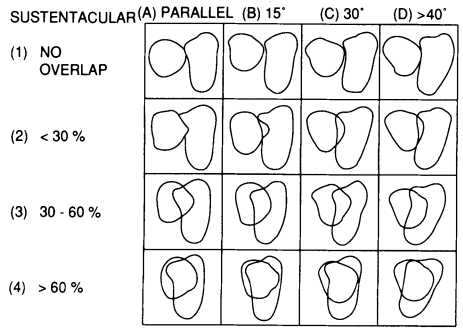
Gait: Heel
0) NORMAL
1) UNABLE
2) <NORMAL
3) ATTEMPT
4) ADAPT. MANEU.
5) N.A.

Gait: Toe
0) NORMAL
1) UNABLE
2) <NORMAL
3) ATTEMPT
4) ADAPT. MANEU.
5) N.A.

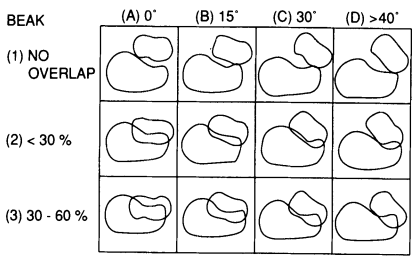
Shoe: Size discrepancy
0) EQUAL
1) −1
2) −2
3) −3
4) N.A.

Shoe: Wear
0) NORMAL
1) ABNORMAL

III. X-ray—AP Film



X-ray—Lateral Film



X-Ray Comments:

Dorsal TC Angle

Lateral TC Angle

V. Clinical Measurements

EPA	*Bimalleolar axis*	*Motion: Total DF*	*Motion: Total PF*	*Motion: Subtalar*
0) NORMAL	0) 80°–90°	0) >30	0) 30	0) NORMAL
1) IR 10°–20°	1) 70°–80°	1) 15–30	1) 20	1) < 50%
2) ER ≤ 15°	2) <70°	2) 0–15	2) +	2) < NORMAL, 50–75%
3) ER > 15°	3) >90°	3) +0		3) EXAGERRATED, OVERCORRECT
		4) <0		

IV. Pain

0) NO PAIN
1) PAIN MILD, RARE USE OF ANALGESICS
2) PAIN MINOR, OCCASIONAL USE OF ANALGESICS
3) PAIN GREAT, REGULAR USE OF ANALGESICS

Summary

	GOOD	FAIR	POOR
I. CLINICAL APPEARANCE			
II. FUNCTION			
III. X-RAY-AP			
X-RAY-LATERAL			
IV. PAIN			
V. MEASUREMENTS OVERALL			

Complications

1) None
2) Wound
3) Avascular necrosis
4) Tendon
5) Other
6) Need complete redo
7) Need second surgery

Pre-, Intra-, and Postoperative Evaluation

Classification and Evaluation of Congenital Talipes Equinovarus

J.L. Goldner and R.D. Fitch

This method of classification and evaluation of true clubfeet Figure 3.7 provides an index of severity that serves as a guide to prognosis, diagnosis, and treatment of clubfeet (Table 3.18 and Figure 3.8).[1,2] Pretreatment assessment by clinical and roentgenographic methods provides a consistent and reproducible rating of a deformed clubfoot regardless of its designated category (classification) (Figure 3.7). The pretreatment assessment uses

PREOPERATIVE, POSTOPERATIVE, CLINICAL AND RADIOGRAPHIC ASSESSMENT OF CLUBFEET
BASED ON GRADE OF SEVERITY Circle proper description. (J.L. Goldner, M.D.)

Step 1 is completed prior to operative procedure and includes clinical and radiographic examination. By Dr. _____.

NAME _____ Duke HISTORY # _____ AGE _____
DATE OF EXAMINATION _____

Descriptive Value	
Positional	0
Minimal	1 -10
Mild	11-20
Moderate	21-40
Severe	41-50
Very Severe	51-60

ANATOMIC CHARACTERISTICS - Grade of Severity	Weighted Value	Grade of Severity (mild, mod., sev.) (circle proper grade)	Designate Final Number (Pre or postop)
1. Skin ligaments, creases, elasticity	3	0 1 2 3	
2. Calf size, foot size, ease of cast or splint application.	3	0 1 2 3	
3. Active muscle motors; peroneals, toe extensors, anterior tibial and posterior tibial muscles.	3	0 1 2 3	
4. Position of head of talus - uncovered, partially covered. Mobility of talus and navicular laterally.	6	0 2 4 6	
5. Tibial - navicular interval (estimate by palpation and manipulation).	6	0 2 4 6	
6. Foot alignment with ankle joint - position of fibula, medial malleolus, and estimated degree of rotation of the talus and calcaneus related to ankle.	6	0 2 4 6	
7. Equinus - severity of heelcord contracture; heel shape - degree of inversion and size, creases, fat pad, and motion.	6	0 2 4 6	
8. Cavus - depression of first metatarsal, height of longitudinal arch, metatarsus adductus. Contracture of anterior tibial affecting inversion.	9	0 3 6 9	
9. Radiographic determination of anatomic position. Hindfoot, tibial - talar position, calcaneal relation to talus by up and down stress laterals.	9	0 3 6 9	
10. Radiographic abduction - adduction; movement of cuboid, metatarsals. Spurious correction of forefoot. AP of ankle joint to include talocalcaneal tier. (Slightly overexposed AP.)	9	0 3 6 9 20 40 60	

FIGURE 3.7. Pretreatment assessment showing clinical and radiographic characteristics of idiopathic congenital clubfoot. The descriptive value of the severity is in the upper right hand corner. The weighted value is designated with the grades of severity. The final column indicates the numerical rating for a specific characteristic. This information can be used preoperatively, adjusted intraoperatively, and repeated three months postoperatively and annually.

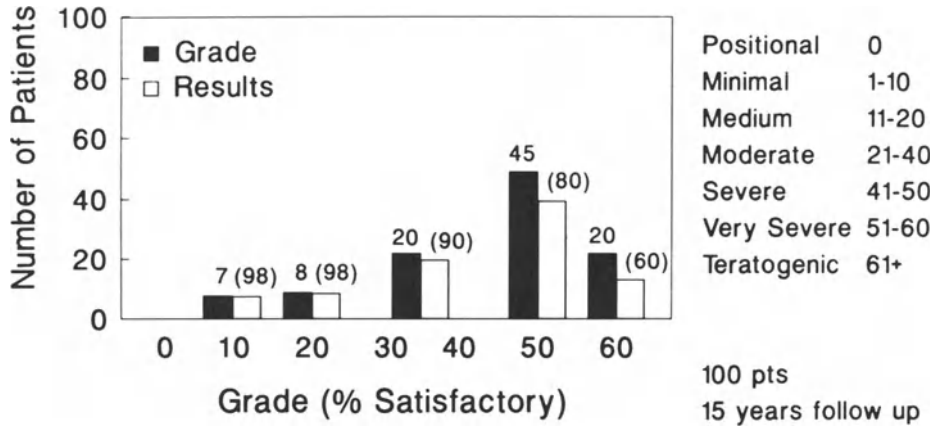


FIGURE 3.8. Clubfoot rating classification showing results of 100 patients followed for 15 years. The preoperative grade designates the severity. The results are listed according to the grade. The numerical rating listed on the right is derived from Figure 3.7.

methods of examination that are based on readily measured characteristics that are recognized and defined during the usual examination of a clubfoot (Figure 3.9). A systematic examination with predetermined weighted values for these anatomical parts (Table 3.18) will result in a descriptive term-numerical value that is consistently reproducible by experienced surgeons, and reproduced with somewhat more difficulty by less experienced surgeons (Figure 3.7). The initial data was obtained after comparative random testing by these two groups who independently examined several patients.[4] There were 10 senior staff and 20 residents in the entire study. One hundred patients were involved in the original prospective study (Figure 3.8). The readings submitted by each group of investigators showed a standard deviation of plus or minus 10. The results were analyzed and subsequently subjected to statistical analysis that indicated sufficient accuracy and reliability for both a single examiner and an accurate comparison among examiners.[6]

Reasons for Clubfoot Classification and Grading

Current and past results of clubfoot treatment in specific published series usually compare random results of all feet in each series neither

TABLE 3.18. Clubfoot classification: mechanism of grading severity.

	Mild	Moderate	Severe
	1	2	3
	2	4	6
	3	6	9
Weighted value in each grade	3	6	9

The grades of severity are designated numerically according to the description of the characteristics based on their importance. Each characteristic was rated separately. This method depended on the severity of the deformity with its weighted value, the difficulty in correcting the deformity, and the relative recurrence or persistence of a specific deformity. The feet designated as *mild* (1–20) were compared with those designated as *moderate* (21–40), and those clubfeet that were designated as *severe* (41–50) and *very severe* (51–60). (Reprinted with permission from Goldner and Fitch.[6])

TABLE 3.19. Clubfoot classification based on tibial-navicular interval prior to surgical release.

	Weighted value
0–6 mm	6 Severe
7–12 mm	4 Moderate
13–18 mm	2 Mild
19–24 mm	0 Normal

The shorter the distance, the less the elasticity, and the more severe the deformity. This correlates with the ratio U/C of the talar head. The measured distance between the medial aspect of the navicular and the medial malleolus varied according to the severity of the deformity. The most severe feet had a short interval and the mild feet had a longer interval between the navicular and the medial malleolus. The actual measurement was made during the early phase of the operative correction. This finding consistently correlated with limited preoperative covering of the head of the talus by manual manipulation.



A



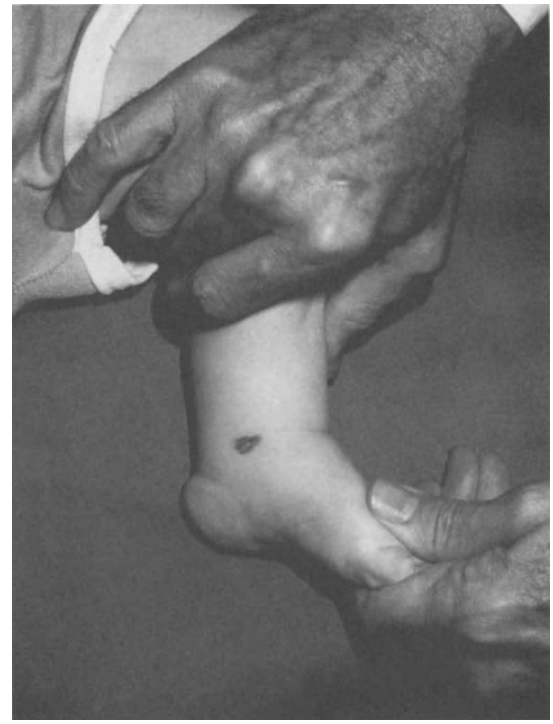
B



C

FIGURE 3.9. A: Prone plantar view of a congenital clubfoot. The proximal segment of the calcaneus (the heel) is in an externally rotated position close to the fibula relative to the tibia. The anterior distal segment of the calcaneus is directed medially according to the anatomical designation. The distal talus and the tarsal navicular are displaced and facing medially. With the tibia stabilized, the examiner attempts to externally and internally rotate the foot to determine the range of movement in both the ankle mortise and the subtalar joint. The degree of equinus, inversion, or supination cannot be determined from this view. B: Medial view of congenital clubfoot. This foot shows a deep crease posterior and superior to the calcaneus, a static equinus position of the talus, calcaneus, and metatarsals, and a flexion contracture of the short and long toe flexors. The tibia is stabilized, and the examiner attempts to force the foot into the maximum degree of dorsiflexion. The degree of cavus is determined by pal-

pating the metatarsals and the calcaneus. The arch is camouflaged by the large abductor muscle. *Comparative calf size* is determined by measuring the circumference of similar points on the left and right calves. The dot is over the medial malleolus. The examiner palpates the tibionavicular interval when the foot is adducted and abducted. Active motor function is determined when the foot is in a relaxed position as the examiner strokes the plantar surface. This maneuver usually stimulated contractions of the anterior tibial, the extensor digitorum longus, and the peroneus longus and brevis muscles. Inversion testing detects active movement of the toe flexors and the posterior tibial muscle. The forced neutral dorsiflexion radiograph is made while the examiner wears lead-lined gloves. C: Testing of a contracture of the triceps surae muscle. The foot is held in slight inversion and supination, and passive dorsiflexion is forced. This maneuver places maximum stress on the heel cord and posterior capsule, and diminishes compensatory subtalar eversion and dorsiflexion as forced upward stress occurs. When the foot is everted rather than inverted, the range of dorsiflexion is increased because of motion at the subtalar and midtarsal joints. This foot is being held in an inverted and dorsiflexed position. There is no tibio-talar or talocalcaneal motion in this position. D: Eversion-forced dorsiflexion of a congenital clubfoot. This foot with a static equinus deformity shows 15° more dorsiflexion in eversion than with the same maneuver in inversion. The everted position partially bypasses the contracted triceps surae because of existing movement in the subtalar-midtarsal joints. This is one of the maneuvers performed in determining the numerical rating of foot severity.



D

differentiated nor classified preoperatively according to severity.[6] Most reports indicate that 60% to 80% of the clubfeet treated surgically by a particular method resulted in excellent or good postoperative ratings within 2 years after initial treatment.[6] These data were obtained by comparing feet of dissimilar severity prior to treatment and arriving at an end-result rating without separating the feet into similar groups preoperatively. However, we have determined that accurate and consistent ratings are possible by pretreatment classification and evaluation (Figure 3.7).[6] The reasons for classifying true congenital clubfeet according to category and grade are as follows:

1. Feet of similar preoperative severity are graded against each other for postoperative results rather than being graded against feet of dissimilar severity in an entire series.
2. Surgical techniques may be planned and completed according to the preoperative severity evaluation and classification. The kind of surgical procedure and the extent of it will vary depending on the initial severity. Logical planning is possible before treatment begins.
3. The particular surgical technique selected is assessed in a more rational way as one technique may be necessary for a very severe teratologic foot and another may be desirable for correcting a mild deformity.[2,3,5,6]
4. Outcome studies based on severity, anatomical description, strength, and function 10 years or more after the treatment is completed will provide information about diagnosis and treatment that is desirable and applicable to the management of all congenital clubfeet (Figure 3.7).

Currently, most surgeons treating clubfeet do not use numerical or quantitative ratings.

Surgical planning and execution are somewhat haphazard. Thus, it is desirable to have a consistent method of physical examination with reproducible radiographs, and to designate this information in a numerical rating in order to plan surgical treatment and to compare end results (Figure 3.7).

Terminology

Recent and old publications show that the meaning of the terminology used by different authors varies. For this study, we have made certain assumptions. The term *clubfoot* refers to a foot with an appearance described as talipes equinovarus, but without differentiating static from dynamic deformity. Thus, the cause and severity of the apparent deformity vary considerably.

For example, a *positional clubfoot* may be manipulated to a physiological appearance with the head of the talus covered completely, the forefoot in a neutral position relative to the foot and ankle, and the hindfoot elevated to at least a right angle with the tibia. When the examiner releases this foot, it springs back to the clubfoot equinovarus position. The collagen of this positional foot has minimal or no abnormality; there is no deformity of the talus, and the muscle-tendon units are physiological in length and tension. However, because of the prolonged, inverted in-utero position of the foot, the peroneal muscles show less active contractions than do the invertor muscles immediately after birth of the infant. Positional feet are realigned by nonoperative treatment because the condition of the foot is due to intrauterine position and not due to a limb bud deficiency.[3,4]

A *true clubfoot* (CTEV) is the result of a limb bud deficiency with certain anatomical characteristics that vary according to the severity of the foot (Figure 3.9). For example, a segment of the spectrum from a positional clubfoot grade 0 to a true clubfoot grade 1 is very small. However, even this differential may require several weeks of cast or splint treatment before the final result is determined (Figure 3.10C). We assume, however, that the "true clubfoot" shows capsular contractures, less collagen elasticity, and less muscle-tendon excursion of the posterior and medial muscle-tendon units than exist in the positional foot. Also, the true clubfoot shows recognizable differences in cartilage contour, bone shape, and other anatomical characteristics when compared to the positional or physiological foot. The severity of deformity varies from minimal (1 to 10) to very severe (51 to 60).[2–6]

Teratogenic clubfoot is a term reserved for those feet associated with eponym syndromes in patients who have multiple congenital deformities that frequently include talipes equinovarus. These feet are usually equivalent to, or more severe than, the most severe idiopathic clubfeet (60/60)(Figures 3.10B and 3.12).

Idiopathic congenital talipes equinovarus (CTEV) refers to the foot arising from a limb bud deficiency that usually shows calf atrophy, abnormal skin creases about the foot and ankle, collagen with diminished elasticity, muscle-tendon units with limited excursion, abnormal tendon insertions, abnormally shaped tarsal bones, and localized areas of cartilage compression due to malposition of the foot segments (Figures 3.11A,B). Also, the tarsal navicular is displaced medially, the tibial navicular interval is less than normal, and the talus shows varying degrees of malformation. Furthermore, the forefoot, hindfoot, and the midfoot are malaligned with the ankle joint (Figure 3.13). The degree of both equinus and cavus deformities varies from minimal to severe. Many of these anatomical characteristics are obvious on pretreatment dynamic roentgenograms (Figure 3.14).

Pretreatment hand-held dynamic roentgenograms are essential to produce both an accurate diagnosis and a treatment plan. For investigational purposes, three-dimensional imaging is desirable. Multiple plane dynamic roentgenograms will provide helpful information about the severity of the deformity, but these are necessarily correlated in three-dimensions before they are meaningful (Figure 3.14).

Classifications

Categories of Clubfeet Based on Causation

Clubfeet may be separated into designated categories depending on causation. These categories are (a) *positional* feet associated with a compact uterus; (b) *idiopathic* feet due to



A

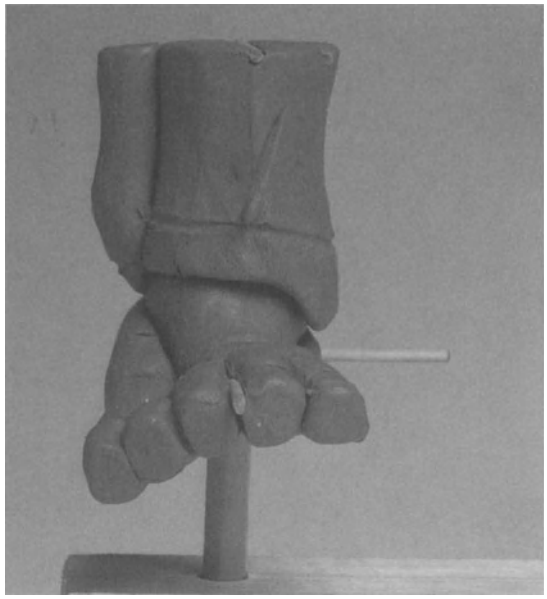


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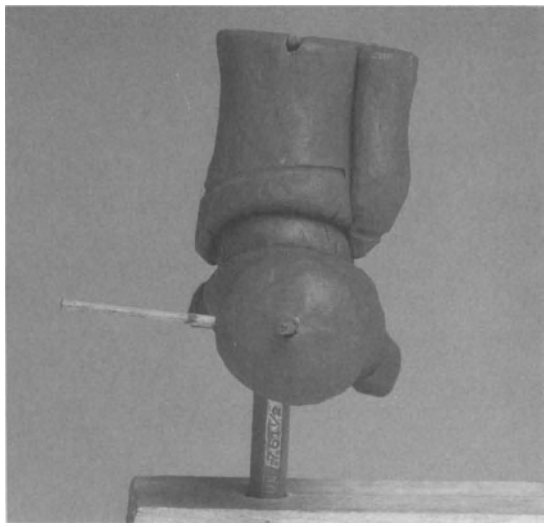


B

FIGURE 3.10. A: Clubfoot roentgenograms. This is an anteroposterior projection of a severe idiopathic clubfoot (50/60). The metatarsals are directed medially and the entire foot is in equinus. The calcaneus is tilted medially and the tibiocalcaneal articulations are oblique. The talus demonstrates a combination of equinus and eversion. On the point system, this foot has a weighted value rating of 9 points. B: A stillborn congenital clubfoot prior to dissection. Note the posteriorly displaced fibula; the body of the talus is in equinus and partially displaced forward in the ankle joint; the calcaneus is in equinus—it is also inverted and the distal segment is directed medially. The adducted forefoot is severely supinated. Incisional elongation of soft tissues on the medial aspect of the foot and ankle realigned the talus and calcaneus with the ankle joint and the forefoot with the midfoot without extensive subtalar arthrotomy. C: Postoperative clubfoot roentgenogram. This roentgenogram of the ankle and subtalar joint is obtained by an anteroposterior projection of the ankle. A "four-quadrant" release has



D



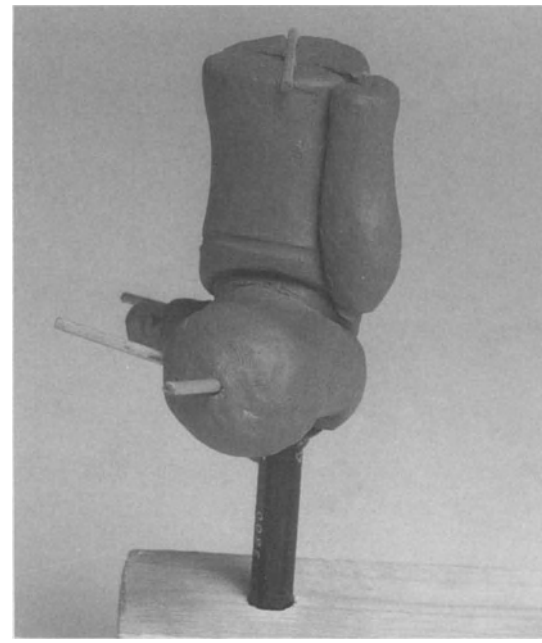
E FIGURE 3.10 (cont.)

been performed to correct a severe clubfoot (50/60). Minimal subtalar arthrotomy was performed. Note the realignment of the calcaneus with the talus even though extensive arthrotomy of the subtalar joint was not performed. D: This is a clay model of a physiological foot of an infant. The bimalleolar axis passes between the tip of the fibula and the medial malleolus. The anteroposterior axis passes through the talar head and neck and is represented by pegs on the superior and anterior surfaces of the tibia. The peg between the second and third digits is an extension of the axis through the neck and head of the talus and the navicular. The peg at right angles to the foot through a horizontal axis in the posterior calcaneus indicates the relationship between the calcaneus and the tibia. In this position there is no equinus. As equinus occurs, the peg moves superiorly. E: Posterior view of a composite clay model of a physiological infant based on several stillborn and surgical dissections. Note the peg that coincides with the posteroanterior axis around which inversion and eversion movements of the calcaneus and talus occur. The peg at right angles to the calcaneus represents a horizontal axis. This elevates with plantar flexion of the foot and depresses with dorsiflexion. The posterior body of the talus is apparent as is the relationship of the fibula to the tibia, the talus, and the calcaneus. This model shows the usual spectrum of anatomical findings in the physiological foot. F: This clay model is a composite reproduction of the uncorrected anatomical findings seen not only during operations on idiopathic clubfeet, but also from stillborn dissections. These feet were given a severity rating of 20–40 points (moderate severity) prior to surgical treatment. The axis of the head and neck of the talus is represented by the peg just proximal to the epiphyseal plate of the tibia, by the peg between the first and second metatarsals, and by pegs embedded superiorly in the tibia in line with the axis of the head of the talus. The body of the talus, although partially uncovered laterally because of equinus and inversion, is *internally rotated relative to the bimalleolar axis*. The anteroposterior axis of the body of the talus is directed medially relative to the bimalleolar axis; the horizontal axis through the body of the talus is also directed medially relative to the bimalleolar axis. The body of the talus, however, is uncovered laterally relative to the position of the navicular, the tarsals, and the metatarsals, but is directed medially relative to the bimalleolar axis. Some investigators do not consider both of these factors in designating position and, for that reason, the talus has been designated as facing laterally by them. Our observations have been, as these models show, that the position of the body of the talus relative to the bimalleolar axis is inverted, in equinus, and rotated medially to a greater degree than occurs in the physiological reproduction. G: This posterior view of a clay model is a composite of idiopathic congenital clubfeet with a severity rating of 20–40 points. The distal calcaneus is in moderate equinus, inverted, and is rotated medially with the attached forefoot bones, whereas the posterior lateral aspect of the calcaneus is rotated toward the fibula. The fibula is displaced posteriorly relative to the medial malleolus, and the superior peg on the tibia designates the direction of

the posteroanterior axis of the neck and head of the talus. This axis indicates that the talus is directed medially relative to the bimalleolar axis. The combined equinus, inversion, and internal rotation of the distal calcaneus, and the posterior placement of the fibula, result in altered relationships between the fibula and the calcaneus when one compares Figure 3.13B with Figure 3.9B. The lateral convex curvature of the calcaneus increases as the severity of deformity increases. H: This clay model is a composite of several idiopathic-teratologic congenital clubfeet with a severity rating of 50–60 points. A line bisecting the bimalleolar axis is directed laterally, but the entire talus is in equinus, inverted, and rotated medially. The navicular is touching the medial malleolus and is displaced medially and plantarward on the head of the talus. The peg between the first and second metatarsals represents the central axis of the navicular. The peg on the superior aspect of the flat surface of the diaphysis of the tibia is in line with the head of the talus which is curved medially; the peg projecting from the tibial epiphyseal plate anteriorly represents the anteroposterior axis of the body relative to the bimalleolar axis. The peg in the medial epiphysis of the tibia illustrates how close the navicular is to the medial malleolus. The most posterior peg is in the posterior calcaneus in an anteroposterior axis and, although it is visible medially, the calcaneus is closer to the posteriorly displaced fibula than it is in less severe feet. Note that the lateral articular surface of the body and the head of the talus are *uncovered* laterally but both are directed medially relative to the bisector of the bimalleolar axis. Furthermore, in order to clarify the direction in which the talus is pointing and how it is rotated, observe that the body and head of the talus are rotated medially to the bisector of the bimalleolar axis but are located relatively lateral to the medially displaced forefoot. In summary, the talus is medial to the bisector of the laterally directed bimalleolar axis, but lateral to the medially displaced forefoot. From a practical standpoint, the talus must be everted, externally rotated, and dorsiflexed in order to align the talus with the bimalleolar axis. Also, if the malrotation of the foot is not corrected by externally rotating the distal segment of the calcaneus (internally rotating the proximal calcaneus through the subtalar joint during surgical correction of severe feet), then an option is to perform a supramalleolar external rotary osteotomy of only the tibia in order to align the tibia, talus, and the calcaneus with the externally directed bimalleolar axis of the tibia and fibula. I: A posterior view of a composite of several clubfeet with severity ratings of 50–60 points. The fibula is posterior to the tibia, resulting

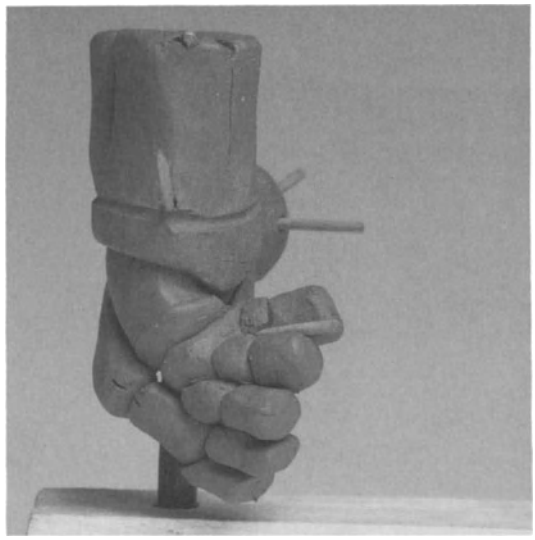


F



G

in the bimalleolar axis between the tibia and the fibula being lateral to the position noted in a normal foot (Figure 3.9A,B). The peg on the superior flat surface of the tibia is in line with the posteroanterior axis of the head and neck of the talus and bisects the bimalleolar axis between the tibia and the fibula at a 30° angle. As the fibula is displaced posteriorly, the bimalleolar axis faces more laterally, the body of the talus becomes more uncovered and prominent laterally, but the posteroanterior axis rotates medially

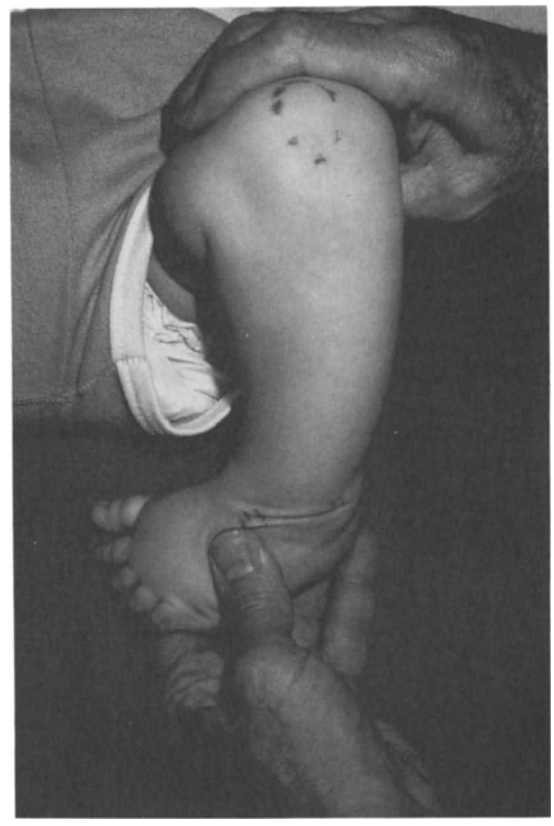


H



I FIGURE 3.10 (cont.)

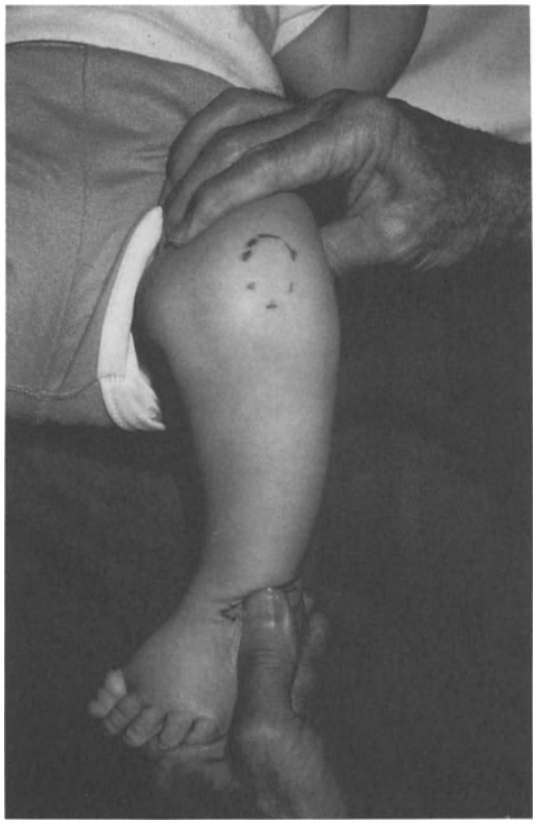
when compared with the physiological position noted in Figure 3.9A and the pathological position seen in Figure 3.13A. During a surgical correction a deformed talus should be externally rotated, everted, and dorsiflexed in order to eliminate the impingement of the neck of the talus on the medial malleolus as dorsiflexion occurs. This requires release of the deep fibers of the deltoid ligament and external rotation of the body of the talus in the ankle joint.



A

FIGURE 3.11. Knee Joint measurements in a patient with a clubfoot. A: This demonstrates complete internal rotation of the knee joint between the tibia and the femur. The femur is stabilized, the tibia is flexed 90°, and the tibia and fibula are internally rotated. The direction is approximately 70°. This rotary motion between the tibia-fibula and femur demonstrates the elasticity of the cruciate ligaments and the mobility of the menisci. In this internally rotated position, the distal fibula has moved anteriorly and the medial malleolus posteriorly. B: The foot and leg are externally rotated at the knee joint but a neutral position is not possible. The relationship between the tibial tubercle, the distal fibula, and the medial malleolus remain the same, indicating that true tibial torsion *is not* present, but abnormal rotary motion at the knee joint, ankle joint, and foot are the causes of the persistent deformity.

a limb bud deficiency of varying degrees of severity of undetermined cause; (c) *neurogenic* feet occurring in patients with myelodysplasia, peripheral nerve agenesis, hypogenesis, or arthrogryposis; (d) *myopathic* conditions



B

FIGURE 3.11 (cont.)

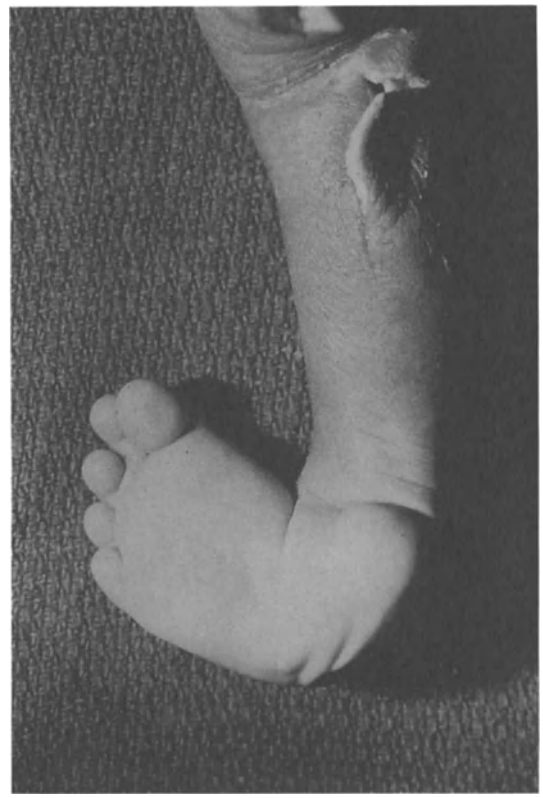
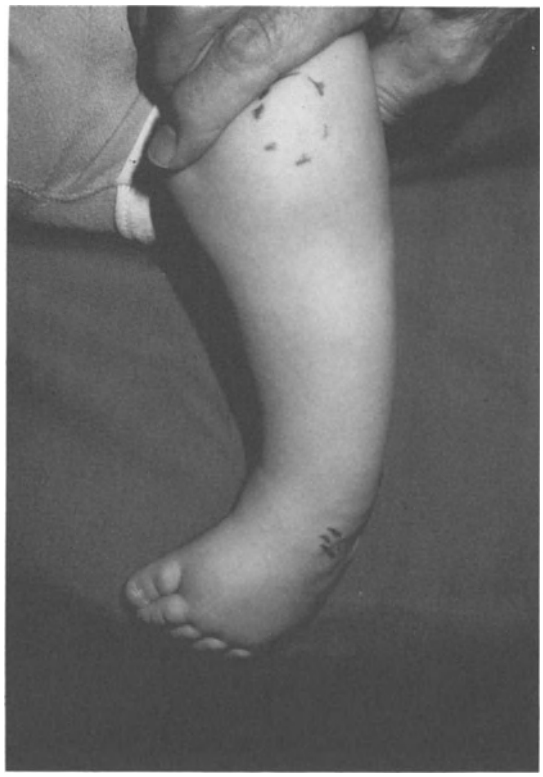


FIGURE 3.12. Clubfoot stillborn dissection. A plantar view of an idiopathic congenital clubfoot grade 60/60. Note the segmental deformity at the ankle and midtarsal joints. The distal segments of the talocalcaneal complex are directed medially and inverted, in addition to being in equinus. The forefoot is at right angles to the hindfoot and a deep medial crease accentuates the midtarsal deformity. The rating of this foot based on the definitions in Figure 3.8 is *very severe* (60/60).

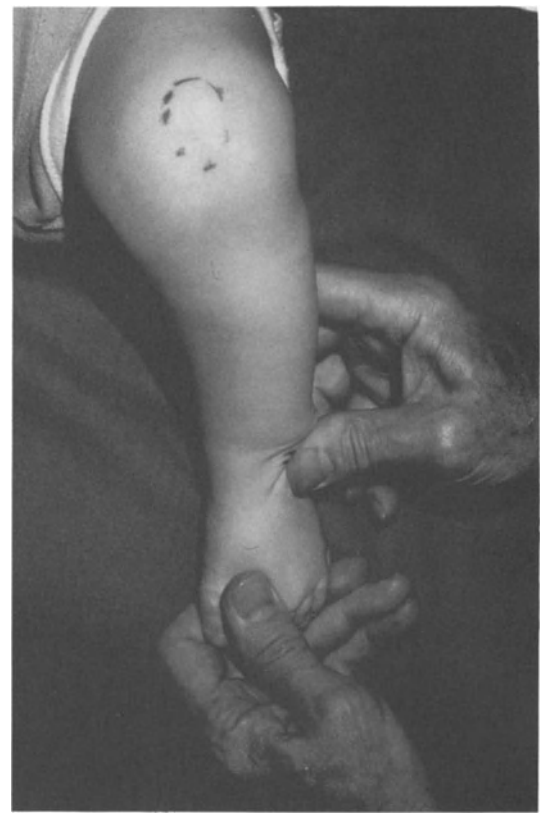
associated with clubfeet; and (e) *teratologic* feet resulting from limb bud deficiencies usually in conjunction with several other congenital deformities.

Evaluation of Clubfeet by Grades of Severity

The clubfoot *grade* is a specific description of the severity of the foot within a particular *category*. The grade or rating is designated as minimal, mild, moderate, severe, or very severe (Table 3.18). In this system, the severity is designated by both a descriptive adjective and a numeral. For example, a grade 41 to 50/60 severe clubfoot designates the grading but not the category. The latter would be specified as idiopathic, neurogenic, myopathic, or teratologic. The tissue characteristics of the feet, the joint mobility, and the specific deformities are usually comparable in all categories. The key part of the examination that indicates mobility, severity, and serves as a treatment guide, as well as providing a reasonable prognosis, is the degree of uncoverage and coverage (U/C) of the head of the talus as determined during a clinical evaluation (Table 3.19). This clinical anatomical observation is not only an indirect reflection of subtalar motion, the tibial navicular interval, and the static alterations that exist at the calcaneocuboid and midtarsal joints, but also reveals the severity of static equinus and varus. These relationships provide both a direct and indirect estimate of the degree of both subtalar movement and midfoot motion.



A



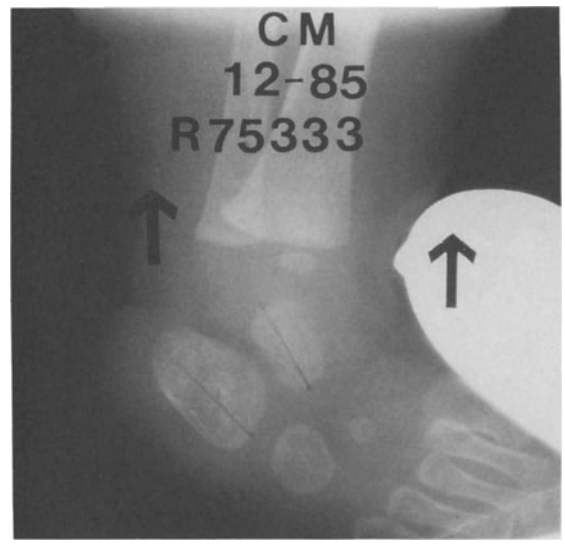
B

FIGURE 3.13. A: Congenital clubfoot with excessive internal rotation of the knee joint. This extremity is in a relaxed position affected only by gravity. The circle is over the patella, and the tibial tubercle is directed medially. The markings on the lateral side of the foot are over the sinus tarsi and the head of the talus. This position of the foot demonstrates the uncovered head of the talus which can be outlined by palpation. The numerical severity of this foot is determined by dynamic clinical examination and roentgenograms. B: The tibia and foot have been externally rotated. The tibia does not reach a neutral position, and the head of the talus is only partially covered. This limited covering of the talar is reflected in the severity rating. The incomplete external rotation of the tibia would account for a persistent toe-in guit.

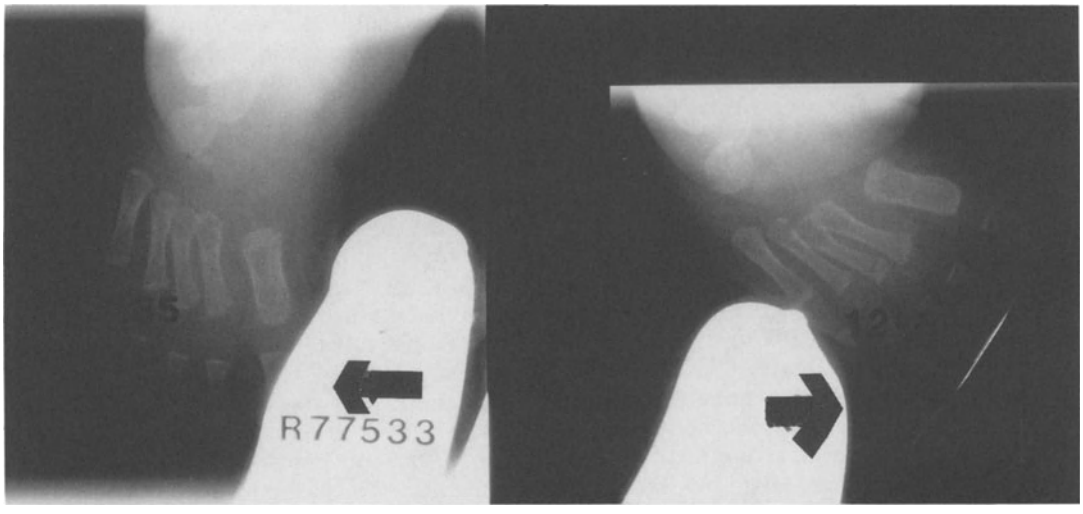
FIGURE 3.14. *A lateral dynamic plantar flexion–dorsiflexion roentgenogram of a preoperative clubfoot.* A: The relationship of the distal fibula to the posterior cortex of the tibia indicates a true lateral projection. The talus is in 75° equinus and the calcaneus and the cuboid are in 48° equinus relative to the tibia. The ossific nucleus of the tarsal navicular has not appeared, and that of the third cuneiform is small. The ossification centers of the other cuneiforms are not visible. The lateral talocalcaneal angle is 45°. The distance between the ossific nuclei of the talus and the calcaneus is 9 mm in equinus. B: This roentgenogram was taken with the foot in forced dorsiflexion. The relationship between the talus and the calcaneus diminished to 3 mm, indicating that motion in the subtalar joint is present prior to treatment. The metatarsals are displaced upward more than the cuboid, indicating a greater range of motion present in the metatarsotarsal joints than in the intertarsal joints. C: Dynanic roentgenograms of the forefoot in abduction and adduction. These dynamic roentgenograms shows relative mobility of



A



B



C

the ossific nucleus of the cuboid, the metatarsals, and the calcaneus and their relationship to each other. The abduction stress roentgenogram on the right shows the fourth metatarsal opposite the cuboid; the adduction stress roentgenogram on the left shows the fifth metatarsal aligned with the cuboid and the calcaneus. These findings suggest that limited midfoot-hindfoot motion is present with more tarsal metatarsal motion occurring than midfoot motion.

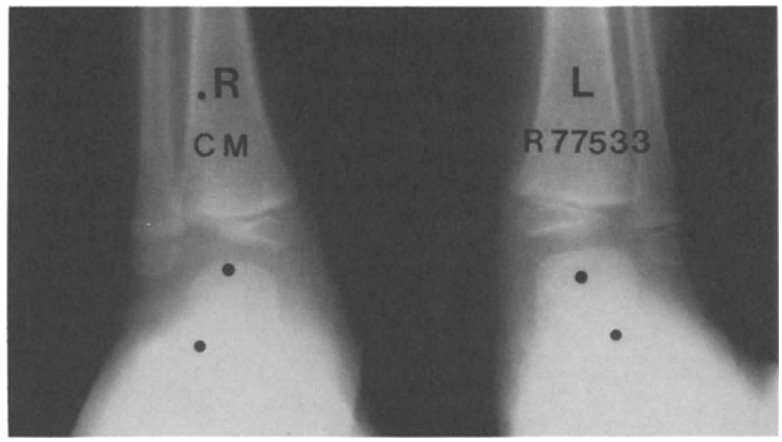


FIGURE 3.15. Standing anteroposterior comparative roentgenogram (clubfoot on right, normal foot on left). This standing anteroposterior projection of the ankle joint, the talus, and the calcaneus with dots on the patient's right show the calcaneus to be more prominent on the patient's normal side than on the clubfoot right side. Also, the right distal tibial epiphysis is small, compressed laterally, and shows delayed ossification of the lateral plafond. The right distal fibular physis is higher than the left. A standing overexposed projection provides an accurate relationship between the tibia, talus, and the calcaneus. As the child grows and develops, this particular projection is used to monitor the valgus position. The site of valgus position should be designated as ankle, subtalar, or midtarsal, or a combination of these. These radiographs show a physiological valgus of the left subtalar region and a 2° tibiotalar valgus on the right.

The fact that the head of the talus may be partially uncovered and covered by manual manipulation prior to treatment indicates that a certain degree of midtarsal and subtalar motion exists prior to cast or surgical treatment. For example, in the mild foot, this degree of potential or actual intrinsic movement is greater than that existing in the severe foot. *Stillborn clubfoot dissections have shown that significant correction of the deformity is possible by release of the extrinsic ligament and tendon contractures without extensive subtalar arthrotomy* (Figures 3.10B and 3.12).[4,8] For example, subcutaneous tenotomy of the heel cord, a procedure that was frequently recommended several years ago, resulted in improvement of foot position through the subtalar joint without significantly altering tibial talar motion. Foot position was changed and the motion in certain joints increased after the extrinsic soft tissues were surgically elongated. Furthermore, the severity of the deformity and the amount of immediate pretreatment correction are dependent on the severity of the capsular and muscle-tendon shortening; this momentary correction is an indirect index of the degree of correction that will eventually be obtained by permanently elongating any contracted collagen. Elongation of tendons and extrinsic collagen contractures will result in increased joint motion to the degree that the potential movement is dynamic and not rigidly fixed by capsular contracture. The static deformity caused by severe capsular contractures requires intrinsic arthrotomy. For example, correction of the medially displaced navicular on the talus requires lengthening of the posterior tibial tendon and release of the tibiotalonavicular ligaments. Immediately after the tendon is lengthened, the navicular may be partially corrected and be moved laterally a few millimeters; but not until the tibiotalonavicular ligaments are incised and the lateral structures released between talus, navicular, and calcaneus will a satisfactory realignment be achieved between the navicular and the head of the talus. This conclusion is based on the senior author's (J.L.G.) observations in over 500 clubfeet in which capsular contracture and tendon shortening were present. The extrin-

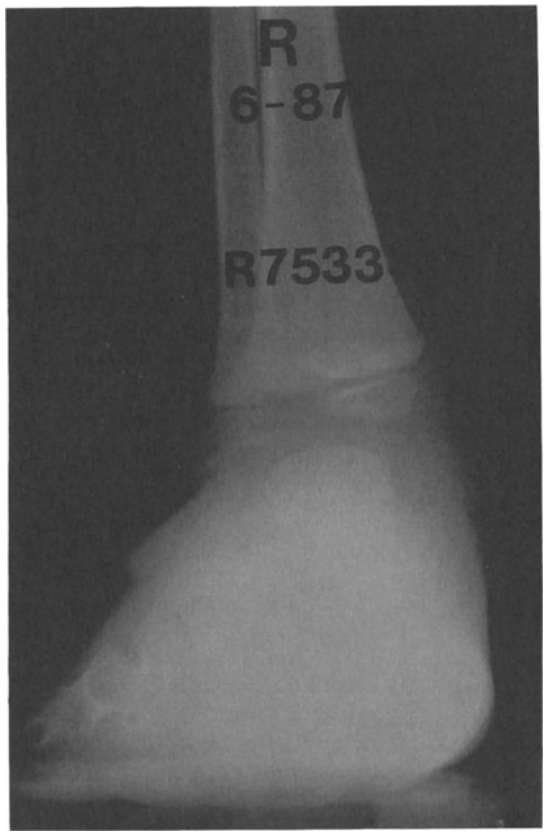


FIGURE 3.16. Clubfoot roentgenogram—postoperative. This is a standing anteroposterior projection of the right ankle joint showing the tibiotalo-calcaneo tier 2 years after a four-quadrant correction with minimal subtalar arthrotomy. The lateral plafond of the tibia is not ossified; the talus is congruent with the tibia and fibula; the calcaneus is lateral to the talus; and the distal fibular physis is 2 mm higher on the right than on the left. The relationship between the talus and the calcaneus is neutral. (Compare this with Figure 3.10A).

sic deformity was caused by the tendons and the intrinsic deformity was caused by the capsular contractures.

Steps in Numerical Grading

The newborn foot is assessed first by measuring the rotational status of the hip joints (anteversion); next by measuring the degree of internal and external rotation of the tibiofemoral joint (Figure 3.12); and next by defining the degree of equinus, inversion, and internal rotation of the foot relative to the ankle mortise and the tibial tubercle (Figure 3.13). Also, the degree of coverage of the head of the talus is determined by adduction-inversion of the forefoot. This is then compared to abduction-eversion–external rotation and dorsiflexion of the forefoot and hindfoot. The percentage of uncovering and covering (U/C) of the head of the talus provides an accurate index of subtalar-midtarsal motion prior to nonoperative or operative treatment. Figure 3.7 shows the numerical and descriptive terms that provide a rating for each clubfoot. The initial rating is performed prior to the primary plaster treatment, repeated after plaster treatment and prior to surgical treatment, and the rating numbers are modified intraoperatively (Table 3.18). For example, the talonavicular interval may not be readily determined in a short, fat foot. This description necessitates direct observation at the time of operation. Additional grading is performed 3 months postoperatively, and annually until the child is 15 years of age.

Clinical examination is supplemented by dynamic roentgenographic examination (Figure 3.14). The positions are described under roentgenographic techniques. Also, as the child becomes older, functional daily activities are recorded, endurance is determined, and the patient is examined at regular intervals until final growth has been achieved.

Measurement of Uncovering and Covering of the Head of the Talus

The degree of uncovering/covering (U/C) of the talus estimated in percentages will establish a baseline for both flexibility and rigidity of the talonavicular and calcaneocuboid joints and provide information about talocalcaneal subtalar motion. A physiological flexible foot, for example, will show uncovering of the head of the talus of 90% and covering of 90% as well as inversion of the calcaneus through 20° and eversion through 20°. This indicates that midtarsal and subtalar motion are present and functional. A *relaxed flatfoot*, however, with the foot in persistent valgus during weight bearing will show uncovering of the head of the talus of 90% and covering of 120% (U90/C120). Conversely, a *severe rigid clubfoot* prior to treatment will show uncovering of the talar

head of 90% with static inversion of the calcaneus of 15° and dynamic covering of only 20% of the talar head with 5° of inversion of the calcaneus. This demonstrates that the head of the talus remains uncovered because of contractures of the posterior medial tendons and the tibionavicular and tibiotalar ligaments on the medial and plantar aspects of the foot and ankle. However, after improvement is obtained by surgical treatment, the sinus tarsi is deep, and the talar head uncovers only 10% on manipulation and covers 100% (U1O/C90). The heel adducts to only neutral and everts about 5°. Thus, this foot is in a functional weight-bearing valgus position with limited subtalar midtarsal motion.

Roentgenographic Examination of the Clubfoot

The roentgenogram shows the ossific nuclei of the distal tibia, the talus, the calcaneus, and the cuboid. Projections are made in plantar flexion and attempted dorsiflexion (Figure 3.15). Roentgenograms taken in the anteroposterior view of the ankle will show ossific nuclei of the medial malleolus, absence of ossification in the lateral plafond of the tibia, and incomplete ossification of the distal fibula. The tier affect of the talus on the calcaneus is evident from this projection (Figure 3.16).

Roentgenograms are taken in several positions[7]:

1. Lateral dorsiflexion–plantar flexion (DF–PF) of the entire foot and ankle under stress (Figure 3.14A,B);
2. Anteroposterior projection of the forefoot in forced abduction and adduction to show the degree of fixation of the cuboid relationship to the metatarsals and to the calcaneus (Figure 3.14C);
3. An anteroposterior projection of the ankle joint slightly overexposed that shows the talocalcaneal tier as well as the ankle joint (Figure 3.15C). Because of the varying degrees of fixed equinus, the ankle joint may be distorted. These dynamic projections are compared with the postoperative projections taken in a similar way.

The weighted values of the lateral DF-PF roentgenograms that show the tibial-talar-calcaneal-cuboid-metatarsal ossific nuclei, and the anteroposterior view of the ankle joint that shows the tibial-fibular-talar-calcaneal centers have received a weighted value of 9 points. These radiographs, in addition to the projections of the abducted-adducted forefoot, show the degree of fixation of the cuboid relative to the metatarsals (Figure 3.14C). This second radiographic projection also has been allotted a weighted value of 9 points.

Mobility of the Untreated Clubfoot

The percentage of uncovering and covering (U/C) of the head of the talus designates the combined motion of the talocalcaneal (subtalar), talonavicular, and calcaneocuboid joints. This is a combination assessment of the subtalar midtarsal joints, an index of mobility that is readily determined by clinical examination. *Roentgenograms alone will not replace the combined clinical and radiographic examination.* The examiner requires a brief learning period during which several patients are assessed and the results are compared with those of an experienced clinician who consistently is able to estimate the degree of uncovering and covering (U/C) of the talus and develop a specific ratio related to motion. The method of performing this examination and of arriving at these numerical values requires practice. One method of obtaining this information is described in the following section.

Examination of Subtalar-Midtarsal Motion

An analysis of subtalar-midtarsal motion is performed with the patient's knee flexed and the leg in a vertical position. The examiner manipulates the clubfoot so that it is moved from its most deformed static position through a range of motion to a position of maximum correction (Figure 3.14). In the deformed position, the foot is in plantar flexion, the navicular articulates with the anterior and medial aspect of the head of the talus, and the cuboid and calcaneus are inverted. The distal segments of these bones are directed medially (the designation consistent with anatomical terminology) (Figure 3.10). When the talus is in equinus,

and the forefoot is inverted, the proximal body of the talus is forced to tilt a varying amount within the ankle mortise (Figure 3.10A). These static positions show that the location of the talus varies according to the severity of the deformity. The body, the neck, and the head of the talus are inverted and the distal segment is rotated medially relative to the anterior tibial-fibular axis. However, the body of the talus when palpated is more prominent laterally relative to the medial position of the forefoot (Figures 3.14B,C).

In the clubfoot, the fibula is in a posterior position relative to the anterior position of the medial malleolus of the tibia. Thus, the ankle mortise is directed in a position corresponding with external tibial-fibular torsion (Figures 3.10B and 3.12). This means that a solid vertical plane passed through the medial and lateral malleoli is directed farther laterally than the usual 15° to 20° in the physiologicaL foot (Figures 3.9A, 3.10B, and 3.12).

For clarification, and to avoid confusion about the position of the talus and the calcaneus in the ankle mortise of the clubfoot, the anatomical designation of the location, position, and movement of the *distal end* of the segment under discussion is always used. The body of the talus is uncovered laterally and this uncovering has resulted in other investigators stating that the talus is lateral in the ankle mortise, but this is only in appearance whereas actually it is medial relative to the bisector of the bimalleolar axis.

Thus, different investigators applying the anatomical terminology in different ways have caused confusion about the relative positions of the bimalleolar axis, the body of the talus versus the entire talus, and the relationship of the talus to the malleoli and to the midtarsal bones. These investigators have attempted to define their method of surgical treatment by describing the way the calcaneus, the talus, and the forefoot are realigned. For example, the hindfoot has been described as being realigned by internal rotation of the calcaneus (medial spin), whereas the anatomical designation would be to specify that the distal end of the calcaneus is rotated laterally. If complete subtalar arthrotomy is performed, the movement of the calcaneus may be separate from that of the talus. However, with limited or no subtalar arthrotomy, as we have managed clubfeet, the realignment of the calcaneus and the talus in the ankle mortise is one of the important aspects of the surgical treatment. Thus, both move together with the distal segments being realigned toward the lateral side of the bimalleolar axis, and the posterior aspects, including the body of the talus and the calcaneus, are rotated medially. At the present time, there is no consensus about which joints, i.e., subtalar or ankle or both, are the ideal locations for maximum hindfoot correction (Figures 3.10C–I and 3.16).

Our investigations show that the equinus inverted position occurs both at the tibial talar and talocalcaneal as well as the midtarsal joints (Figures 3.10 and 3.15). Specifically, the calcaneus is in equinus, and the distal end is rotated and directed medially because it moves with the talus; the posterior prominence of the calcaneus necessarily is displaced laterally adjacent to the fibula as this occurs while the distal segments of the talus and the calcaneus tilt and rotate medially (Figure 3.10D,E).

Our stillborn dissecticns and clinical observations have been documented by clinical photographs, radiographs, and photographs during operative procedures that confirm these opinions, i.e., that the talus, the calcaneus, the navicular, and the cuneiform bones are displaced in three dimensions and move contemporaneously in three different axes. Those axes are (a) vertical through the tibia, talus, and calcaneus around which medial and lateral rotation occurs; (b) horizontal around the malleoli and talus around which dorsiflexion and plantar flexion occur (at both the subtalar and tibiotalar joints); (c) an anteroposterior axis around which inversion and eversion occur primarily at the subtalar joint and minimally at the ankle joint (Figure 3.10).

Clubfoot Rating Objectives

The clinical ratings plus the roentgenographic information are included in a weighted value designation (Figure 3.7) that varies according to the severity cf the foot deformity. Anatomical and pathological conditions considered in grading the feet are as follows:

1. collagen elasticity that is determined by preoperative examination with the U/C ratio and by examining the elasticity during the operative procedure;

2. muscle excursion as it is determined intraoperatively and muscle function as it is detected both preoperatively and postoperatively by plantar stimulation of the foot;
3. the contour of the talus as it is determined intraoperatively;
4. lateral impingement as it is determined by direct examination of the calcaneocuboid joint;
5. the relationship of the navicular to the beak of the calcaneus and the third cuneiform;
6. the degree of plantar contracture, as this is important in preventing recurrence; equinus and inversion of the forefoot affect the hindfoot as the child grows;
7. the rotary components of the knee, ankle, and foot assist in determining if external rotary osteotomy of the tibia is necessary to diminish or eliminate persistent toe-in gait after 1 or 2 years of weight-bearing after the primary foot surgery.

If the examiner follows this pattern of assessment, the examination will be thorough, the pathological lesion adequately described, and both students and peers will have a clear understanding of the pathological process. Methods of obtaining a rating and of assessing results based on the ratings are illustrated in Figure 3.8.

Composite Rating Table and Results of a Prospective Study of 100 Patients

One hundred patients with clubfeet were the basis of a prospective study that consisted of a preoperative, combined clinical and roentgenographic classification based on a specific category and a grade of severity designated for each foot. Ninety of the feet were idiopathic and 10 were either very severe or teratologic. This method of study provided a consistent pretreatment designation of the feet, an additional presurgical rating after plaster treatment, and a final follow-up rating after treatment was completed.

The prospective study of 100 infants with idiopathic congenital clubfeet included a protocol that was rigidly and consistently followed. Certain assumptions and prerequisites were made prior to initiating the study and certain prerequisites were required before surgical treatment was initiated. All feet were operated on by the "four-quadrant" approach through medial and lateral incisions. The classification was based on separating positional from "true" clubfeet. *Positional feet* were considered as an extension of intrauterine position without limb bud deficiency and all were treated by Kite plaster techniques. All feet had pretreatment radiographs to document the clinical examination. Radiographs were repeated before initiating surgery. No foot was operated upon that could be realigned (by nonoperative methods) in such a way that all major deformities were eliminated. In these nonoperated feet, the sinus tarsi was deep, dorsiflexion at the ankle joint was at least 10° above the right angle and 80% uncovering of the head of the talus could be demonstrated with at least 90% covering of the talar head with the forefoot in neutral position. Furthermore, the feet that were considered to be positional and treated in plaster only were followed for 10 years with no evidence of recurrent clubfoot deformity. Occasionally these patients showed a congenitally short heel cord that required stretching casts during a rapid growth period, but there were no radiographic or clinical indications that this was a true clubfoot.

True Clubfeet

The feet that were classified in the 1 to 20 category were considered as true clubfeet with minimal or mild deformity, which usually included moderate contracture of the posterior capsule and the triceps surae, contractures of the posterior tibial and toe flexor muscles, medial displacement of the navicular to a moderate degree, contracture of the superficial fibers of the deltoid ligament, minimal cavus, minimal contracture of the anterior tibial muscle, and uncovering of the head of the talus of almost 75% and covering of about 70%. Major deformity was usually posterior contracture detected with the knee straight, the heel inverted, and 10° to 20° of fixed equinus with passive dorsiflexion.

The radiographs in this grade of severity always showed incomplete dorsiflexion of the talus and the calcaneus with attempted forced dorsiflexion with the foot inverted, and the appearance of a grade 1 rocker-bottom or subluxation of the calcaneocuboid joint with forced dorsiflexion with the foot everted. This implied that subtalar motion was present but tibiotalocalcaneal contracture prevented full

dorsiflexion of the calcaneus and the talus in conjunction with the contracture of the triceps surae. Nonoperative treatment in these patients showed persistent noncorrection.

The feet graded from 1 to 40 responded to the "four-quadrant" approach with limited degrees of surgery in each area with minimal or no subtalar arthrotomy and excellent correction.

Those patients who rated from 40 to 50 required more extensive procedures that took a longer time to perform, and because of the articular alterations and the collagen index, a greater percentage of recurrence existed.

The feet that were graded from 50 to 60 responded best to earlier surgery (age 3 to 4 months) and complete "four-quadrant" release with limited subtalar arthrotomy usually involving the posterior talocalcaneal capsule and the anterior talocalcaneal facet capsule.

Sixty-five of the patients were in the severe category with a rating greater than 40 points (Figure 3.8); the other 35 patients were in the minimal to moderate grades (20 to 40). The results were consistently better in the minimal, mild, and moderate feet than in the severe and very severe feet. *The higher the numerical ratings, the greater was the recurrence rate.* For example, of the seven feet graded as minimal (1 to 10) severity, all were considered good to excellent with a single, limited "four-quadrant" approach. The same was true for the eight feet graded as mild (medium) with a numerical rating of 11 to 20. The 20 feet rated moderate (21 to 40) showed a 90% satisfactory result with two requiring an additional surgical treatment to provide a maximum end result. Of the 45 patients rated as severe (41 to 50), 36 patients (80%) were satisfactory and required no additional surgical treatment, but 9 patients (20%) required additional operations for a maximum end result. Finally, of the 20 patients in the very severe grade (50 to 60+), 12 (60%) were considered as satisfactory and 8 (40%) required additional surgery to correct recurrent or residual deformities (Figure 3.8).

All of the 100 feet were graded as satisfactory by the time the patients were age 15 by assessing function, pain, and conventional shoes as the baseline for that definition. However, the patients in the minimal, mild, and moderate grades had fewer operative procedures and less overall limitation than did those feet in the severe and very severe categories. The latter required the greatest number of operative procedures, had some degree of functional impairment in a greater number of activities, and were overall less satisfactory that those feet in the lower grades.

From a demographic standpoint, for any series or geographic region, the greater the number of minimal, mild, and moderate feet, the better will be the end results. If the specific series being studied contains a large number of feet graded as severe and very severe, the results will be less satisfactory both anatomically and functionally, and the number of surgical procedures required to reach a maximal end result will be greater than for the series with less severe foot involvement.

The methods of surgical treatment selected will affect the end results. This is particularly true in those feet in the severe and very severe groups. For example, if the entire deltoid ligament is not released and repaired in a severe or very severe foot, or if maximum correction of dorsiflexion and rotation is attempted primarily in the subtalar joint, rather than obtaining full correction of the ankle joint, valgus overcorrection is probable and the range of dorsiflexion in the ankle joint will be severely limited.

This study has indicated that from the perspective of surgical treatment there are two major divisions of idiopathic clubfeet: those in the minimal, mild, and moderate division, and those in the severe and very severe group. The less severe group usually responds to surgical techniques that elongate the shortened extrinsic structures and release certain critical joint contractures (Table 3.18). Realignment of the foot, ankle, and knee are usually not difficult. *Subtalar arthrotomy is usually unnecessary* in correcting these feet. In the more severe group, however, extensive release of the subtalar joint has been avoided with corrective efforts directed toward the ankle joint, release of extrinsic contractures, and realignment of the foot and ankle with the knee joint and femur by supramalleolar osteotomy of the tibia alone (i.e., not the fibula) if necessary.

Growth and development affect the end results in both groups. However, temporary changes in the less severe group such as contracture of the heel cord during a growth spurt are easier to manage by nonoperative treatment in the group with lesser deformity than when similar changes occur in the less elastic tissue of the more severe group. The final goal

of an evaluation, however, is to plan surgical treatment in feet of similar severity, to compare end results of feet of similar severity in order to plan logical surgical treatment, to determine the results of different forms of treatment, and to provide an accurate prognosis for the treatment of all clubfeet.

Details of the Prospective Study of Idiopathic Clubfeet 1980–1984

During the years 1980 to 1984, 100 feet were examined and graded prior to treatment of any kind, and reexamined presurgically, intraoperatively, and again 6 months postoperatively. Subsequent annual examinations were performed to provide consecutive numerical ratings. The feet were assessed by the principal investigator, other cooperative staff surgeons, and senior and junior residents. This distribution of examinations provided a pattern of accuracy for the investigators who were involved for only a short time (Figure 3.7 and Table 3.18).

Results of the Numerical Grading Project

The accuracy of the grading depended on the clinician's experience. The greater the number of patients examined, the more consistent were the ratings. The average number of patients examined by residents for comparative grading was three. The cooperating senior clinicians averaged eight. The principal investigator (J.L.G.) examined all of the feet in the study. The experienced investigators showed a plus or minus 10% grading for the mild, moderate, and severe feet. The senior residents, however, showed a plus or minus variation of 15%; the junior residents had a plus or minus variation of 20%.

Conclusions Concerning Another Group of 100 Feet Followed for 15 Years Comparing the Original Grading and the End Results (Figure 3.8)

Another group of 100 patients followed for 15 years was divided into the groups based on the numerical grading. Thirty-five feet were in the minimal to moderate grades from 1 to 39 points. Of these patients, 31 (89%) were in the excellent or good categories. The remaining four patients were in a good or fair category but all were functionally acceptable. An additional surgical procedure converted these four patients to a good rating.

Of the 65 patients in the 50 to 60 category, 9 of the 50 (18%) and 18 of the 60 (30%) were unsatisfactory at some time during their treatment and required secondary surgical procedures to convert them to a satisfactory result. Twenty-seven of 65 patients required at least one additional operation and 13 of these required a third operation before they reached maturity and a final functional result.

Classification and Evaluation Related to Outcome Studies—12 Years

Since 1950, the plan was to follow as many patients as possible on an annual basis until at least age 15 and as many patients as possible through their entire adulthood. An effort was made to examine each clubfoot annually to determine function, pain, activities of daily living, and to document these observations by roentgenograms on an annual basis until age 15 and at 5 year intervals after that age.

Feet of similar severity were graded and compared with each other and different sets of feet of different severity were compared. Alterations in prospective study techniques were made as necessary.

Recurrence or progression of deformity was managed by following an algorithm that progressed from initial operative treatment based on severity to either nonoperative or operative treatment for recurrence. The feet in the minimal and mild categories usually required no secondary surgical procedures; those feet graded as moderate required occasional secondary surgical procedures; the feet in the severe and very severe categories showed a high incidence of secondary and tertiary surgical procedures before an acceptable end result was reached.

The value of the classification and evaluation was documented by the outcome study. This study showed that the grading of the feet was valuable to allow comparison between the right and left feet in the same patient. Furthermore, with this kind of rating, it was easier to compare feet in other patients treated by the same

surgical technique, and also to compare the feet in other series treated by different surgical techniques.

The postoperative management may vary according to the severity of the foot. In the mild foot, there is less need for frequent cast changes and additional attempts at collagen stretching after surgery. Total cast time is usually less than in the severe foot. Also, the initiation of active and passive motion are usually delayed in the severe foot because the static deformity requires a longer time in a cast in a corrected position postoperatively.

Finally, the duration of night splints used for the prevention of recurrence of deformity after surgical treatment was much longer in the severe feet as compared to the relatively short period of time that night splints were used in the mild feet.

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Discussion

Barnett (Minneapolis): On the Intraoperative Evaluation Form Checklist (included earlier in chapter), which I have made, I simply check what I've done. This form allows me to do two things. First, if one of my colleagues does an operation and makes out that list, it can be put into the computer very easily. Second, when I see the patient in the clinic or in the office, I can look at that and know in a few seconds what operation was done.

We also use a postoperative evaluation checklist that was developed by Dr. Stark. We use it to record function and clinical measurements, e.g., the foot progression angle, the bimalleolar axis, motion, etc. We try to rate pain, which is very difficult to do, in my judgment. On the x-rays, we try to correlate AP and lateral talocalcaneal angles, as well as the sustentacular overlap with the talus and the calcaneal beak overlap with the talus. This also fits into the computer easily and it helps with our dictation (Figure 3.7).

Carroll (Chicago): The residents rotate through our service every 2 months. Therefore, a system has to be simple and teachable in a short period of time. We check only ten parameters, the ones listed in Table 3.9. The resident examines the foot and rates it on a scale from 1 to 10. Then I examine the foot. The very mild positional foot is 1 or 2 and the very rigid foot is 10.

Lehman (New York City): Twenty-five percent of our clubfoot surgery is for recurrent clubfeet. Therefore, I have attempted to develop an evaluation system that would help me to determine which failed clubfoot should be operated on, then to bring that failed clubfoot into the same system as the unoperated CTEV and upgrade it. After revision surgery, it would

then fall into the category of an acceptable result. We graded motion, appearance, the radiographs, whether or not the child wore regular shoes, whether he was functionally normal, whether he had pain, whether the flexor tendons were movable. Less than 60 points was a failure (Table 3.16, page 114). We evaluated 45 clubfoot revision procedures and were able to upgrade the failure so that the total of 51% became excellent, 11% good, 8% fair, and only 3% failed. When I have followed them for a number of years, I am going to have more failures, of course. This group was followed for only 3 years. I think a preoperative classification is very important but, in my area, everyone is doing clubfeet surgery, so I see many failures. Therefore, I am trying to figure out which ones I should operate on and which ones I should not. Children I evaluated as excellent after my revision surgery did not have good self images. The foot is not as good as a normal foot but it is not a simple foot; by comparing it with the revision feet, it is then gradable.

McKay (Ville Platte, Lousiania): I also try to evaluate my postoperative clubfeet by a very simple method. I want to emphasize appearance, function and strength of the foot (see Postoperative Rating System for Clubfeet, page 117). I didn't include x-rays because I never felt I could preoperatively assess a child by x-ray and, therefore, I didn't feel that I should postoperatively assess a child by x-ray.

Stevens (Lexington, Kentucky): Our system of evaluating clubfeet is based on measuring the degree of residual equinus after maximal correction of the varus. I believe there is a correlation between the degree of equinus and the other deformities so that, in selecting one deformity, I choose residual equinus. I believe some of the motions of the foot are interdependent and they can be looked at as one. We also customarily required measurement of the residual equinus under anesthestic before the operation so the number was also available retrospectively for us when we started this classification. This is a child with a unilateral deformity. The normal foot has 40° dorsiflexion. The abnormal foot has about 22° of dorsiflexion, which should classify the child as grade 3. It is a major degree of equinus but basically it shows a correlation between the grade of equinus and the outcome following surgery (Table 3.11, page 102).

Stanitski (Pittsburgh): I'd like to ask how one can measure the small round ossification centers in the immature foot and correlate this with Kite's angle made in the more mature foot. Will there be correlation between these two angles? Do these measurements have any significance or should we forget about radiographic measurements in assessing pre- and postoperative clubfeet?

Lehman: I'm not sure x-rays are greatly significant in the beginning; to compare it to x-rays later on is impossible. I think the MRI is probably going to be the answer. You really can see the whole bone. It's very effective.

Carroll: There are a number of problems with MRI. First, the young child has to be sedated. Second, the appearance of the MRI seems to change with changes in position of the foot. The foot should be corrected to its maximally corrected position and then a small cast put on to hold it. Finally, our radiologists are fairly intelligent but are having great difficulty in telling what they're looking at.

Goldner (Durham): In answer to the question about the usefulness of x-rays, I think x-rays are helpful. On the preoperative x-rays, the tibia, the ossific nucleus of the talus, and the calcaneus and the cuboid are usually present. Lateral stress x-rays are very important. Second, the same radiographic examination can be performed postoperatively, and the relationship between the tibia, the talus, and the calcaneus can be compared, so I think it's very useful. Kite's angle has never been useful to me, however, because of the position of the foot and the various other things required. I think the AP view of the ankle joint is very useful. The MRI provides $800 worth of experimental information. If you're going to do an experimental study with the MRI, it may be of some use but I do not believe that the MRI tells you how to treat a clubfoot. The MRI is not as good as a good physical examination or an examination when the wound is open.

Drennan (Albuquerque): I think that we need something far more objective than our visual examination of the foot at the time of surgery.

Watts (Los Angeles): The rating system should not be presented to an audience such as this unless the authors provide their reproducibility data. Dr. Cummings should be genuinely applauded for doing this. We've had rating sys-

tems for years. Why is it that we aren't doing these if they're so easy and so universally applicable? I think the reason is that there is significant variability between examiners. Each of the rating system proponents should return to future congresses with reproducibility data to tell us what the difference is between examiners and within examiners. We have done this with clubfeet and, in my view, there is virtually no significant variability when you compare one person's reading of the same film with another person's reading.

Tachdjian (Chicago): Dr. Cummings, you said x-rays are useful.

Cummings (Jacksonville): One has to ask a more specific question, such as, "Is looking at the arch important?" If looking at the arch is important, then one has to decide the best way to look at it. There are two ways to look at it: with physical exam or with a radiologic exam. It could be a plain x-ray or it could be an MRI. As for the arch itself, you can achieve reproducibility equally well either on physical exam or plain x-ray. We didn't have MRIs to compare with plain films. Looking back at Drennan's MRI data on the AP talocalcaneal index, it looked like his measurements and standard deviations were comparable to x-ray measurements. The MRI does not seem to be much more reproducible than the plain x-ray views.

Thometz (Milwaukee): I should like to give a few points in favor of radiographic measurements. The variability of measurements depends on how well-developed your ossific nuclei are for both the talus and the calcaneus and, to a lesser extent, the cuboid. In the very young infant where the talus and the calcaneus are globular, true, they aren't helpful. There will be great variability in your measurements on both the AP and the lateral in those children; therefore, we simply wait until the ossification centers are of sufficient size and configuration to allow reasonably accurate measurements to be made. This is usually between 4 and 6 months of age. Occasionally we will delay until 7 or 8 months if necessary in order to obtain radiographic measurements. The radiographic parameters in talipes equinovarus, like Baumann's angle or Cobb's angle, have a certain amount of variability. Dr. Watts' study showed that there was quite a bit of variability. In our experience, there has not been nearly the variability as claimed in his paper. It depends on the technique which is used. To obtain good visualization of the hindfoot, the x-ray unit must be centered on the talar head, the proper techniques for positioning the patient on the x-ray unit must be employed, and the proper techniques used in taking the film. Failure to use adequate exposure for the hindfoot (not burning out the forefoot) is one of the most common pitfalls and is probably the reason for Dr. Watts' high degree of measurement variability. Our results show an acceptable degree of variability.

Paley (Baltimore): I've never made these measurements in clubfeet, but I have had experience with a long-term calcaneal fracture study, taking x-rays of both the normal side and the injured side and then looking at numbers like Boller's angles, etc. I found that, when I looked at just the number and compared it to a population average, the numbers were all over the map and there was always variability. When one compared it to the paired control, their opposite limb, one got actually very tightly controlled numbers. Possibly we should be using ratios and not the absolute numbers.

Editor's Comments

There are more than 30 criteria that may be evaluated once the clinical, functional, and radiographic criteria have been subdivided as above. If all of these are taken into consideration, the task of evaluating the clubfoot becomes overwhelming.

Therefore, as **Cummings et al.** point out, three important questions remain unanswered:

1. Which are the most important criteria and subcriteria to be used in the evaluation of the clubfoot?

2. Which are the best means by which to measure these various criteria?
3. What is the inherent measurement error of the essential criteria?

Stevens and **Meyer** compare a clinical assessment of equinus deformity that persists following conservative treatment with a conventional clinical, radiographic, and functional rating system. They conclude that the CTEV Severity Grading System provided a useful means for evaluation of CTEV both pre- and postoperatively.

In my experience, assessment of equinus deformity is most accurately performed by assessing the lateral tibiocalcaneal angle in dorsiflexion. This excludes forefoot and hindfoot motion but, more important, it is more precise than clinical measurements.

Cummings et al. conclude that x-ray angular measurements tend to be more reproducible (interrater) than physical examination measurements, history, or x-ray items, with a better rate of agreement than physical examination items. They also conclude that we must define which criteria we can measure in a reproducible manner, decide which criteria are significant, and determine their confidence levels.

Lehman et al. also make a comparison of surgical results reported in the literature between 1971 and 1988. With all due respect to these authors, it is the editor's opinion that this type of evaluation should be discouraged, as the results are frequently invalid and may be misleading for the following reasons: 1) the patients are frequently not classified and studied according to type of TEV (i.e., typical, arthrogrypotic, etc.); 2) at least 4 basically different surgical techniques were used in the 12 series reported (Goldner's, McKay's, Turco's, Lloyd-Roberts'); 3) to date there has not been any agreement on the best clinical and/or radiographic parameters for the evaluation of CTEV either preoperatively or postoperatively. Although attempts are currently underway (by **Cummings et al.**) to evaluate numerous criteria, it is unlikely that these will be generally accepted and available in the near future.

4
Radiographic Evaluation

Introduction

In the opening paper **Barriolhet** describes a simple angular measurement for forefoot adduction that can evaluate adduction independently of supination.

In the first of two papers presented by **Yamamoto** and **Furuya**, the authors describe the relationship between their functional and radiographic results using the conventional Turco posterior medial release. They also describe two new angular measurements. In their second paper they report their more recent results using a modification of Turco's procedure and compare these results with those of the standard Turco procedure. The cases also were evaluated using their two new angular measurements as well as the conventional lateral tibiocalcaneal angle.

Stevens and **Meyer** use the talocalcaneal angle on the lateral intraoperative radiograph to assess the adequacy of operative correction of CTEV.

Kitada and colleagues describe the use of arthrography to assess the accuracy of (a) the angle between the talar *body* axis and the calcaneal axis and (b) the angle between the talar *neck* axis and the calcaneal axis. They compare these two angles to determine which is more closely associated with good functional results when measured on the standard AP radiograph.

The First Ray Angle

J. Barriolhet

Many radiographic measurements have been described for the evaluation of congenital clubfeet (CTEV).[1–8] Recently an analysis of numerous radiographic measurements of the feet of children and adolescents has been published along with the normal ranges for various angles in clubfeet. In this study, three standard radiographic views were made of 74 infants and children and 11 angles were analyzed.[9]

The purpose of this paper is to present yet another angular measurement not described in the article by Vanderwilde et al.,[9] which mea-



FIGURE 4.1. The technique of measurement of the first ray angle.

sures the position of the forefoot isolated from the hindfoot and also provides a normal range of values for this measurement.

Materials and Methods

The *first ray angle* is the acute angle formed by the axis of the first metatarsal and the tangential line from the base of the first metatarsal to the base of the fifth metatarsal (Figure 4.1); therefore the name "first ray angle." An anteroposterior (AP) radiograph is taken with the x-ray tube placed vertically. Special attention is given to assure that all the metatarsal heads touch the cassette at the time of exposure.

To determine the normal range of measurement, the first ray angle was measured on the AP radiographs of 58 infants, children, and teenagers who were considered to have normal lower extremities. Half of the radiographs were obtained from films made previously and the other half were made for this purpose. The control patients were divided into six groups according to age (Figure 4.2). As in the study by Vanderwilde et al.,[9] data for both sexes were pooled for the analysis.

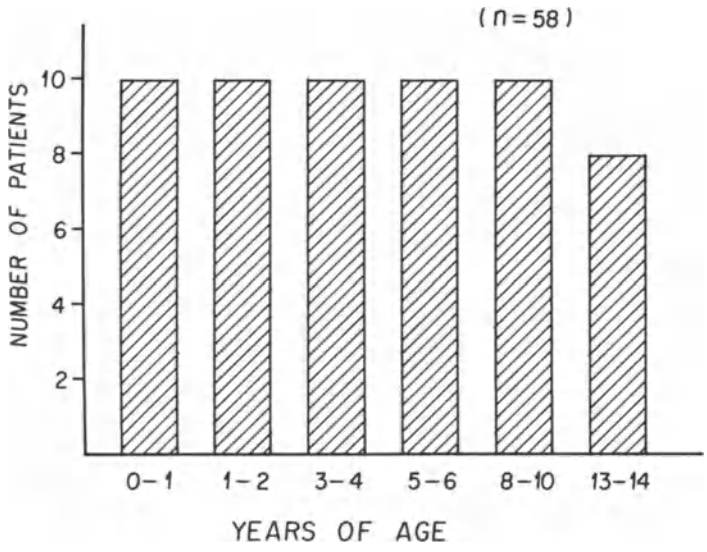


FIGURE 4.2. Distribution of normal control patients by age.

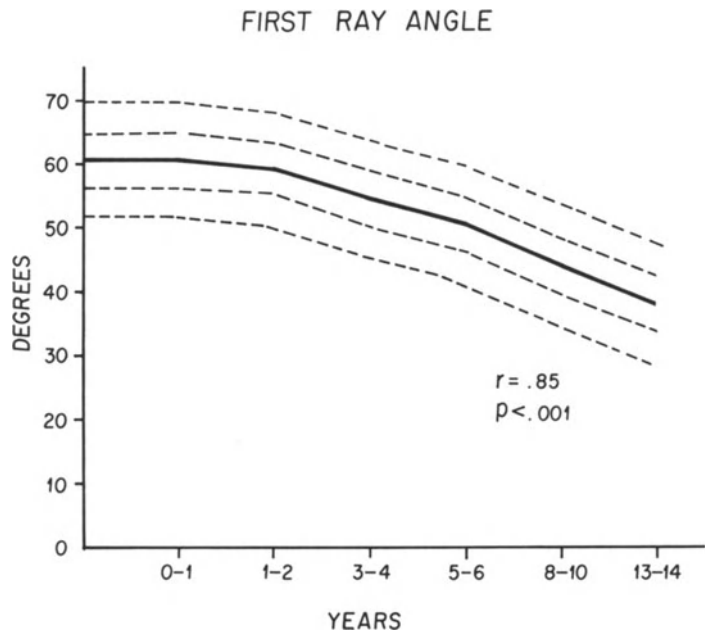


FIGURE 4.3. Variation of the first ray angle by age.

Results

There was only a slight difference between the first and the second group, which suggests that, under 3 years of age, the first ray angle should be about 60° (0 to 1 years averaged 60.5°, 1 to 2 years averaged 58.9°) with a range from 52° to 70°. As frequently seen in measurements of other angles, after 4 years of age this angle decreased significantly (Figure 4.3).

Discussion

Radiographic evaluation of deviation of the forefoot has been studied previously by two well-known angles: the AP talo–first metatarsal angle, and the AP calcaneo–fifth metatarsal angle.[9] For the measurement of these angles it is important to have good visualization of the talus and calcaneus. But often only the anterior ends of these bones are visualized. Furthermore, in premature babies and newborns, the talus and calcaneus are represented by two tiny circular ossification centers on which accurate measurement is not possible.

However, in determining the first ray angle, visualization of the hindfoot is unnecessary. The effect of supination of the metatarsals is negated by placement of all of the metatarsal heads on the cassette. However, varus of the

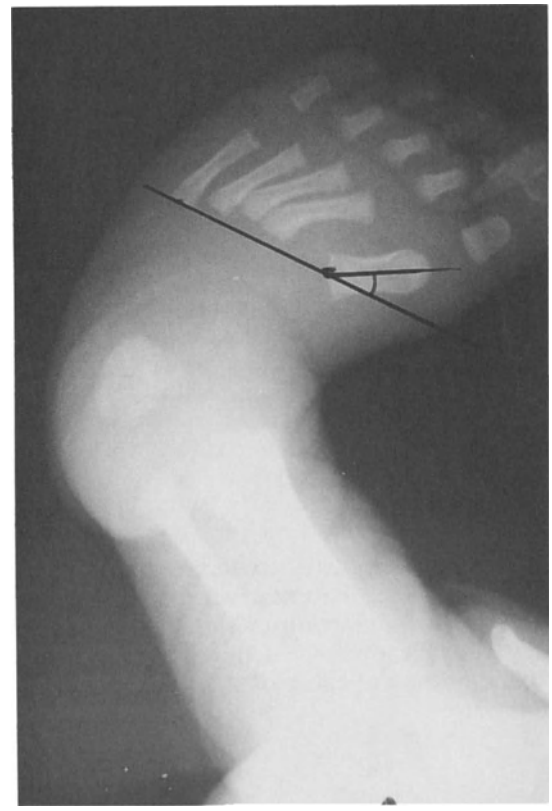


FIGURE 4.4. The metatarsal heads must be placed flat on the cassette and the hindfoot position disregarded when severe deformity is present.

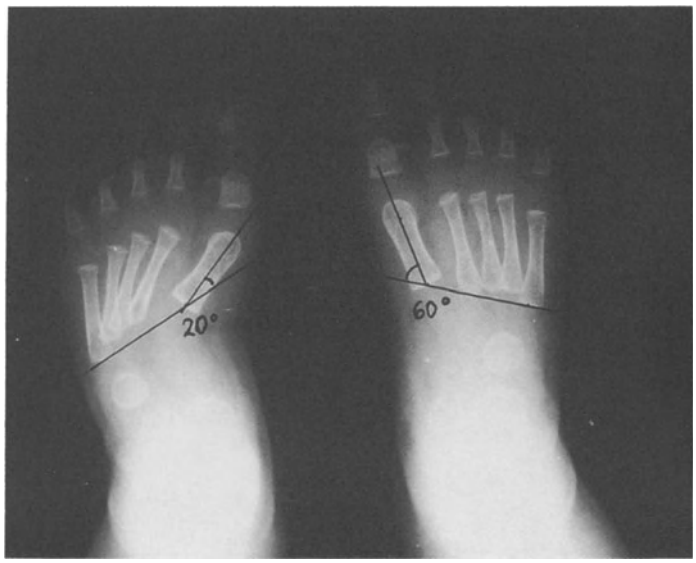


FIGURE 4.5. A normal first ray angle on the right and an abnormal first ray angle on the left.

hindfoot may produce an error in measurement if the heads of the metatarsals are not properly positioned (Figure 4.4).

Under 3 years of age the normal range of the first ray angle is 50° to 70°; after 3 years of age it decreases (Figure 4.3). When the first ray angle is decreased (less than 50°), adduction deformity of the forefoot is present (Figure 4.5). When the angle is increased (more than 70°), abduction deformity is present.

This method has been useful in the evaluation of metatarsus adduction as well as for the evaluation of CTEV pre- and postoperatively. Daily practice has proven that this angle is easily understood by the surgeon as well as by the anxious parents of the child with CTEV and other forefoot deformities.

Summary

The first ray angle is a new radiographic angular measurement that may be used to evaluate adduction or abduction of the forefoot. This angle may be obtained without the effect of supination or the effect of the position of the hindfoot.

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The Relationship Between Functional Results and Radiographs in One-Stage Posteromedial Release

H. Yamamoto and K. Furuya

Radiographs have been used to evaluate the deformities of congenital clubfeet (CTEV) since Barwell first described their use in CTEV in 1896. Radiographs show the alignment and the deformities of bones in CTEV, whereas numerous angular measurements have been described to evaluate the degree of the various deformities. Simons[5] standardized the technique for positioning the patient, the x-ray machine and the cassette, and the technique of measurement of the films. According to these standards, we evaluated our results of Turco's one-stage posteromedial release of congenital clubfeet. We also examined the relationship between the clinical results and the functional results, and reported that the functional results showed a close relationship to angular measurements.[8] In this study, 64 congenital clubfeet are functionally and radiographically evaluated in order to further examine the relationship between the functional results and the radiographic alignment of tarsal bones.

Materials and Methods

Turco's one-stage posteromedial release has been performed on 70 congenital clubfeet in 49 children since 1973; 44 children with 64 surgically treated feet returned for follow-up evaluation. Thirty children had bilateral clubfeet and 14 had unilateral clubfeet, of which 29 were male and 15 were female. The mean age at surgery was 3.6 years, with a range from 10 months to 8 years 7 months. The mean period of follow-up was 7 years, with a range from 3 years 6 months to 13 years. Eight feet had previously undergone posterior release. Indications for surgery were (a) persistent deformities, (b) an angle of the ankle (lateral tibiotalar angle) in maximum dorsiflexion of less than 10°, and (c) a lateral tibiocalcaneal angle in maximum dorsiflexion of more than 80°.

Surgical Procedure

The surgical procedure was a variation of Turco's[7] one-stage posteromedial release. The skin was incised horizontally from the base of the first metatarsal to the lateral side of the Achilles tendon. The Achilles, posterior tibial, flexor hallucis, and flexor digitorum longus tendons were lengthened using the z technique. The posterior talofibular ligament, the calcaneofibular ligament, the posterior third of the deep deltoid ligament, the superficial deltoid ligament, the interosseous talocalcaneal ligament, the spring ligament, and the bifurcate (Y) ligament were all transected. The anterior end of the calcaneus was moved laterally, the navicular was moved forward, and the talar head was moved medially. In this corrected position, a Kirschner wire was inserted from the talus through the first metatarsal to transfix the talonavicular joint. An above-the-knee cast was applied with the ankle in 10° of plantar flexion to avoid tension on the skin. The cast was changed once every week for 6 weeks. The angle of the ankle was gradually increased to maximum dorsiflexion when the cast was changed. The Kirschner wire was removed 5 weeks after surgery. After 6 weeks of immobilization, the foot was protected by a Denis Browne splint with a shoe insert.

Method of Assessment

The functional results were assessed using the McKay rating system,[3] which includes 10 categories giving a maximum of 180 points: ankle motion (30 points), angle of the bimalleolar plane to the longitudinal plane of the foot (20 points), strength of triceps surae (20 points) and flexor hallucis longus (10 points), the position of the heel (10 points) and forefoot (10 points), ankle pain (20 points), subtalar pain (20 points), shoe wear (15 points), and sports ability (15 points).

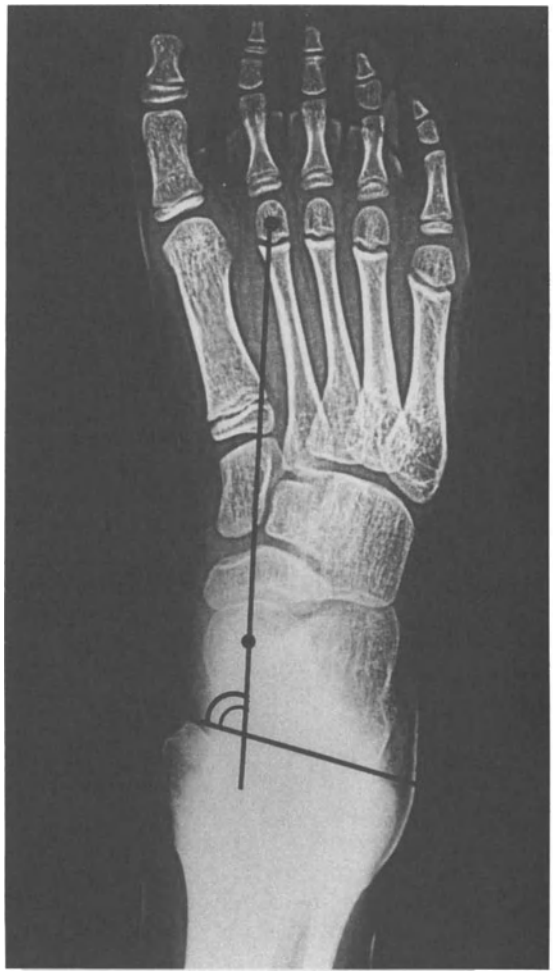


FIGURE 4.6. The metatarsotalobimalleolar (MTB) angle is the angle formed by the metatarsotalar line and the bimalleolar line. This is an index of adduction deformity of the forefoot.

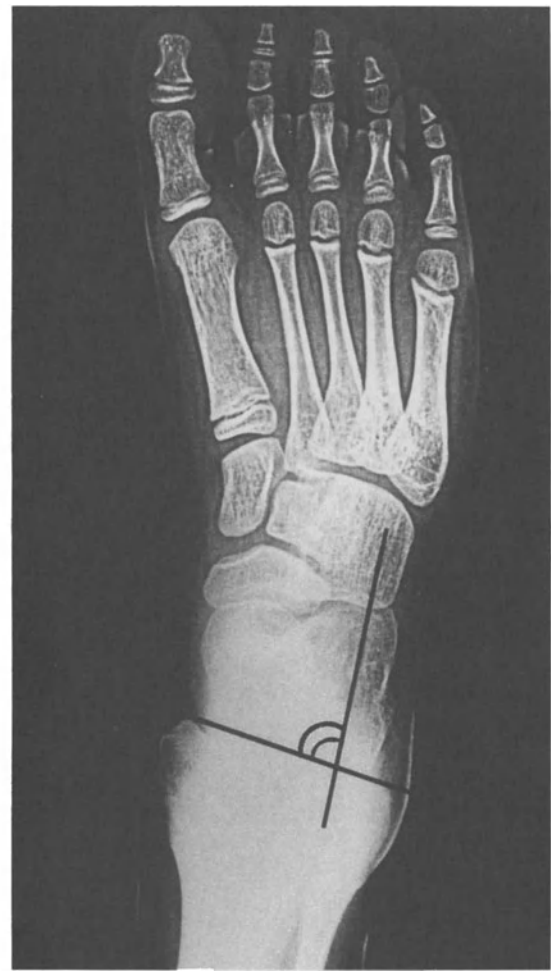


FIGURE 4.7. The bimalleolocalcaneal (BMC) angle is the angle formed by the longitudinal line of the calcaneus and the bimalleolar line. This is an index of varus deformity of the calcaneus.

Radiographic assessment was made by anteroposterior and lateral radiographs of the feet taken during standing, and a lateral radiograph taken in maximum dorsiflexion. An anteroposterior radiograph was taken with the beam angled at 30° from the vertical while the patient stood on the cassette with the tibial tubercle directed anteriorly. From this radiograph the talocalcaneal angle, the metatarsotalobimalleolar (MTB) angle, and the bimalleolocalcaneal (BMC) angle were measured. The MTB angle[2] is the angle formed by the metatarsotalar line (from the center of the second metatarsal head to the center of the talar head) with the bimalleolar line (from the tip of the medial malleolus to the tip of the lateral malleolus). This is an index of the adduction deformity of the forefoot (Figure 4.6). The BMC angle is the angle formed between the longitudinal line of the calcaneus and the bimalleolar line. This is an index of varus deformity of the hindfoot (Figure 4.7). The talocalcaneal and tibiocalcaneal angles were measured on the lateral radiograph during maximum dorsiflexion. The first metatarsotalar angle was measured on the standing lateral radiograph.

TABLE 4.1. Results using the McKay rating system.

Results	Feet	Percentage
Excellent	38	59.4
Good	10	15.6
Fair	8	12.5
Poor	3	4.7
Failure	5	7.8

Results

The feet were graded as excellent (175 to 180 points) in 59.4% (38 feet), good (160 to 174 points) in 15.6% (10 feet), fair (125 to 159 points) in 12.5% (8 feet), poor (90 to 124 points) in 4.7% (3 feet), failure (under 90 points) in 7.8% (5 feet) (Table 4.1). The percentage of good and excellent results was 75%.

The radiographic angular measurements are shown in Table 4.2. The mean MTB angle of feet graded excellent and good was 90.4°. In the feet graded fair, poor, and failure, the mean angle was 65.8°. The mean BMC angle of feet graded excellent and good was 90.9°. In the feet graded fair, poor, and failure, this angle measured 76.6°. The mean anteroposterior talocalcaneal angle of feet graded excellent and good was 25.6°. In those feet graded fair, poor, and failure, this angle was 15.8°. The mean tibiocalcaneal angle of feet graded excellent and good was 62.2°. In the feet graded fair, poor, and failure, the mean angle was 79.3°. The mean lateral talocalcaneal angle of feet graded excellent and good was 31.8° and in the feet graded fair, poor, and failure, this angle was 24.4°. The mean lateral first metatarsotalar angle of feet graded excellent and good was 174.2°. In the feet graded fair, poor, and failure, the mean angle was 165.2°.

The relationship between the functional results and angular measurements was analyzed using multiple regression (see Appendix at end of this chapter). The functional results seem to be most closely related to the MTB angle in the anteroposterior radiograph during standing and the tibiocalcaneal angle in the lateral radiograph during maximum dorsiflexion.

Discussion

Simons[5,6] standardized the radiographic evaluation of clubfeet and used the lateral talocalcaneal angle, the anteroposterior talocalcaneal angle, and the anteroposterior talo–first metatarsal angle to evaluate equinus, varus, adduction, and talonavicular dislocation. Many au-

TABLE 4.2. McKay's functional rating versus angular measurements* of patients with modified posteromedial release (PMR) (Turco).

	AP view		
	Metatarsotalobimalleolar (MTB) angle	Bimalleolocalcaneal (BMC) angle	Anteroposterior talocalcaneal angle
Foot graded as excellent and good	90.4° ± 8.4°	90.9° ± 7.0°	25.6° ± 4.4°
Foot graded as fair, poor, or normal	65.8° ± 11.7°	76.6° ± 7.4°	15.8° ± 8.9°
Normal foot	93.5° ± 3.5°	96.7° ± 6.6°	28.6° ± 5.0°
	Lateral view		
McKay's rating	Lateral tibiocalcaneal angle	Lateral talocalcaneal angle	Lateral first metatarsotalar angle
Foot graded as excellent and good	62.2° ± 7.6°	31.8° ± 5.4°	174.2° ± 6.0°
Foot graded as fair, poor, or normal	79.3° ± 12.0°	24.4° ± 5.8°	165.2° ± 12.2°
Normal foot	40.5° ± 4.8°	37.5° ± 6.3°	180.2° ± 0.5°

*Mean + SEM.

thors have used the anteroposterior and the lateral talocalcaneal angles to evaluate equinus and varus deformities. However, we feel that it is occasionally difficult to accurately draw the long axis of the talus in infants, because the ossification center of the talus only occurs in the anterior part of the talus and, in severe clubfeet, the talus is angled at the neck.

Kamagai et al.[2] proposed the use of the MTB angle to evaluate the adduction deformity of the forefoot. They reported that there was little angular variance when the anteroposterior radiograph was taken during standing with the beam angle from 15° to 35° from the vertical.

In addition, we propose the use of the BMC angle to evaluate the varus deformity of the calcaneus with respect to the lower leg because in clubfeet the calcaneus is inverted under the talus and there is rotation, varus, and equinus deformities of the hindfoot[1,4] and adduction deformity of the forefoot in relation to the lower leg.

McKay[3] measured the angle of the bimalleolar plane to the longitudinal plane of the foot to evaluate the horizontal subtalar rotation. We think that we can use this angle to evaluate the varus deformity of the foot to the lower leg, but it may be inaccurate for measuring from the outside of the foot. Therefore, we prefer to use the BMC angle, which is an index of hindfoot varus (and subtalar rotation) and is easily measured. There was little angular variance when the anteroposterior radiograph was taken during standing with a beam angle of 25° to 35° from the vertical while patients stood on the cassette with the tibial tubercle directed anteriorly.

From the analysis of the results using multiple regression, the functional results are most closely related to the MTB angle and the lateral tibiocalcaneal angle. We have used both of these angles as an index of the indication for surgery and for the correction of the alignment of tarsal bones at the time of surgery.

Simons[6] pointed out that to obtain intraoperative radiographs requires minimal increase in operative time and greatly increases the probability of full correction with only a single operative intervention. We also confirm correction of the alignment of tarsal bones at the time of surgery (as well as pre- and postoperatively) with the measurement of the MTB angle and the lateral tibiocalcaneal angle.

Summary

Turco's one-stage posteromedial release was performed on 70 congenital clubfeet in 49 children since 1973. Of the 70 CTEV, 64 returned for follow-up 7 years after surgery and were evaluated using McKay's functional rating system. The feet were graded as excellent in 59.4%, good in 15.6%, fair in 12.5%, poor in 4.7%, and failure in 7.8%.

The relationship between functional results and angular measurements was analyzed using multiple regression. The functional results appeared to be most closely related to the MTB angle on the standing anteroposterior view and the tibiocalcaneal angle on the lateral view in maximum dorsiflexion. The MTB angle correlated with the BMC angle and the anteroposterior talocalcaneal angle. These angles (MTB and lateral tibiocalcaneal) may be used to verify correction and to assure maintenance of alignment of the foot during surgery as well as after surgery.

Appendix

The model of regression was: $Y = 1.37\ x_1 - 0.46\ x_2 + 0.44\ x_3 - 1.11\ x_4 - 0.33\ x_5 + 0.12\ x_6 + 137.93$, where Y is the score, x_1 is the MTB angle, x_2 is the BMC angle, x_3 is the anteroposterior talocalcaneal angle, x_4 is the tibiocalcaneal angle, x_5 is the lateral talocalcaneal angle, and x_6 is the lateral first metatarsal angle. The multiple correlation coefficient was 0.83. The regression coefficient was high in x_1 and x_4; x_1 correlated with x_2 ($r = .85$, $p < .001$) and x_3 ($r = .76$, $p < .001$), and x_4 correlated with x_5 ($r = (-).74$, $p < .001$) and x_6 ($r = (-).25$, $p < .05$).

Then, using x_1 and x_4, the model of simple regression was: $Y = 1.37\ x_1 - 1.00\ x_4 + 115.8$. This coefficient was the same as that of the model using x_1, x_2, x_3, x_4, x_5, and x_6.

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Modified Posteromedial Release

H. Yamamoto, K. Furuya, and T. Muneta

Numerous radiographic measurements have been described to evaluate the deformities of congenital clubfeet. These angular measurements have been used as an indication for surgery and in the evaluation of the results.

We[7,8] previously evaluated the results of Turco's one-stage posteromedial release radiographically and functionally. The functional results correlated very closely with the metatarsotalobimalleolar (MTB) angle[1] (the angle of the line from the center of the second metatarsal head to the center of the talar head to the bimalleolar line) on the standing anteroposterior radiograph and the tibiocalcaneal angle on the lateral radiograph taken with maximum dorsiflexion. The MTB angle significantly correlated with the bimalleolocalcaneal (BMC) angle[7] (the angle of the longitudinal line of the calcaneus to the bimalleolar line) and with the anteroposterior talocalcaneal angle.

Purposes

This paper describes our short-term results with a modified version of Turco's posteromedial release. Also, two new angular measurements are used for the interoperative as well as postoperative evaluation of our results.

Materials

A modified (Turco) posteromedial release was performed in 17 children with 21 congenital clubfeet. Nine children had a unilateral clubfoot and eight children had bilateral clubfeet. The mean age at surgery was 4.3 years with a range from 7 months to 8.6 years. The mean period of follow-up was 2.5 years with a range from 1 year to 3.3 years. Four feet had previously undergone posteromedial release, three had undergone posterior release, and one foot had undergone posterior release and medial release.

Surgical Procedure

The surgical procedure was identical to that used in the series reported earlier in this monograph, with the following exceptions: the medial portion of the interosseous talocalcaneal ligament (ITCL) was incised whereas the lateral part of the ITCL was retained (Figure 4.8). A Kirschner wire was introduced into the calcaneus posteriorly. This was used to rotate the anterior calcaneus laterally beneath the talus (with the axis of rotation being the ITCL) to correct the BMC angle (Figure 4.9). Another Kirschner wire was introduced into

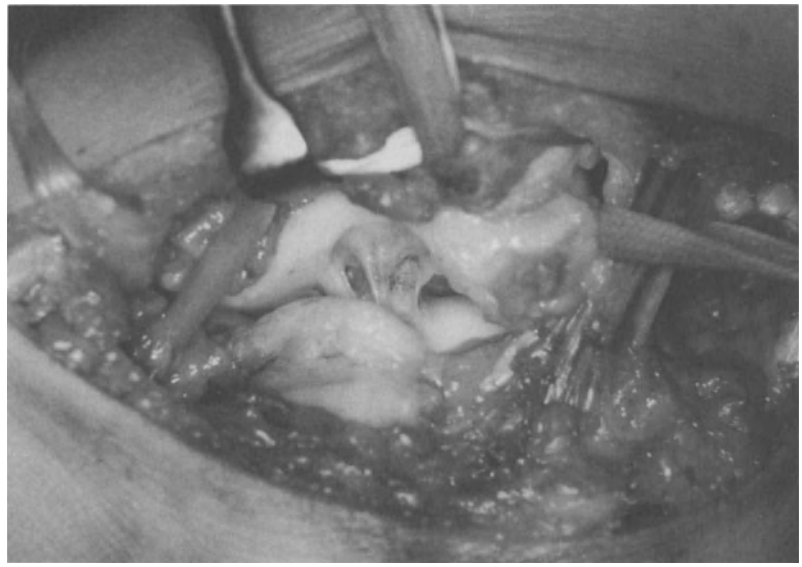


FIGURE 4.8. Posteromedial release is performed through the horizontal skin incision from the base of the first metatarsal to the lateral side of the Achilles tendon. The interosseous ligament is retained.

the calcaneus posteriorly, which fixed the calcaneocuboid joint while the adducted forefoot was manually abducted (Figure 4.10).

Results

Using McKay's rating system,[3] the feet were graded as excellent (175 to 180 points) in 90% (19 feet) and good (160 to 174 points) in 10% (2 feet). Radiographic measurements preoperatively and at follow-up are shown in Table 4.3.

In the unmodified conventional Turco procedure, we achieved approximately 60% excellent and 15% good results for a combined good and excellent result of about 75%. When these results were compared with the results of the modified procedure (rotating the calcaneus beneath the talus with a Kirschner wire), we achieved 90% excellent results with 10% good results. Thus this one variation in technique accounted for improvement of 25% in the good and excellent categories.

A Case Report

A 10-year-old boy with bilateral congenital clubfeet underwent bilateral posterior releases at 2 years 6 months of age. He came to our hospital with deformities of the left foot and a toeing-in gait at 8 years of age. His score using the McKay rating system was 65 points. The

TABLE 4.3. Radiographic measurements found in the study.

Angle	Preoperative	Postoperative	Change	Normal
MTB	73.5° ± 15.5°	90.0° ± 8.7°	17°	93.5° ± 3.5°
BMC	82.9° ± 10.6°	91.5° ± 6.8°	8°	96.7° ± 6.6°
APTC	22.4° ± 8.8°	25.7° ± 3.5°	3°	28.6° ± 5.0°
Lateral Tibiocalcaneal	85.4° ± 15.9°	60.7° ± 8.1°	24°	40.5° ± 5.8°
Lateral Talocalcaneal	22.3° ± 9.7°	32.8° ± 7.4°	11°	37.5° ± 9.3°
Lateral 1st metatarsal	169.2° ± 11.2°	178.3° ± 4.5°	9°	180.2° ± 0.5°

Mean ± SEM.
APTC, anteroposterior talocalcaneal; BMC, bimalleolocalcaneal; MTB, metatarsotalobimalleolar.



FIGURE 4.9. A Kirschner wire is introduced into the calcaneus posteriorly and is rotated so that the anterior calcaneus moves laterally, while the posterior calcaneus moves medially under the talus at the axis of the interosseous talocalcaneal ligament.



FIGURE 4.10. Another Kirschner wire is introduced into the calcaneus; it fixes the calcaneocuboid joint while the adducted forefoot is manually abducted.

angle of dorsiflexion of the ankle joint was (−) 10°. The MTB angle was 62° and the BMC angle was 76° on the standing anteroposterior radiograph. The tibiocalcaneal angle in the lateral radiograph during maximum dorsiflexion was 86° (Figure 4.11). A modified posteromedial release was performed and intraoperative radiographs showed the MTB angle to be 89°, the BMC angle to be 91°, and the lateral tibiocalcaneal angle to be 62°. Two years after surgery, the correction of deformities was maintained, the toeing-in gait disappeared, and the McKay score was 180. Dorsiflexion was 20°. The MTB angle was 91°, the BMC angle was 93°, and the tibiocalcaneal angle was 60° (Figure 4.12).



FIGURE 4.11. The radiograph before surgery. The MTB angle was 62°, the BMC angle was 76°, and the lateral tibiocalcaneal angle was 86°.

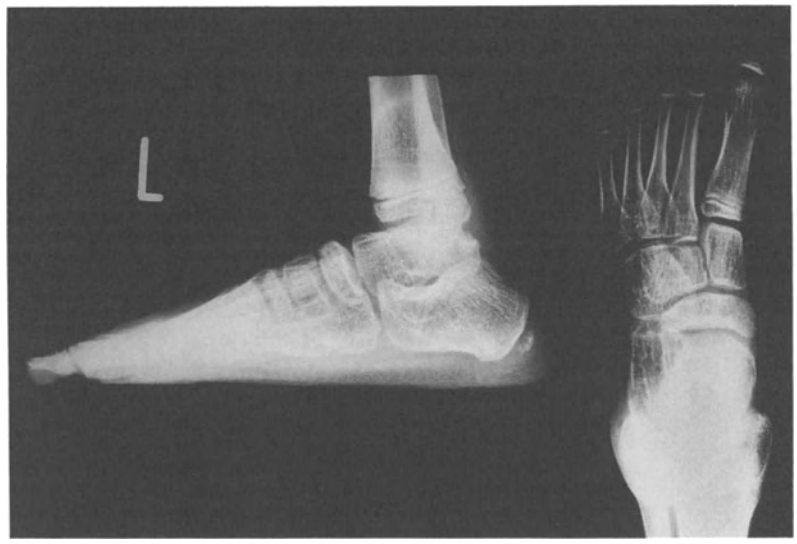


FIGURE 4.12. The radiograph 2 years after surgery. The MTB angle was 91°, the BMC angle was 93°, and the lateral tibiocalcaneal angle was 60°. The normal ranges for these angles are MTB = 93.3° ± 3.5°, BMC = 96.7° ± 6.6°, lateral tibiocalcaneal = 40.5° + 4.8°.

Discussion

Since Turco[6] reported the one-stage posteromedial release, most surgeons have selected this procedure to correct congenital clubfeet. We[8] reported the results of this procedure in which 70% of feet were graded as excellent and good. In 30% of feet graded as fair, poor, and failures, radiographs showed poor alignment of the tarsal bones. From the analysis[7] of the results using multiple regression, the functional results seem to be very closely correlated with the MTB angle and the lateral tibiocalcaneal angle. The MTB angle significantly correlated

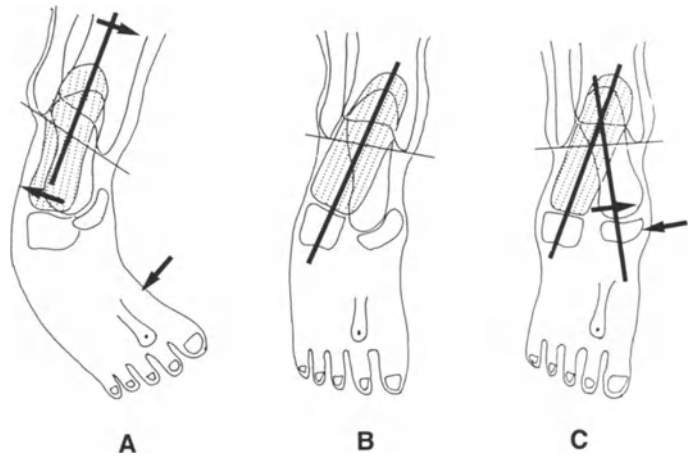


FIGURE 4.13. The procedure to correct the alignment of tarsal bones. A: Correction of the calcaneus using a Kirschner wire, while the adducted forefoot is manually abducted. B: Fixation of the calcaneocuboid joint with another Kirschner wire. C: Fixation of the talonavicular joint after the head of the talus has been rotated medially and the navicular has been reduced onto the talar head.

with the BMC angle and the AP talocalcaneal angle. Therefore, we used these angles (MTB and the lateral tibiocalcaneal) to verify the correct alignment of the tarsal bones during the release with the use of intraoperative radiographs.

The procedure that we use to correct the alignment of the talus and calcaneus is to introduce a Kirschner wire into the calcaneus posteriorly. This wire is used to rotate the anterior calcaneus laterally from under the talus with the axis of rotation being the ITCL (Figure 4.13). The BMC angle is used as an index for correction of the relationship between the talus and the calcaneus in this procedure. Then another Kirschner wire is introduced into the calcaneus posteriorly. This fixes the calcaneocuboid joint in this position while the adducted forefoot is manually abducted. The talonavicular joint is fixed with a Kirschner wire inserted posteriorly while the head of the talus is rotated medially and the navicular reduced onto the talus. The anteroposterior talocalcaneal angle is an index for correction in the procedure. The MTB angle is an index for correction in both procedures.

There is considerable controversy about release of the ITCL. McKay[2] incised this ligament when it prevented derotation of the talocalcaneal joint. Simons[5] invariably released this ligament because this release yielded greater correction than when it was not released. We retain the ITCL for two reasons: (a) to prevent overcorrection and (b) because we use this ligament as an axis for correction of the subtalar rotation, varus, and equinus deformities of the calcaneus. The ITCL is a broad and thick ligament that resists this correction, therefore, only the medial part is incised. McKay[2] corrected the rotation of the calcaneus manually. However, we found this to be difficult without extensive release because the calcaneus is too small to rotate easily by hand.

Simons[4] proposed taking intraoperative radiographs and checking angles in order to increase the probability of complete correction. We measure the MTB angle, the BMC angle, and the tibiocalcaneal angle in intraoperative radiographs to confirm correction. The described realignment of the foot should be repeated if these angles are not within the normal range.

Summary

Seventeen children with 21 congenital clubfeet underwent a modified posteromedial (Turco) release in which angular measurements (MTB angle, the lateral tibiocalcaneal angle) were used to verify the correction of the alignment of the tarsal bones.

After the posteromedial release was performed, a Kirschner wire was introduced into the calcaneus posteriorly. Using this wire, the anterior calcaneus was rotated laterally and the posterior calcaneus was rotated medially. The interosseous talocalcaneal ligament served as the axis of rotation. The talonavicular joint was reduced and fixed with a Kirschner wire. After these procedures were performed interoperative radiographs were taken to check the align-

ment of tarsal bones. All feet were graded as excellent or good using McKay's rating system. Radiographs showed good alignment of the tarsal bones using angular measurements.

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Intraoperative X-Ray as a Standard for Accuracy of Correction by Posteromedial Release of CTEV

D. Stevens and S. Meyer

We performed a retrospective study to determine the validity of intraoperative lateral radiographs as a method of assessing the adequacy of surgical correction of congenital talipes equinovarus (CTEV).

Materials and Methods

Since 1970, 835 patients have presented to the Shriner's Hospital for Crippled Children, Lexington, Kentucky, with CTEV. From this patient group, 297 have required operative treatment and have received their primary surgery at the Shriner's Hospital. Of the remaining patients, 150 had operations elsewhere or did not require operative treatment. A total of 221 had a primary posteromedial release performed at the Shriner's Hospital and, of these, 128 have completed the criteria for assessment. The criteria are 2 years of postoperative follow-up care with a final clinical and radiographic examination.

Thus, in this group of 128 patients, there were 187 feet: 59 patients had bilateral disease, 34 left only, and 35 right only.

Because the senior author (D.S.) was not always present at the operation, a routine was established wherein each patient had a lateral radiograph, positioned in maximum dorsiflexion at the completion of the dissection. This provided objective data for each case and provided an opportunity for retrospective review. In the last few years, the lateral talocalcaneal angle has been measured on the lateral radiograph to determine the quantitative reduction. Prior to that time, only a qualitative review of the radiograph was done in the operating room.

The lateral talocalcaneal angle is a convenient measurement that can be reproduced by different observers in a reliable way. Six lateral

TABLE 4.4. Inter-investigator comparison of measurements of the lateral talocalcaneal angle.

Physicians	1 X-ray-1	2 X-ray-2	3 X-ray-3	4 X-ray-4	5 X-ray-5	6 X-ray-6	7 X-ray-7	8 Means
1 MD #1	30.000	28.000	45.000	38.000	40.000	50.000	30.000	37.28
2 MD #2	29.000	22.000	42.000	25.000	38.000	50.000	20.000	32.28
3 MD #3	25.000	19.000	46.000	39.000	35.000	38.000	22.000	32.00
4 MD #4	25.000	20.000	43.500	30.000	39.000	48.000	24.000	37.78
5 MD #5	32.000	23.000	49.000	39.000	41.000	47.000	21.000	36.00
6 MD #6	30.000	25.000	41.000	32.000	40.000	48.000	24.000	34.28
7 MD #7	28.000	21.000	43.000	30.000	35.000	50.000	25.000	33.14
8 MD #8	26.000	25.000	46.000	34.000	43.000	46.000	20.000	34.28
9								
10 Mean	28.125	22.875	44.440	33.375	38.875	47.125	23.250	34.63
11 Maximum	32.000	28.000	49.000	39.000	43.000	50.000	30.000	
12 Minimum	25.000	19.000	41.000	25.000	35.000	38.000	20.000	
13 S deviation	2.587	2.997	2.583	5.069	2.799	3.979	3.327	
14 Range	7.000	9.000	8.000	14.000	8.000	12.000	10.000	

radiographs of clubfeet were circulated among the attending staff and residents with some duplications of the same feet. The inter- and intraobserver variations were measured (Tables 4.4 and 4.5). The lateral talocalcaneal angle was measured on the lateral radiograph. A line was drawn through the central axis of the talus to intercept a line drawn along the inferior border of the calcaneus. The intersection of the two lines forms the talocalcaneal angle (Figure 4.14).

The patient population previously described was retrospectively reviewed. Initially, posteromedial releases were performed, but subsequently, posteromediolateral releases were introduced by some of the surgeons. Some surgeons have used the posteromedial approach, whereas others have used the Cincinnati approach. In all cases, the correction obtained was stabilized by one or more temporary Kirschner wires. Usually, the radiograph is made before all wires are placed but after the placement of the talonavicular wire, and before repair of the Achilles tendon.

TABLE 4.5. Intrainvestigator comparison of measurements of the lateral talocalcaneal angle.

0 Physicians	1 X-ray-2	2 X-ray-7	3 diff
1MD #1	28.000	30.000	2.000
2MD #2	22.000	20.000	2.000
3MD #3	19.000	22.000	3.000
4MD #4	20.000	24.000	4.000
5MD #5	23.000	21.000	2.000
6MD #6	25.000	24.000	1.000
7MD #7	21.000	25.000	4.000
8MD #8	25.000	20.000	5.000
9			
10 Mean	22.875	23.250	2.875
11 Maximum	28.000	30.000	
12 Minimum	19.000	20.000	
13 S deviation	2.997	3.327	
14 Range	9.000	10.000	



FIGURE 4.14. The technique of drawing the lateral talocalcaneal angle.

Postoperative management of our patients has generally been maintenance of immobilization until the foot retains its correction in a satisfactory position. The child is then placed in an orthosis, either of the traditional variety or, more recently, the plastic ankle-foot orthosis type, which is then worn for about a year until satisfactory correction is maintained throughout the gait cycle and radiographs suggest that adequate remodeling of the foot has occurred.

Results

Final results were then determined based on our rating scale (see Table 3.10 in Chapter 3). The results of the surgery were graded into the two categories, good and poor. If the patient had satisfactory correction, required no further operative treatment, and the grading scale was greater than 80, the result was considered good. If the patient required reoperation or had less than 80, the result was considered poor.

The final outcome was related to the lateral talocalcaneal angle. This was plotted on a linear scale (Table 4.6). Of note is the cutoff between greater or less than a 30° talocalcaneal angle (Tables 4.6 and 4.7). If the patients had less than a 30° angle, their good results were only 30% to 40%. If the lateral talocalcaneal angle was greater than 30°, their good results were 70%. There was no significant difference between those patients who had a 30° to 45° lateral tibiocalcaneal angle and those who had greater than a 45° angle. Tables 4.8 and 4.9 show the relationship between the various groups as is summarized in Table 4.10.

Discussion

Besides the talocalcaneal joint, the lateral radiograph of the uncorrected CTEV reveals the external rotation of the foot around the vertical axis. This can be deduced from the relationship of the silhouette of the calcaneus to the ankle joint. In an uncorrected clubfoot, the ankle joint appears to be oblique. Furthermore, as the foot is usually held parallel to the x-ray cassette, the film shows a lateral view of the calcaneus but an oblique view of the ankle if there is no rotation between these two segments. Correction by internally rotating the foot restores the true lateral projection of the ankle and the calcaneus. The talus also appears in true lateral profile in a corrected clubfoot.

Conclusion

A lateral x-ray on which the talocalcaneal angle is measured provides an accurate method for assessing and documenting adequate operative correction of CTEV.

TABLE 4.6. Intraoperative talocalcaneal angle (TCA) outcome.

	Good result	Poor result		
Intraop. TCA	≥80 assess + one operation	Reoperation	<80 assess + one operation	# Feet
<30°	13 (39.4%)	13 (39.4%)	7 (21.2%)	33
30°–45°	81 (69.8%)	18 (15.5%)	17 (14.7%)	116
>45°	25 (69.4%)	3 (8.3%)	8 (22.2%)	36
No. of feet	119	34	32	185

One patient (2 feet) excluded because no intraop X-rays were available.

TABLE 4.7. Intraoperative lateral talocalcaneal angle (TCA) results.

	Good result	Poor result	
# Feet	≥80 assess + one operation	Reoperation	<80 assess + one operation
187	120 (64.2%)	34 (18.2%)	33 (17.6%)

TABLE 4.8. Results for groups I and II.

Group	TCA	Good result	Poor result	No. of feet	Reoperation rate
I	<30°	13	20	33	13 (39.4%)
II	30°–45°	81	35	116	18 (69.8%)

Good/Poor: Significant difference between the two groups $p = .001573$.
Reop rate: Significant difference between the two groups $p = .021992$.

TABLE 4.9. Results for groups II and III.

Group	TCA	Good result	Poor result	No. of feet	Reoperation rate
II	30°–45°	81	35	116	18 (15.5%)
III	≥45°	25	11	36	3 (8.3%)

Good/Poor: No significant difference between the two groups $p = .559345$.
Reop rate: No significant difference between the two groups $p = .253368$.

TABLE 4.10. Summary of results.

Group	TCA	Good result	Poor result	No. of feet	Reoperation rate
I	<30°	13	20	33	13 (39.4%)
II + III	≥30°	106	46	152	21 (13.8%)

Good/Poor: Significant difference between the two groups $p = .00117$.
Reop rate: Significant difference between the two groups $p = .009468$.

Arthography of Congenital Clubfoot

C. Kitada, Y. Takakura, and S. Tamai

Following dissection studies of fetuses with clubfeet, Irani and Sherman[4] and Settle[6] described the various congenital deformities that occur in clubfeet. Deformity was most pronounced in the talus, in the form of medial and plantar deviation of its neck and head. In the treatment of congenital clubfoot, it is important to recognize these deformities. However, standard radiographs cannot give enough information because some of the tarsal bones in infants have small or absent ossification centers that cannot be measured.

Arthrography is a useful method to observe the relationship among the tarsal bones. In this paper, the arthrographic findings of a consecutive series of clubfeet are presented.

Materials

Simultaneous arthrography of the ankle and midtarsal joints was carried out in 47 congenital clubfeet and 23 normal feet in infants between the age of 5 months and 6 years between 1976 and 1978. The opposite feet of the unilateral cases and the feet with minor anomalies, e.g., polydactyly and syndactyly, were used as normal feet. In the clubfoot, 22 were male

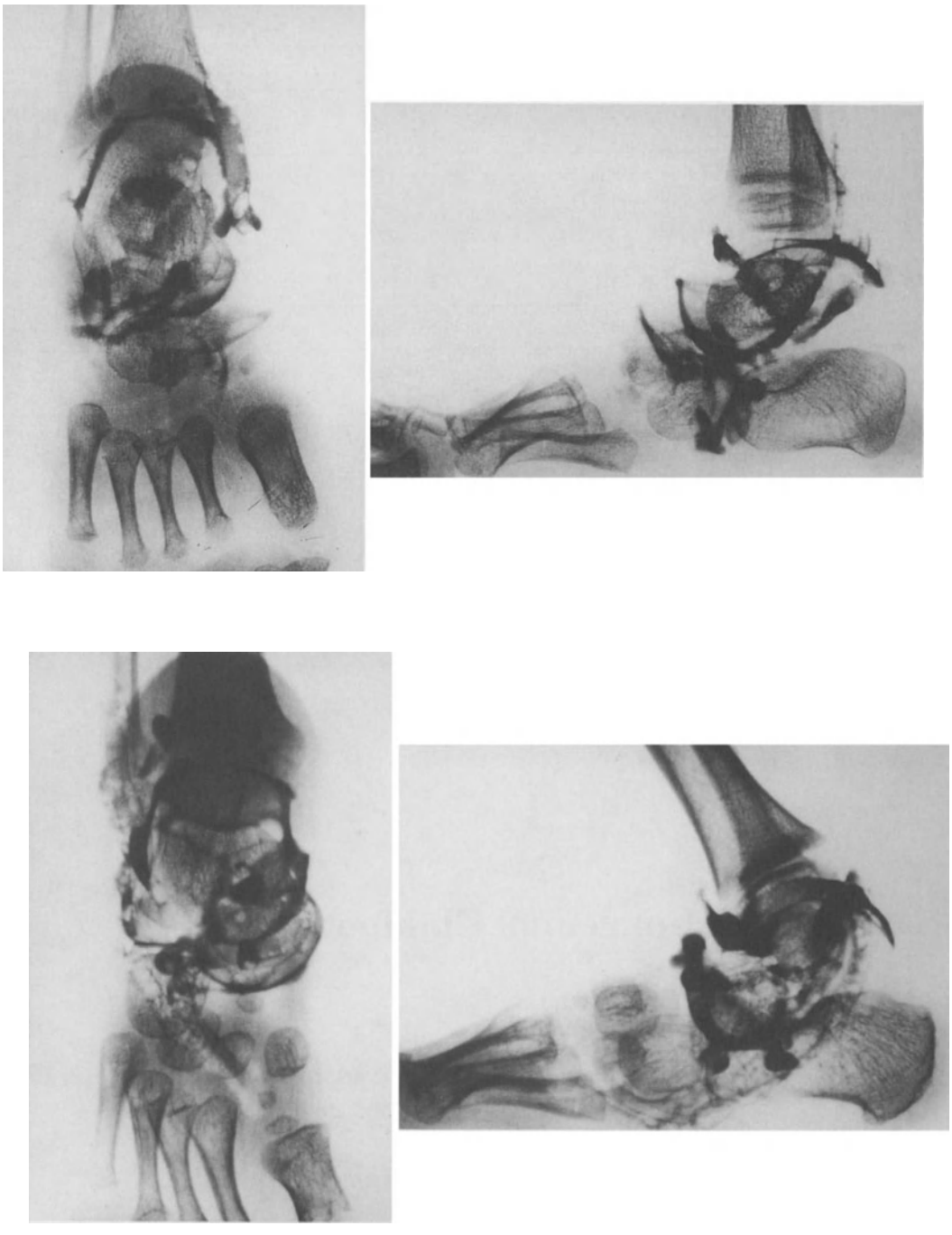


FIGURE 4.15. Arthrograms of a 4-year-old boy. Dysplasia of the talar head, shortening and medial deviation of the talar neck, and flattening of the talar trochlea were apparent in the congenital clubfoot at the bottom as compared with normal foot at the top. (Arthrograms of both of this patient's feet were printed on the same side for ease of comparison.)

and 9 were female. There were 15 unilateral cases and 16 bilateral cases. In the normal foot, 11 were male and 6 were female. There were 11 unilateral cases and 6 bilateral cases.

Arthrography

The patient was placed supine under general anesthesia. Sixty percent urographine using No. 16–gauge needles and small syringes was injected into the ankle joint by an anterior approach and in the talonavicular joint by a lateral approach. When arthrography was performed in an infant less than 3 years old, 1.0 ml of contrast medium was injected in the ankle and 0.5 ml of contrast medium in the talonavicular joint.

The technique for obtaining anteroposterior and lateral arthrograms was standardized. The distance from the focus of the x-ray tube to the film was 1 m, and the x-ray tube was placed perpendicular to the film. The anteroposterior arthrogram was taken with the foot in 30° plantar flexion and maximum abduction and the lateral arthrogram in maximum dorsiflexion.

The shape of the talus, the growth of the ossific nucleus of the talus, and the relationship between the talus and the calcaneus were evaluated on the basis of arthrographic analysis.

Results

All simultaneous arthrograms were not performed successfully, but all arthrograms available for measurement were used.

In general, arthrograms showed that the congenital clubfoot had medial deviation and shortening of the talar neck, dysplasia of the talar head and flattop talus, and the ossific nucleus of the talus was eccentric in the talar neck (Figure 4.15). This ossific nucleus of the talus gradually spread over the whole bone with the passing of time and its shape was nearly similar to that of adults by 6 years of age.

The following measurement was made to determine in detail the talar deformities and relationship between the ossific nucleus of the talus and that of the calcaneus in the congenital clubfoot:

1. *Ratio of the width of the trochlea to the radius of the head of the talus*. The width of the posterior portion of the trochlea and the radius of the head of the talus were measured on the anteroposterior projection (Figure 4.16). The mean ratio of the width of the talar trochlea to the radius of the talar head in normal feet was 0.639 ± 0.9 S.E., maximum 0.71 to minimum 0.57.

   The mean ratio of the congenital clubfeet

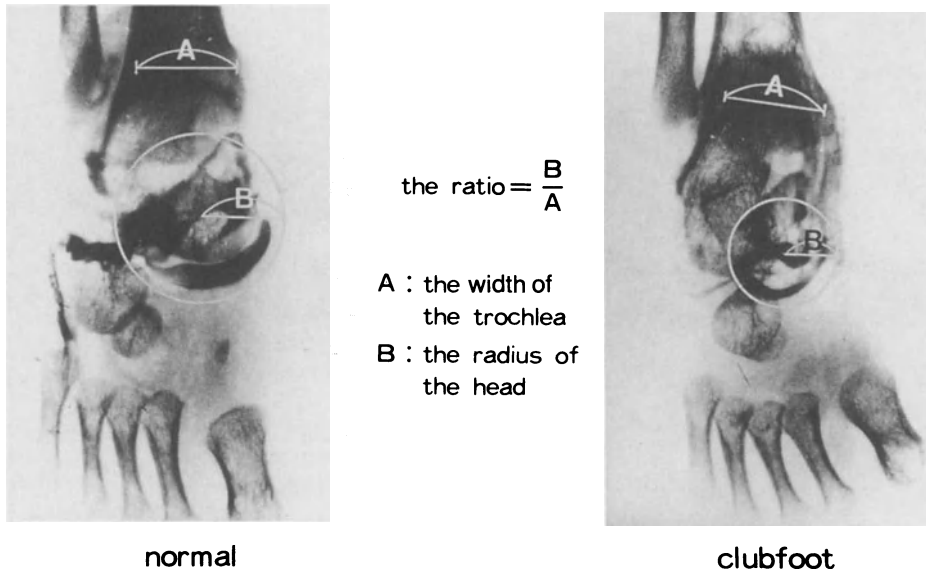


FIGURE 4.16. Measurement of the width of the talar trochlea and the radius of the talar head on the anteroposterior projection.

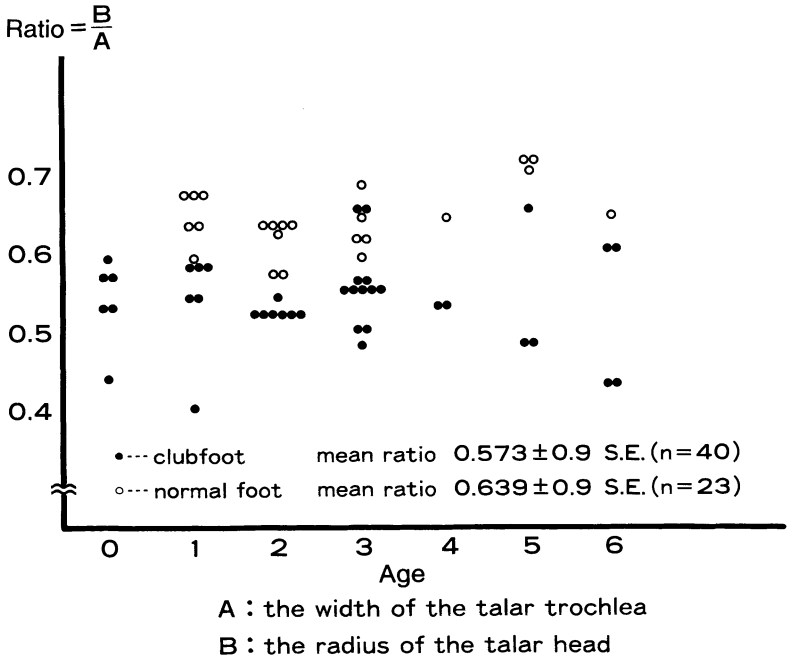


FIGURE 4.17. Ratio of the width of the talar trochlea to the radius of the head of the talus.

was 0.537 ± 0.9 S.E., maximum 0.65 to minimum 0.40. Thus, the ratio was reduced about 10% in congenital clubfeet compared with normal feet (Figure 4.17). The same results were obtained with six unilateral cases in which arthrograms of bilateral feet were made successfully. The results revealed that the head was much more deformed than the trochlea of the talus in the anteroposterior projection.

2. *The ratio of the height of the talar trochlea was measured on the lateral projection.* The length of the trochlea was represented by the distance from the anterior margin to the posterior margin of the trochlea. The height of the trochlea was represented by the dis-

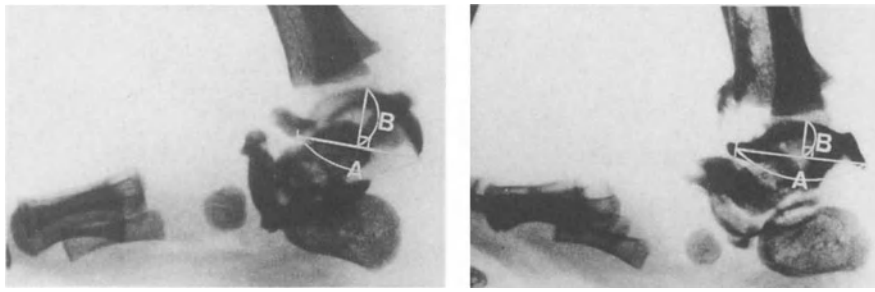


FIGURE 4.18. Measurement of the height of the talar trochlea. The base line is drawn tangentially to the anterior and posterior ankle recesses. A line is drawn perpendicularly from the top of the trochlea curvature to this base line. The ratio is determined by measuring the distance from the anterior to the posterior recesses and from the top of the trochlea to the base line.

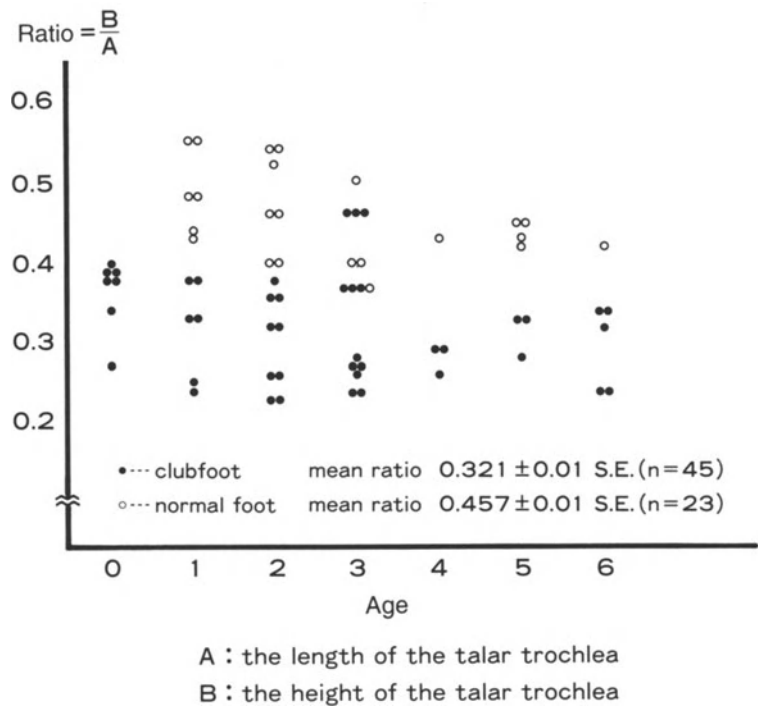
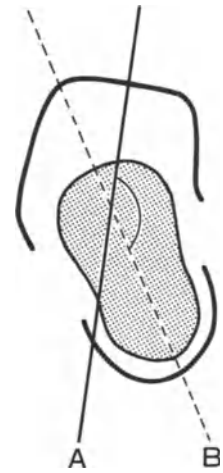


FIGURE 4.19. Ratio of the length of the talar trochlea to the height of the talar trochlea.

tance from the top of the curvature of the trochlea to the baseline which was drawn from the anterior to the posterior recesses of the trochlea. The flattop talus was represented by the ratio of the length to the height of the trochlea (Figure 4.18).

The mean ratio of the normal feet was 0.457 ± 0.012 S.E., maximum 0.55 to minimum 0.37. That of the congenital clubfeet was 0.321 ± 0.01 S.E., maximum 0.47 to minimum 0.23. The ratio of the congenital clubfeet was smaller, about 14% less than that of the normal feet (Figure 4.19). It was clear that these congenital clubfeet had more or less flattop tali.

3. *The relationship of the long axis of the talar body to the long axis of the ossific nucleus of the talus and calcaneus*. The angle between the long axes of the talar body as determined arthrographically and the ossified nucleus of the talus in the anteroposterior projection was the talar neck angle (Figure 4.20). The mean angle of the talar neck was $147.0° \pm 1.0°$ S.E. in the normal feet and $139.9° \pm 0.9°$ S.E. in the congenital clubfeet (Figure 4.21). It was clear that the congeni-



A : the long axis of the talar body
B : the long axis of the nucleus of the talus

FIGURE 4.20. The long axis of the talar body is the bisector of the angle between the medial and lateral articular margins of the trochlea. The long axis of the talar nucleus is the bisector of the angle between the medial and the lateral margins of the ossific nucleus.

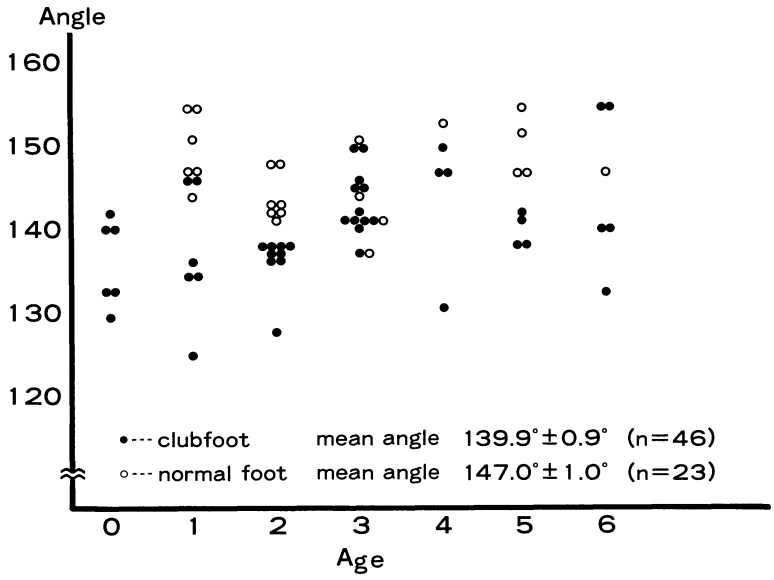
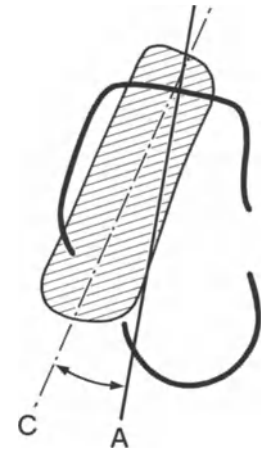


FIGURE 4.21. The angle between the axes of the talar body and the ossific nucleus of the talus in the anteroposterior projection.

tal clubfoot had medial deviation of the talar neck in greater or lesser degrees.

The mean angle between the long axes of the talar body as determined arthrographically and the ossific nucleus of the calcaneus (Figure 4.22) was $7.3° \pm 0.6°$ S.E. in the normal feet and $-8.9° \pm 1.2°$ S.E. in the congenital clubfeet. The angles of all normal feet were constant and not less than 0°. On the other hand, all of the congenital clubfeet had negative angles (Figure 4.23).

The results showed that these congenital clubfeet had medial deviation of the talar neck, dysplasia of the talar head, and flattop talus. Also, the angle between the axes of the talar body and the nucleus of the calcaneus was most reliable in the assessment of the correction.



A: the long axis of the talar body
C: the long axis of the nucleus of the calcaneus

FIGURE 4.22. The long axis of the talar body is the bisector of the angle between the medial and lateral articular margins of the trochlea. The long axis of the calcaneal nucleus is drawn parallel to its lateral border. The angle is negative if the long axis of the calcaneal nucleus is adducted to the long axis of the talar body.

Discussion

Settle[6] simulated arthrography of the talonavicular joints by covering its articular surface with lead foil. Hjelmstedt and Sahlstedt[3] have performed simultaneous arthrography of the talocrural and talonavicular joints in clinical practice.

Our arthrographic analysis showed the position of the talar ossification center, medial deviation of the talar neck, dysplasia of the talar head, and flattening of the talar trochlea. These findings agreed with the pathological findings described in dissection studies by Irani and Sherman[4] and Settle.[6]

In most reports, correction has been assessed on the clinical appearance of the foot as a whole and upon its function. Some authors

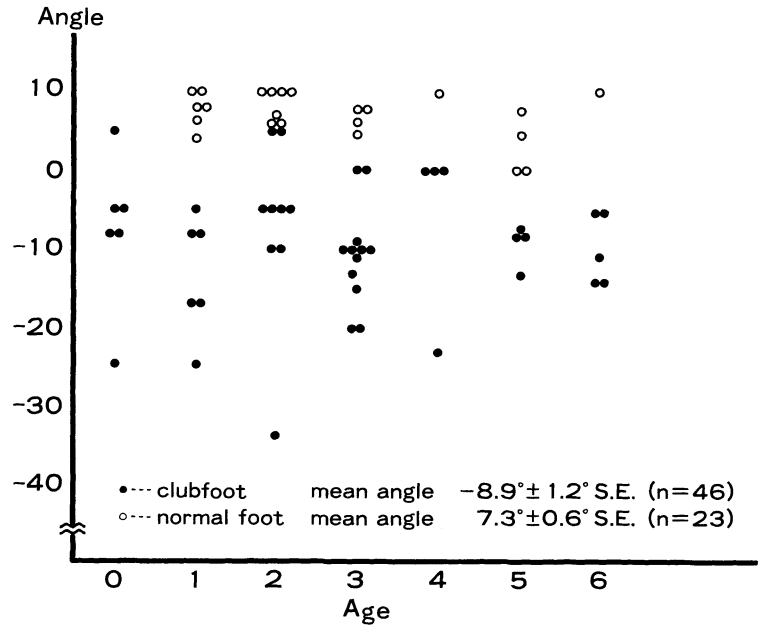


FIGURE 4.23. The angle between the axes of the talar body and the ossific muscles of the calcaneus in the anterior projection.

have made radiological assessments by measuring the talocalcaneal angles in the anteroposterior and the lateral projections.[1,2] Beatson and Pearson[1] advocated assessment by the talocalcaneal index where the talocalcaneal angles in the anteroposterior and lateral projection were added together. They stated that the correction was inadequate if the talocalcaneal index was under 40°. Turco[7] has not used this method for assessing correction because he believes there is a wide range of variation within the limits of normal. The talocalcaneal angle was somewhat useful in the lateral projection but, in my experience, the talocalcaneal angle on the anteroposterior projection was not as reliable for assessing the correction because the anteroposterior talocalcaneal angle proved to be more variable with arthrography.[5]

Therefore, it is suggested that the assessment based on the angle between the long axis of the talar body and the axis of the calcaneal nucleus on the anteroposterior radiograph is very important in making a decision for surgical treatment preoperatively and in accurately evaluating the correction of the clubfoot postoperatively. It has been demonstrated by arthrographic analysis that the angle between the long axes of the talar body and the ossific nucleus of the calcaneus is more accurate than the angle between the axes of the talar neck and the calcaneus.

Summary

Arthrography of the ankle and midtarsal joints was carried out in 47 clubfeet and 23 normal feet in infants. The shape of the talus, the growth of the ossific nucleus, and the relationship between the talus and the ossific nucleus of the calcaneus were evaluated on the basis of arthrographic analysis.

1. The nucleus of the talus exists eccentrically in its neck in infants and gradually the ossific nucleus spreads over the whole bone with the passing of time.
2. Dysplasia of the talus, especially in its head, and medial deviation of the talar neck, which were found arthrographically, corresponded with the anatomical findings that previous investigators have reported in the congenital clubfoot.
3. The anteroposterior talocalcaneal angle on the standard radiographs in infants was the angle between the long axes of the ossific nucleus of the talus and calcaneus and was not reliable in the assessment of correction.
4. The angle between the long axis of the talar body as determined arthrographically and the ossific nucleus of the calcaneus in the anteroposterior projection was more reliable than the talocalcaneal angle on the standard anteroposterior radiographs.

5. It is suggested that the assessment based on the angle between the long axes of the talar body and the nucleus of the calcaneus, as determined on the anteroposterior arthrogram, is very important in evaluating the correction of CTEV.

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Discussion

Watts (Los Angeles): We've recently done a study in which we attempted to determine the reproducibility of x-ray lines and measurements. On the AP view, there was a mean difference of 15° between anteroposterior talocalcaneal (APTC) angles measured by different people. For example, if you have a mean of 45° for an excellent result and then another examiner made the measurements and he measured 30°, does this truly represent a difference? I would say no; those are measurement errors. If the x-ray was measured 100 times by 100 different examiners they would fall within the same group.

Stevens (Lexington): I think Watts' point is correct in that we need to establish the reliability of the various measurements. However, I believe the reliability is better than Watts reports because we have informally made these same studies.

Realyvasquez (Pasadena): I can tell from the lateral view of the calcaneus that the foot is uncorrected, as the calcaneus has the appearance of an olive before it has been moved to its normal position. If the child is 7 or 8 months old and one takes a good lateral view of the calcaneus when the foot is corrected, the calcaneus will have a normal outline on the lateral radiograph.

Yamamoto (Tokyo): I find that the talocalcaneal angle is variable. So I use two angles, the tibiocalcaneal and the lateral (AP) MTB angle, as described.

Kitada (Nara, Japan): I did an assessment on the basis of the long axis of the talar body. For the talocalcaneal angles, I think the lateral radiograph proves most reliable. I think it is important to observe the shape of the talus and calcaneus, rather than to measure the talocalcaneal angle in assessing the correction. If good correction is achieved, you can see that the anterior part of the talus and calcaneus where there is contact and the shape of the calcaneal nucleus is similar to that of the calcaneus in adults in the lateral radiograph with full dorsiflexion.

Watts: So it's not only the angle, it's also the appearance. Dr. Barriolhet, what do you think about the accuracy of the measurements of the angle which you described for the forefoot?

Barriolhet (Santiago): Well, I think that it is a very simple method. It has a normal range of between 50° and 70° in young children. I'm interested mainly in the normal ranges in small children) as this is when I'm going to make a decision about surgery on the forefoot.

Watts: Dr. Barriolhet, I would like to ask how you differentiate your measurement of the forefoot between adductus of the forefoot and supination of the forefoot, because if the forefoot is supinated, by the time you put the first metatarsal down on the cassette, this angle presumably increases.

Barriolhet: You have to check that the heads of the metatarsals are all firmly placed on the cassette. I am not interested in the hindfoot in this projection. Therefore, the forefoot is flat on the cassette while the hindfoot is off the cassette.

Ward (Pittsburgh): Dr. Watts, you claim that radiographs for clubfeet are not reproducible and certainly not precise. Furthermore, we don't have very much data that shows that clinical evaluation is reproducible either; therefore, where do you think we should go from here without reproducible clinical or x-ray criteria?

Watts: I disagree with the statement that we do not have criteria. Dr. Cummings just presented data about clinical criteria. This is the first time we've had reproducibility data on some of the clinical criteria. However, even if our measurements are very bad, at least if we have confidence limits, we have a start. That is, if you know that the variability of measurement is 15°, it doesn't matter. If you take the same measurement 100 times and it's plus or minus 15°, at least you have a confidence limit against which you can check. I think that this is what we need for every measurement we use in orthopedics, x-ray or clinical.

Turco (Hartford): I would like to make a plea for the use of the stress dorsiflexion lateral view. One should measure the tibiocalcaneal angle on this view. The calcaneus assumes its adult shape very early. So, it's a good angle to measure. If you position the foot correctly, the fibula overlies the middle of the tibia normally. The degree of dorsiflexion in the normal child gradually diminishes from the day of birth until the child is about 7 years of age. In some cases, you can correct the subtalar incongruity and the midtarsal deformity but the tibiotalar incongruity may prevent full dorsiflexion. In the unilateral case, measurement of the tibiocalcaneal angle is excellent. You've got the normal to compare with. The bilateral case is not as much help. However, once you get the calcaneus to fully dorsiflex and the talus to dorsiflex in the mortise, the result will be good.

I take x-rays but not intraoperative films. There is an advantage to using intraoperative x-rays and that is to tell whether the K wires are too long or not. As far as checking for deformity, I don't use intraoperative x-rays. I know that the subtalar joint is unlocked and I know the navicular is where it should be.

Editor's Comments

No chapter in the clubfoot saga reveals more disagreement among observers than that on radiographic evaluation. The papers presented at the congress relative to the use of radiographs in clubfeet all had a common theme. Each author was dissatisfied with the current radiographic measurements and suggested new measurements to replace the old.

For example, **Barriolhet** proposed the first ray angle, which he claims is better than the calcaneo–fifth metatarsal angle or the talo–first metatarsal angle to measure forefoot adduction. **Yamamoto et al.** claim that the MTB angle is better than the talo–first metatarsal angle to measure forefoot adduction. They also believe that the lateral tibiocalcaneal angle is more valid than the lateral talocalcaneal angle for the measurement of equinus. Finally, they introduce the BMC angle as a measurement of varus of the hindfoot and rotation of the hindfoot, which they believe to be better than the APTC angle. However, **Stevens** and **Meyer** argue that the lateral talocalcaneal angle is better than the APTC angle, as they believe that it is the only angle that needs to be measured when evaluating the clubfoot. **Kita-**

da et al. have demonstrated by arthrography that the angle formed by the talar body and calcaneal axis is better than the angle formed by the talar neck and calcaneal axis (the APTC angle) in measuring varus and subtalar rotation of the hindfoot. Finally, another new measurement (the calcaneocuboid relationship) is presented in a paper in Chapter 8 by **Thometz et al.** The use of radiographs in the evaluation of CTEV is clearly an area of considerable controversy that must be given much attention in the future.

Barriolhet's first metatarsal angle would seem to be the optimal measurement for forefoot adduction. It is a measurement of movement only at the tarsometatarsal joints. Thus the midfoot proximal to this level and the hindfoot are excluded from this measurement. Furthermore, with the foot properly positioned, supination is also excluded from this measurement. Thus this represents a pure measurement of abduction or adduction of the forefoot—unlike previously described measurements, e.g., calcaneo–fifth metatarsal angle and talo–first metatarsal angle. Finally, it is easily measured but requires a separate view when supination is present.

In the first paper by **Yamamoto** and **Furuya**, the authors describe two new angular measurements, one of which they claim is more closely associated with good functional results than other currently used measurements. These measurements are the metatarsotalobimalleolar (MTB) angle and the bimalleolocalcaneal (BMC) angle. The first is a measurement of forefoot adduction, and the second is a measurement of varus and subtalar rotation of the calcaneus. Both angles are measured on the AP view. In addition, they claim that the MTB angle on this view and the tibiocalcaneal angle on the lateral view are more closely associated with good functional results than the other commonly used measurements. Multiple regression was used to verify the correlation between these measurements and the functional results. They use these angular measurements intraoperatively as well as pre- and postoperatively.

Yamamoto, **Furuya**, and **Muneta**, in a second paper, report their results using a modification of Turco's procedure and compare these results with their earlier series of conventional Turco procedures. Their modification of Turco's technique involves insertion of a Kirschner wire into the posterior portion of the calcaneus, which is then used to rotate the calcaneus beneath the talus after the medial portion of the interosseous ligament has been incised. Previously, their attempts at manual correction had frequently been unsuccessful.

I have also observed that this rotation is frequently impossible to achieve manually without releasing the interosseous talocalcaneal ligament (ITCL). This technique of partial release of the interosseous talocalcaneal ligament with Kirschner wire rotation of the calcaneus may be especially helpful in those children who have excessive ligamentous laxity (but who nevertheless have significant contracture of the interosseous talocalcaneal ligament), and in whom the chances of the navicular drifting into overcorrection (lateral talonavicular subluxation and valgus) following complete subtalar release (CSTR) with ITCL release is a major consideration.

I agree with **Yamamoto et al.** that the lateral tibiocalcaneal angle is a more valid angular measurement of equinus than the lateral talocalcaneal angle, which measures only the angular relationship between the talus and the calcaneus, whereas the lateral tibiocalcaneal angle measures the relationship between the calcaneus and the tibia. The lateral talocalcaneal angle is much more commonly used at present.

I agree with **Stevens** and **Meyer** that the lateral talocalcaneal angle, if uncorrected, is indicative of persistent deformity, especially equinus. I would have some apprehension, however, about not obtaining an interoperative AP view (as recommended by the authors), as I would be concerned that deformities that can be identified in this view might go unrecognized, for example, hindfoot varus, talonavicular subluxation, calcaneocuboid subluxation, and forefoot adduction. In addition to these, various deformities of overcorrection may also be present.

Kitada and colleagues conclude that the talar body axis and calcaneal axis form a more accurate angular measurement of the position of the talus and calcaneus relative to one another than does the long-accepted angle between the talar neck axis and the calcaneal axis. They use preoperative and postoperative arthrographic studies to evaluate the angle between the talar body axis and the calcaneal axis.

5
Vascular Aspects

Introduction

Two papers in this chapter deal with different techniques of evaluating the abnormal arterial patterns in clubfeet. The paper by **Crider et al.** describes the comparison of arteriographic and Doppler techniques, whereas that by **Stanitski et al.** describes a comparison of Doppler and pulse oximetry techniques. In addition, **Crider et al.** have presented a very informative table comparing the techniques of color Doppler ultrasound imaging with digital subtraction arteriography and conventional arteriography.

The final paper in the chapter deals with anamolous circulation in CTEV. **Simons** describes a case of congenital absence of the posterior tibial artery and veins. The four patterns of arterial anatomy of the lower leg are reviewed and a technique for identification of the foot with anomalous vascularity is presented with the author's method of treatment for this problem.

Noninvasive Vascular Studies in Clubfoot

C.L. Stanitski, W.T. Ward and W. Grossman

Implications of abnormal vasculature in congenital idiopathic clubfoot (CTEV) are important at all stages of clubfoot study from etiology to sequelae of treatment.

Over the past 80 years a variety of cadaveric and in vivo clubfoot studies have reported a high incidence of hypoplasia or absence of the anterior tibial artery with dominance of the posterior tibial artery.[1,2,6–8,15,16,18] To investigate blood flow and tissue oxygen saturation in clubfeet at the time of surgery, a two-phase noninvasive study of clubfoot vasculature was carried out.

Phase 1 consisted of pulse oximetric study of the great toe.[12,13] Phase 2 used Doppler flowmeter evaluation of the peroneal, dorsalis pedis, and posterior tibial arterial pulses.[17] Both phases assessed the foot in various similar positions.

Materials and Methods

Phase 1

A consecutive series of 40 idiopathic clubfeet in 27 children ages 3 to 8 months (5.1 average) were studied. All feet had been resistant to manipulation and serial casting. No patient had previous surgery. All patients were less than 1 year old at time of surgery.

A Nellcor N25 Oxisensor was used to assess pulse oxygenation of the clubfoot great toe using simultaneous Oxisensor right thumb oxygenation saturations for comparison. At surgery, pulse oximetry was determined in all 40 clubfeet in three positions per foot: normal resting attitude, position of maximal passive correction, and immediately postoperatively following a comprehensive soft tissue release via a Cincinnati incision with pin fixation. In 22 feet (16 patients), pulse oximetric measurements of the great toe were made at the time of cast change 3 weeks postoperatively.

Phase 2

Doppler studies were done on 28 feet in 17 children ages 3 to 8 months (average 5.6 months) that were resistant to serial casting and were to undergo comprehensive soft tissue release. Dorsalis pedis, posterior tibial, and peroneal pulses were recorded at three stages: preoperative resting posture, preoperative maximal passive correction, and 3 weeks postoperatively.

In unilateral cases, the opposite normal foot and radial artery were used as controls. The radial artery was used as control in bilateral cases.

Results

Phase 1

Pulse oximetric results showed the following: in a resting position, all (40 of 40 feet) had oxygen saturation recordings of between 94% and 100%; in maximal passive correction, 90% (36 of 40 feet) had oxygen saturations of 95% to 100%; and immediately postoperatively, 39 of 40 feet demonstrated oxygen saturations of 97% to 100%. One foot's oxygen saturation was less than 90%. At the time of the postoperative cast change, 22 of 22 feet demonstrated great toe pulse oxygenation measurements of 97% to 100%.

Phase 2

Doppler studies demonstrated dorsalis pedis and posterior tibial pulses to be present in *all* feet. Peroneal pulses were noted in 13 of 20 feet studied. Posterior tibial pulses were unaffected by changes in position, either passively or operatively, in 70% of the foot positions studied. Dorsalis pedis pulses were unchanged by foot position in 60% and peroneal pulses were unchanged by foot position in 40% to 50%.

Diminution of pulse with change of position was noted least often with the posterior tibial i.e., 30%, whereas the dorsalis pedis was 40% and the peroneal was 40%. In 30% of the peroneal, 13% of the dorsalis pedis, and 10% of the posterior tibial, pulses were increased when comparing change of passive corrective pulse to that noted at time of postoperative cast change.

Posterior tibial artery and radial artery controls were equal in all specimens studied in the premanipulated state.

Discussion

All previous papers on dissections of full-term postmortem infant clubfeet that have described the vasculature of these limbs note that the vessels are all "normal."[10,11,14,18] Previously reported postmortem injection studies of both fetal and term specimens as well as in vivo arteriography of clubfeet report significant abnormalities of foot vasculature in 90% of feet.[7,8,15]

The absence of adequate vascular supply to the foot has been postulated as an etiological factor of clubfoot since Böhm[3] (1929) hypothesized an embryonic arterial dysgenesis that arrested the development of the foot at the 5-week stage, when all feet are in a "clubfoot" posture. He theorized that the anoxia secondary to loss of blood flow caused differential lateral foot overgrowth.

Atlas et al.[1] in 1980, following arteriographic

assessment of fetal limbs, incriminated loss of vascular supply to the sinus tarsi, which resulted in talar deformation, medial fibrosis, and subsequent progressive fixed deformity of clubfoot.

Edelson and Husseini,[5] by Doppler examination, noted absence of dorsalis pedis arteries in 6.7% of severe clubfeet in children less than 3 years of age and almost 40% of clubfeet (39.9%) in children over 3 years of age. They found no such deformity in mild cases of clubfoot. These authors suggested that the absence of the dorsalis pedis pulse was secondary to adaptive changes in severe clubfeet aggravated with extrinsic factors such as casting and ambulation.

Sodre et al.[15] performed arteriograms in 30 feet of 17 patients with CTEV of which 10 feet were previously untreated. In 89% of the feet they noticed a diminution or absence of the dorsalis pedis and anterior tibial artery and medial plantar artery or plantar arch. This was in contradistinction to the "normal" congenital deficit in the anterior tibial artery of 2% to 7% depending on the series studied.[4] These authors found no relationship between the severity of the clinical clubfoot and the degree of arterial insufficiency. The peroneal and posterior tibial arteries appeared normal in all studies. In three patients, comparison of preoperative and postoperative arteriograms showed no change.

In nine feet in five patients, Sodre et al.[15] used Doppler studies to assess the anterior tibial, posterior tibial, and dorsalis pedis vessels in 3- to 12-year-old patients with clubfeet. These authors felt that the Doppler data did not correlate with the arteriograms in these children for either anterior tibial or dorsalis pedis pulses. They felt that the Doppler was able to pick up pulses not identified arteriographically.

These authors also felt that retrograde flow may be a source of pulsations picked up by Doppler that could not be assessed by arteriography. Despite enhanced vasculature assessment by Doppler versus arteriography, they felt that the Doppler failed to provide a sufficient degree of detail to discriminate clearly between various vessels and was of less value.

The Doppler studies in this series were done with accurately positioned pediatric-sized Doppler flowmeters that were aligned in the direction of the vessel studied, with care taken not to compromise the signal by excessive pressure and/or malorientation of the transducer. Doppler measurements record transcutaneous flow with the amount of frequency shift related to the velocity of the moving object relative to the point of observation. Doppler measurements are thus measurements of velocity and not volume,[17] which may account for some of the discrepancies of the studies noted by Sodre et al.[15] The ages of the patients in our series were significantly younger than those of Sodre et al. and Edelson and Husseini,[5] and this may account for some of the data discrepancies.

At resting postures, all of the clubfeet had dorsalis pedis and posterior tibial pulses present with excellent oxygenation of the great toe. With passive manipulation, even though some diminution of oxygen saturation and pulse did occur in some feet, these two factors were not always correlated. At postoperative cast change, all feet evaluated had normal great toe oxygen saturation. Release of soft tissue and bone tethers and improvement in collateral flow may account for this postoperative vascularity.[9] No postoperative wound healing or skin problems were noted in any of the clubfeet in our series.

Summary

We feel that pulse oximetry is a sensitive monitor of blood flow in the idiopathic clubfoot. We also feel that Doppler assessment of pulses in clubfoot is a reproducible monitor of blood flow velocity that may change with position either during the manipulative and/or surgical correction of clubfeet.

Pulse oximetry and Doppler flowmeter studies are safe, noninvasive, reproducible, and accurate means of monitoring vascular integrity in clubfeet.

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A Comparison of Arteriographic and Doppler Techniques in Evaluating the Abnormal Arterial Patterns in Talipes Equinovarus

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Since the etiology of clubfoot (CTEV) is unknown, there has been recent interest in the frequency of arterial dysgenesis in limbs exhibiting congenital idiopathic clubfoot. Arteriographic studies performed in limbs with the clubfoot deformity showed that 63 out of 71 limbs (89%) exhibited reduction or absence of the anterior tibial and dorsalis pedis arteries,[1,3,5,7,8,12] whereas congenital deficiency of the anterior tibial artery in otherwise normal populations has reported a range of incidence of only 2.4% to 7.1%.[10] In the largest of these studies,[13] 17 patients with 30 congenital clubfeet underwent arteriography preoperatively at the Escola Paulista de Medicina in São Paulo.[12,13] Ten limbs in seven of these patients had not been treated, and the remaining limbs had been treated by casting only. No relationship between the severity of the clinical condition and the degree of arterial deficiency was noted in the surgical patients studied arteriographically. Ten patients with bilateral clubfeet (20 feet) were less than 16 months old at the time of arteriography. Abnormal arterial

patterns were revealed in all but two limbs in one patient. The abnormalities consisted primarily of hypoplasia or premature termination of the anterior tibial artery in 93% of the limbs and absence of the medial plantar artery as well in 93% of the limbs. The posterior tibial and peroneal arteries were normal in all the limbs they studied.

Arterial deficiencies demonstrated by arteriography conflict with data gathered by the continuous-wave Doppler technique,[2] which has shown deficiency of the dorsalis pedis artery in only 6.7% (2 of 30) of limbs with severe clubfoot in patients less than 3 years of age and 38.9% (7 of 18) in patients over 3 years of age. No deficiencies were noted in mild cases. Furthermore, the investigators reported no retained embryonic vessels, incomplete plantar vessels, or arterial hypoplasia, which have been noted previously.[5,6] They suggested that dorsal pedal pulselessness represents a secondary adaptive change to severe, prolonged deformity.

Since the arteriographic pattern has been shown not to be altered by surgical correction in TEV,[3] we assume that the results of the Doppler examination performed postoperatively also remain unaltered and reveal the same pattern perioperatively. The purpose of the present study is to assess the usefulness of arteriography and the continuous-wave Doppler technique in evaluating the arterial patterns in limbs with clubfeet.

Materials and Methods

To delineate the relationship between the results obtained by iodinated contrast arteriography and by continuous-wave Doppler examination, nine limbs in five patients were studied with both techniques. Four patients with bilateral deformities and one patient with unilateral deformity were studied. These patients were part of the larger group of patients with 30 clubfeet studied arteriographically by Sodre et al.[10,11]

The arteriography was completed before surgery and the Doppler studies were performed postoperatively. The vascular surgeon performing the Doppler examination used a 5-MHz continuous-wave Doppler transducer and was blinded to previous arteriographic findings. The pressure data were obtained by placing a pressure cuff with attached manometer at a level approximately 3 cm proximal to the medial malleolus. Detection of blood flow was accomplished with the continuous-wave Doppler transducer. The cuff was inflated and subsequently deflated while the surgeon insonated for restoration of blood flow with deflation of the blood pressure cuff. Pressures were recorded while the surgeon insonated with a continuous-wave Doppler over the customary anatomic position of the dorsalis pedis artery on the dorsal portion of the midfoot, the anterior tibial artery approximately 2 cm above the ankle on the anterior aspect of the limb, the posterior tibial artery immediately posterior to the medial malleolus, and the brachial artery in the antecubital fossa.

Results

The results of the Doppler examinations are examined in Table 5.1. The patients are numbered according to their position in the report of Sodre et al.[10] Arterial pressures (mm Hg) measured in the right brachial, anterior tibial, dorsalis pedis, and posterior tibial arteries are shown for each patient. The brachial artery pressures are shown for reference. Patient 12 exhibited pulses anterior to the distal fibulae, which were interpreted as a variant of the peroneal artery, a finding confirmed with arteriography. The pressure in these arteries was 90 mm Hg on the right side and 70 mm Hg on the left.

The Doppler findings did not correlate with the arteriograms for the anterior tibial and dorsalis pedis arteries (Table 5.1). Although the pressure level of the anterior tibial and dorsalis pedis arteries was reduced in seven of nine cases, the Doppler technique identified pulses in limbs in which arteriography had demonstrated hypoplasia in one limb and proximal termination of the anterior tibial arteries in the others. The Doppler studies in all patients revealed normal brachial arterial pressures with roughly equal or stronger posterior tibial arterial pressures.

Examples of the typical abnormal arterial pattern demonstrated by arteriography can be seen in Figure 5.1. For comparison, a normal arteriogram is shown in Figure 5.2.

TABLE 5.1. Results of Doppler examination.

		Arteriographic data				Doppler data*			
Patient number	Age (yr, mo)	Side	Anterior tibial†	Plantar arch	Age (yr, mo)	Anterior tibial	Dorsalis pedis	Posterior tibialis	Brachial right arm
1	8,10	R‡	Normal	Deficient	12,6	100	100	100	90
		L	Proximal	Deficient		100	100	100	
7	0,9	R	Middle	Deficient	3,1	60	60	100	70
		L	Middle	Deficient		60	60	100	
12	1,1	R	Middle	Deficient	3,6	80	80	80	80
		L	Middle	Deficient		70	70	80	
13	0,11	R	Distal	Deficient	3,3	70	70	90	70
		L	hypoplasia throughout	Complete		70	70	90 80	
16	5,0	R	Distal	Deficient	8,3	60	25	80	80
		L	Distal	Deficient		40	70		

*Pressure (mm) at which the sound disappeared.
†Point of termination of the anterior tibial artery in proximal, middle, and distal third of the leg.
‡Only normal limb in this set of limbs. All other limbs had a clubfoot deformity.



Figure 5.1. The abnormal arteriograms of patient #13 reveal severe deficiencies of the anterior tibial arteries (the first major branch in the leg). The corresponding Dopplers, however, indicate that arterial sounds are present as shown in Table 5.1.



Figure 5.2. Arteriogram of the leg demonstrating the normal pattern and equal caliber of the anterior and posterior tibial arteries.

Discussion

Arteriographic studies of limbs with idiopathic congenital clubfoot deformities have revealed a high incidence of associated arterial anomalies.[1,3,5,8,10] Proximal termination or hypoplasia of the anterior tibial artery is usually present and the lateral plantar artery provides the dominant blood flow to the foot. This was the case in our patients, since none of the nine limbs we studied had demonstrated complete filling of the anterior tibial artery and its derivatives in the foot.[9] However, all of the limbs exhibited anterior and posterior tibial and dorsalis pedis pulses when assessed by the continuous-wave Doppler technique. The results of the continuous-wave Doppler assessment and iodinated contrast arteriography in describing the anterior tibial and dorsalis pedis arterial circulation of children with TEV deformity were completely different. Doppler frequency-shift signals were obtained from the dorsal surface of the ankle and foot. The signal was present even in individuals with no arteriographic evidence of an anterior tibial artery.

One possible explanation for the discrepancy between the Doppler readings and the arteriographic findings may be that the dorsalis pedis artery is hypoplastic and develops spasms in the presence of arteriographic contrast medium. These arterial spasms might cause the radiographic "absence" of the artery.

We favor the more likely explanation that small vessels that have anastomosed with the lateral plantar artery result in retrograde flow and an audible pulse. The illustration in the article by Edelson and Husseini[2] supports the latter supposition by demonstrating the waveform of biphasic collateral flow rather than the triphasic waveform expected with direct antegrade unimpeded arterial flow. Thus, the continuous-wave Doppler examination may

demonstrate a dorsal "pulse" indicating the presence of a functional artery on the dorsum of the foot. A positive dorsal signal does not prove that there is an underlying arterial flow that is a normal derivative of the anterior tibial artery, nor that it contributes significantly to the viability of the foot. This interpretation is strongly supported by the arterial pattern noted in the detailed anatomic dissection of a clubfoot.[6]

Dissection is clearly the most sensitive and accurate way to identify arterial patterns. The observation that arteriography strongly correlated with dissection in a previous study[6] causes us to place more confidence in the anatomic information discerned from arteriography than from continuous-wave Doppler assessment.

In viewing these data with respect to the etiology of TEV, the arterial deficiencies in untreated preambulatory children suggest that the anomalies are congenital.[5] Thus, abnormalities of both the anterior tibial and the medial plantar arch would not both have been caused by walking or casting.[1–3] We disagree with the hypothesis suggested by Edelson and Husseini[2] that these vascular abnormalities are caused by extrinsic postnatal factors, because the arteriographic patterns in most patients in the study by Sodre et al.[10] were abnormal regardless of their age, ambulatory status, or treatment. Among the five patients in the Doppler group were three children less than 1 year of age at the time of arteriography. These three children, in addition to seven others with bilateral deformity, were less than 16 months of age before arteriography and, therefore, had walked little or not at all. Since these abnormalities appear to be congenital and not acquired by walking or prolonged deformity, they may have great etiologic importance,[4–6,11] and support the theory that the etiology of idiopathic TEV may be related primarily to arterial dysgenesis.

Since the clubfoot is usually supplied by only a single functioning artery, the posterior tibial, great care must be taken in performing a posteromedial release. We recommend routine perioperative monitoring by pulse palpation and observation of skin color to determine the status of posterior tibial arterial patency while the foot is held in the position of casting. If further arterial evaluation is necessary, color angiodynography should be considered (Table 5.2).[10] (The advantages, disavantages, and limitations of resolution of three Doppler imaging techniques are compared in Table 5.2.) Damage to this artery by direct surgical trauma or premature dorsiflexion of the ankle could be catastrophic.[12] Furthermore, absence of the dorsalis pedis pulse may indicate severe deficiency of the plantar arch. Sporadic reports suggest that foot amputation secondary to necrosis[7,8] as well as medial skin sloughs[3] and poor wound healing[5,12] may be anatomically related to deficient arterial flow. Recognition of this abnormal arterial pattern in the surgical treatment of clubfoot is imperative!

TABLE 5.2. Arterial imaging at 1 cm depth in children.

Technique	Limiting lateral resolution	Advantages	Disadvantages	Timing of image
Color Doppler ultrasound imaging 7.5 MHz transducer quantum QAD1	0.1 cm	No anesthetic Best screening modality	Detail in the foot sometimes obscured by highly echogenic bone	Not important—detects flow to 0.3 cm/sec
Intra-arterial injection–digital subtraction arteriography	0.14–0.20 mm ideal with 0.3 mm focal spot (movement of vessel with cardiac cycle will degrade resolution)	Less contrast required	Arterial puncture General anesthesia Limited field of view	Not important
Conventional cut film arteriography	0.08–0.14 mm with 0.3 mm focal spot	Full field of view	Arterial puncture General anesthesia More contrast exposure	Important—can miss contrast as it flows into small distal arteries

Summary

Preoperative arteriography in 30 uncorrected clubfeet demonstrated abnormal vascular patterns in all but two limbs. Hypoplasia or absence of the anterior tibial and dorsal pedis arteries was evident in 93% of the limbs. Postoperative Doppler study of nine of the limbs with this abnormal arteriographic pattern indicated that these arteries were present. We suggest that the continuous-wave Doppler technique is less useful for the study of the vascular pattern in limbs with congenital defects than either dissection or arteriography. Furthermore, arterial dysgenesis may play a role in the etiology of clubfoot. Since the posterior tibial artery usually provides the only significant blood supply to these clubfeet, it must be protected at surgery and during subsequent ankle dorsiflexion. We recommend color (Doppler) arteriodynography as the most accurate and practical technique for the perioperative evaluation of the arteries in clubfeet when indicated.

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Anomalous Circulation in Clubfoot

George W. Simons

Sarrafian[6] described four patterns of vascularity in the normal foot and leg, and several recent papers on the arterial supply of clubfeet have employed different methods to study arterial patterns of blood flow to the foot. The methods used have included arteriography,[4,5,9] the ultrasonic Doppler,[1,3,7,11] and pulse oximetry.[10,11]

The Doppler and pulse oximetry studies do not agree with the arteriographic studies. One arteriographic study (19 clubfeet) reported that the dorsalis pedis artery is usually missing in the extremity with a clubfoot.[4] A second arteriographic study (30 clubfeet) showed that the anterior tibial artery was hypoplastic or absent in 90%.[9] Both studies concluded that the posterior tibial artery is the primary artery and, in most cases, provides the only blood supply to the clubfoot.

One ultrasonic Doppler study, however, reported that in 2.2% of the general population the dorsalis pedis is absent.[1] A second Doppler study (79 clubfeet) showed that only 14% of clubfeet lacked a dorsalis pedis pulse entirely, whereas another 10% had a barely detectable pulse.[7] A third study (63 clubfeet) reported that the dorsalis pedis was always present in mild and moderate clubfeet and was absent in 2 out of 30 feet in children under 3 years of age with severe deformity. In this study, the incidence of pulselessness correlated with the severity and duration of the deformity, but not to the extent suggested by arteriography.[3]

Finally, a study using pulse oximetry revealed that 14 of 15 clubfeet had +99% oxygen saturation in all phases of the study. No significant change in peripheral oxygen saturation was noted in 86% of clubfeet at the time of surgery or 3 weeks after surgery.[10]

It is difficult to reconcile these various, and to some degree, contradictory reports without further studies, yet two conclusions can be drawn. First, the incidence of anomalies of the vasculature in this area is relatively uncommon, but not rare. Second, the incidence of very thin or absent vessels from the three major branches of the popliteal artery is reported to be between 2% and 8% of cases;[6] surgeons who operate on a patient with clubfeet should be aware of these congenital arterial anomalies. This paper presents a previously unreported anomaly of this type and suggests a technique for the safe handling of this anomaly.

Methods for recognizing arterial anomalies during surgery and a technique for safely handling the anomalous vasculature have not been reported in the current literature.

Purpose

This paper reports a case of a typical clubfoot with an arterial anomaly and describes how this anomaly was successfully treated without injury to the vascular structures. A second case is discussed briefly to develop the clinical implications of the presence of such anomalies.

Case History

The patient was a 6-month-old boy born with Down syndrome and bilateral "typical" clubfeet. Treatment at birth consisted of plaster cast changes at weekly intervals. The child was referred to Children's Hospital of Wisconsin after a plateau in treatment had been reached. When first seen at our hospital, the patient's feet were thought to be "typical" in type. They were not the mild postural clubfeet occurring in the last trimester of pregnancy, nor the rigid clubfeet seen with arthrogryposis. The feet had a moderate degree of stiffness with all of the original deformities remaining uncorrected to some degree. A family history of clubfeet was negative. The child had no other anomalies.

At surgery, the patient was placed in the prone position and the Cincinnati incision was made after the foot was exsanguinated and the tourniquet inflated.[2] Initial dissection was directed to the exposure of the neurovascular bundle. The tissue thought to be the neurovascular bundle was identified through the overlying crural fascia. However, the partially filled veins normally visible were not observed. Believing the exsanguination of the vessels to



Figure 5.3. Posterior medial view of the lower leg and foot. The heel is at the lower left of the photograph. An umbilical tape (3 large arrows) is shown retracting: (1) the anomalous vessels on the left (a), and (2) the posterior tibial nerve (n) and its calcaneal branch on the right (c). Distal to the umbilical tape the flexor hallucis longus (f) is seen lying deep to and between the posterior tibial nerve and calcaneal branch on the right and the anomalous vessels on the left. Observe that the anomalous vessels originate posteriorly, pass in a medial-distal direction, and lie superficial to the flexor hallucis longus (f) at the level of the subtalar joint (j). Normally, the posterior tibial artery and veins lie adjacent to the posterior tibial nerve.

be complete, the tourniquet was released for approximately 2 seconds to allow the vessels to fill. Following this, and two subsequent brief attempts to perfuse the vessels, filling of the veins was not seen. The neurovascular sheath was then carefully opened and its contents inspected. The posterior tibial nerve and its calcaneal branch were identified and appeared normal. Fibrous tissue filled the remainder of the sheath and neither the vein nor the artery could be identified.

With the origin of anomalous vessels anticipated to be more posteriorly, careful dissection was directed posteriorly. Two veins were identified lying anterior to the flexor hallucis longus tendon. Upon careful inspection, an artery was identified lying between the veins. These vessels were dissected free proximally and distally for a total of approximately 3 to 4 cm.

In the proximal portion of the incision, the anomalous vessels were located posterior to the flexor hallucis longus; they coursed distally over the flexor hallucis longus and were lying beside the calcaneal branch of the posterior tibial nerve at the level of the tibial plafond (Figure 5.3). In order to determine whether these provided the main blood supply to the foot, the vessels were occluded with a small forceps and the tourniquet was released. After releasing the forceps, perfusion occurred gradually over a period of approximately 30 seconds. The surgical procedure was then continued with special attention to the preservation of further vessels if found, but none was observed. When the soft tissue dissection was complete (complete subtalar release, plantar release, and calcaneocuboid release)[8] and verified with intraoperative radiographs, the tourniquet was released, and the perfusion of the foot was slow but complete. The child's postoperative course was complicated by necrosis of the skin of the posterior heel bilateral-

ly. These areas required almost 3 months to heal but did not require skin grafts.

Discussion

Unfortunately, Doppler testing was not performed preoperatively in this patient. A Doppler signal would probably not have been obtained over the portion of the ankle where the posterior tibial artery is normally located.

The congenital absence of the posterior tibial vessels was unilateral. Thus, one may speculate about the cause for the bilateral necrosis.

It is well known to anesthesiologists that children with Down syndrome have very small and thin vessels; thus, the blood supply and healing may have been suboptimal in these patients. Thus, a possible cause of the bilateral skin necrosis was Down syndrome. Skin complications should be anticipated in patients with clubfeet who have Down syndrome and every effort made to avoid these complications.

Another possible cause was the use of the Cincinnati incision but this was used in both feet.[2] In our experience, posterior heel necrosis is rare with this incision. Mild wound edge necrosis along the posterior medial margin of the proximal skin edge is not uncommon, but that is of no significance other than producing a mild widening of the scar. If the anomaly had been present in both feet, the incision could have been erroneously incriminated as the etiologic factor.

Normal Arterial Anatomy of the Lower Leg

The normal arterial anatomy of the lower leg is described by Sarrafian[6] as follows:

At the level of the tibial plafond, the tunnels of the posterior tibial tendon and flexor digitorum longus are (lying obliquely) side by side and are separated from the tunnel of the flexor hallucis longus by an interval, the intertendinous interval. The neurovascular tunnel is superficial to the intertendinous interval and to the tunnel of the flexor hallucis lon-

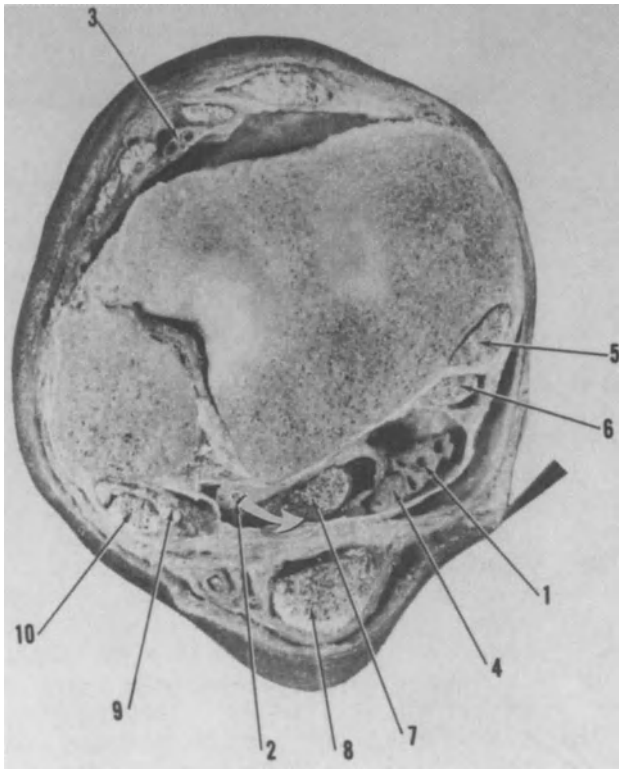


Figure 5.4. Cross section of the left ankle of a cadaver specimen 1 cm proximal to the tibial plafond. The anomalous artery and veins crossed the flexor hallucis longus tendon lying superficial to it just distal to the level described here. The white arrow shows the change of position between the normal posterior peroneal vessels and the anomalous posterior peroneal vessels. At a more proximal level, the distance between the tendon and anomalous vessels is greater. 1, Posterior tibial artery and accompanying veins; 2, posterior peroneal artery and veins; 3, anterior tibial artery and veins; 4, posterior tibial nerve; 5, tibialis posterior tendon; 6, flexor digitorum longus tendon; 7, flexor hallucis longus tendon and muscle; 8, Achilles tendon; 9, peroneus brevis tendon; 10, peroneus longus tendon. (Reprinted by permission from Sarrafian.[6])

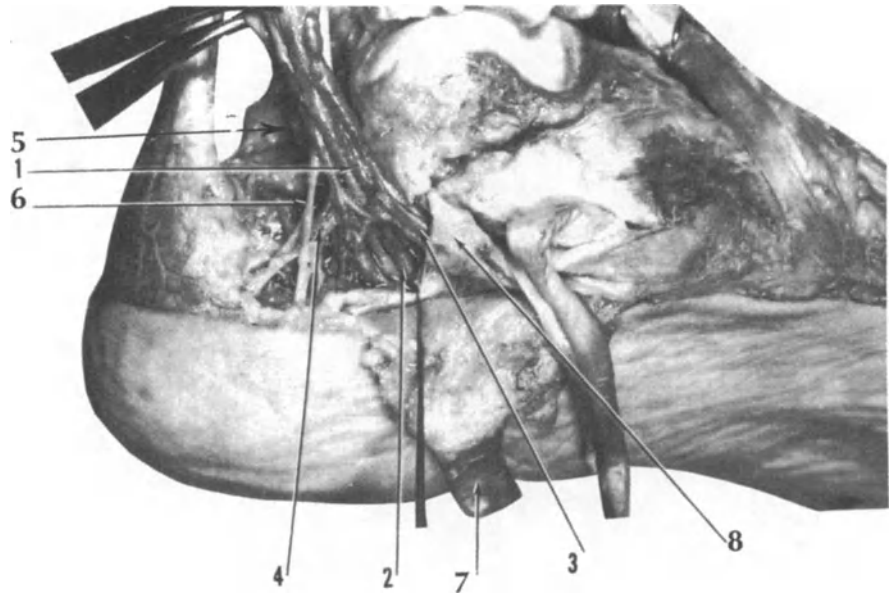


Figure 5.5. Medial aspect of the left foot of a cadaver specimen. The neurovascular bundle and tendons lie in the frontal plane at the upper level of the figure; as they pass behind the medial malleolus, they move into a nearly sagittal-oblique plane. The anomalous vessels were located posteriorly to the calcaneal branch of the nerve, approximately in the position denoted at 5. 1, Posterior tibial artery; 2, lateral plantar artery; 3, medial arterial branch; 4, posterior medial calcaneal arterial branch; 5, approximate location of anomalous vessels; 6, medial calcaneal nerve; 7, reflected flexor retinaculum; 8, deep investing aponeurosis. (Reprinted by permission from Sarrafian.[6])

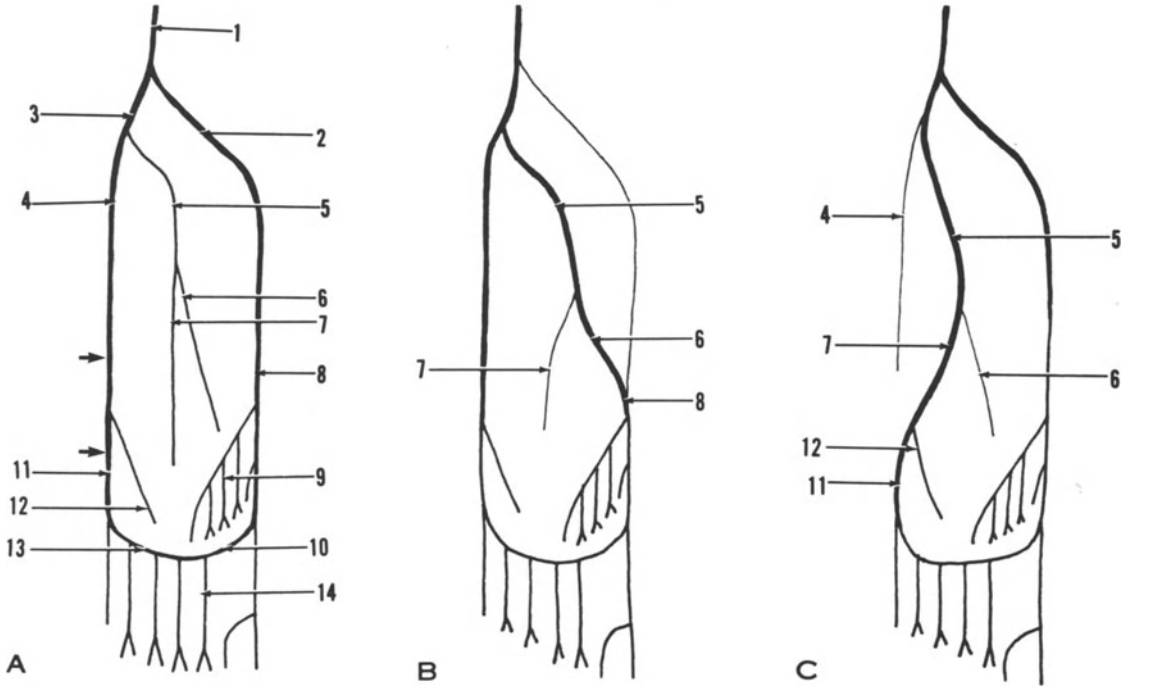
gus. The posterior tibial artery and veins are in this (intertendinous) tunnel, medial to the posterior tibial nerve. This compartment is covered by the deep crural fascia [Figure 5.4].

[Just distal to the level of the tibial plafond (i.e., retromedial malleolar level)] the passage zone curves anteriorly so that the tendons and neurovascular bundle change from the frontal plane to a sagittal-oblique plane [Figure 5.5]. The neurovascular bundle is now posterior to the tunnel of the flexor digitorum longus and is superficial and medial to the intertendinous interval and to the tunnel of the flexor hallucis longus. The posterior tibial artery follows the anterior cavity of its compartment and is accompanied by its two veins.[6(p281)]

Arterial Variations in the Lower Leg

The arterial supply to the foot and ankle is provided by three arteries: the posterior tibial, the anterior tibial, and the peroneal. The anterior and posterior tibial arteries are the major suppliers of the foot (Figure 5.6A), but the peroneal artery may predominate when the anterior and posterior tibial arteries are absent in their distal segments. As described by Dubreuil-Chambardel (cited by Sarrafian[6]), the anterior branch of the peroneal artery (or perforating branch) may supply the dorsalis pedis artery (Figure 5.6B), or the posterior branch of the peroneal artery may be the only supplier of the plantar artery (Figure 5.6C). When the terminal segments of the posterior and anterior tibial arteries are absent simultaneously, the peroneal artery with its anterior and posterior branch is the sole supplier of the dorsal and plantar arterial network (Figure 5.6B).[6(p261)]

The posterior tibial artery may be greatly attenuated or absent (Figure 5.6C,D). Adachi (cited by Sarrafian[6(p261)]) reports the absence of the posterior tibial artery as being nearly 2%. This is in close agreement with the author's estimate of this anomaly in his own series (approximately 0.5% to 1%). In the case reported in this paper, the presumed variation of the arterial configuration is that of either



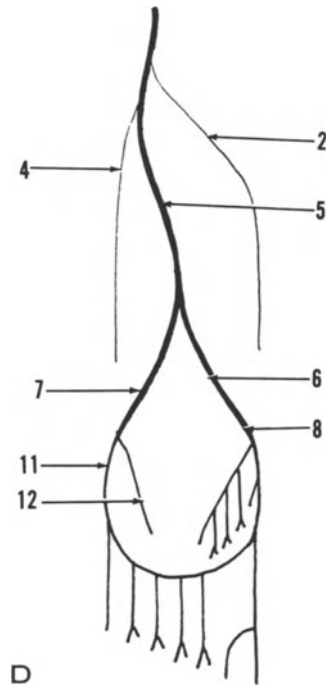


Figure 5.6. Variations of the arteries of the leg and foot. A: Habitual pattern. Unlabeled arrows indicate approximate region of exposure of vessels during surgery. 1, Popliteal artery; 2, anterior tibial artery; 3, tibioperoneal arterial trunk; 4, posterior tibial artery; 5, peroneal artery; 6, anterior peroneal artery; 7, posterior peroneal artery; 8, dorsalis pedis artery; 9, dorsal metatarsal arteries; 10, perforating artery of the first interspace; 11, lateral plantar artery; 12, medial plantar artery; 13, deep plantar arterial arc; 14, first plantar metatarsal artery. B: The anterior peroneal artery (6) becomes the dorsalis pedis artery (8). 5, Peroneal artery; 7, posterior peroneal artery. C: The posterior peroneal artery (7) supplies the lateral and medial plantar arteries (11 and 12). 4, Posterior tibial artery, incomplete; 5, peroneal artery, well developed; 6, anterior peroneal artery. D: The peroneal artery (5) supplies the dorsalis pedis artery (8) through the anterior peroneal artery (6) and the plantar arteries (11 and 12) through the posterior peroneal artery (7). The anterior tibial artery (2) and the posterior tibial artery (4) are incomplete or absent. (From Dubreuil-Chambardel, L.: *Variations des Arteres du Pelvis et du Membre Inferieur*. Paris: Masson et Cie, 1925; 246, (Reprinted by permission from Sarrafian.[6])

Figure 5.6C or 5.6D. The anomalous vessels crossed the lower leg from posterolateral to posteromedial over a distance of approximately 3 cm, just above the level of the tibial plafond. This is in keeping with both of these anatomical configurations (Figure 5.6C,D).

The peroneal artery usually is small and, if seen, is normally sacrificed at surgery when the posterior capsular incision is performed. However, since the case reported in this paper, the author has seen a patient with clubfeet in whom there was a large peroneal artery in addition to an apparently normal posterior tibial artery. The peroneal artery was occluded temporarily during surgery, the tourniquet released, and poor filling through the posterior tibial artery was seen. When the occlusion of the peroneal artery was released, the foot filled rapidly. Thus, the posterior tibial artery alone did not provide the major blood supply to the foot.

Perhaps the occlusion test may be useful in determining the relative contribution of blood supply to the foot by these two vessels when they are both present. If poor filling occurs with the peroneal artery occluded, this artery should not be sacrificed. In this patient, the artery was retained. Whether this foot would have had adequate circulation if the peroneal artery had been sacrificed is not known.

Method of Treatment

A search of the English literature failed to reveal information about how to recognize and deal with major vascular anomalies during extensive clubfoot procedures.

It is my opinion that all feet should be tested by the Doppler technique prior to surgery. All three vessels should be carefully looked for. In addition, the foot and leg should be only partially exsanguinated, with an Ace bandage applied under moderate tension, thus allowing a small amount of blood to remain in the veins when the tourniquet is inflated.

The following technique is recommended when the normal vascular structures are not found in their usual location.

1. If the posterior tibial veins are not visible beneath the ankle retinaculum, release the tourniquet briefly. If this does not allow the veins to fill, release the tourniquet briefly once or twice more.
2. If the veins are still not visible, the surgeon should suspect an anomalous circulation and should proceed cautiously with the posterior dissection. The deep peroneal artery and veins should then be sought coursing distally from posterolaterally to posteromedially, lying just anterior to the flexor hallucis longus tendon.
3. When the anomalous peroneal vessels are located, it should be determined whether they represent the primary blood supply to the foot. These vessels should be occluded and the tourniquet released.
4. If the foot perfuses poorly when the anomalous peroneal vessels are occluded, it should be assumed that they represent the only major blood supply to the foot and dissection should be carried out accordingly, with great care to preserve those vessels. If the perfusion is rapid when the anomalous vessels are occluded, there is additional circulation to the foot, probably through the dorsalis pedis branches.
5. When the ankle is placed in dorsiflexion following correction of this equinus deformity, the anomalous vessels will be stretched beyond their presurgical length when the ankle was in equinus. Therefore, dissection of the perivascular tissues should proceed far enough along the course of these vessels to allow them to stretch enough to perfuse the foot when the ankle is fully dorsiflexed.
6. If a plantar release is performed, it must be done with great caution, as the anomalous vessels lie more posteriorly than normal at the retromedial malleolar level.

Summary

A child with Down syndrome and bilaterally typical clubfeet with anomalous circulation in one foot was presented. The four patterns of arterial anatomy in the leg and foot were discussed. A technique for the identification and treatment of the anomalous vasculature was described.

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Discussion

Rab (Sacramento): Simons showed us a picture of what, I assume, was an artery and incompletely exsanguinated veins in the back of the foot. Dr. Schwartz showed us a color Doppler sonogram of a posterior tibial vein without an artery. Don't the veins always accompany the artery?

Simons (Milwaukee): In my experience, the veins always accompany the artery. In the case I showed this morning, the artery and vein were both missing from the posterior tibial sheath, but there was an artery with two accompanying veins lying over the posterior aspect of the foot and ankle joint where I would normally have expected to see the deep peroneal vessels.

Rab: What can the panelists tell us about finding a vessel in an exsanguinated or partially exsanguinated clubfoot?

Simons: If the veins are in their normal location without an accompanying artery, as appeared to be the case in the sonogram shown by Dr. Schwartz, the presence of the vein in the sheath would not alert the surgeon to the fact that the artery is absent from this location within the sheath. The anomalous artery would not be looked for and might accidentally be incised. Therefore, in the future, if color Doppler is available, it may be possible for the surgeon to establish whether the artery and vein are both missing or only one of these structures is missing. It would also be helpful if it could be determined whether an anomalous artery also has veins accompanying it.

As far as finding the vessel in an exsanguinated leg, I made the point about releasing the tourniquet if the vein cannot be seen within the neurovascular sheath. The veins should fill quickly and, if they don't, it then must be assumed the veins are absent and that one may be dealing with anomalous circulation.

Catterall (London): Do you think as we let the tourniquet down at the end of an operation that we should use a pulse oximeter on the big toe to see that it has adequate blood supply?

Stanitski (Pittsburgh): As I mentioned, there was one foot of the 40 that we examined that had pulse oximetry levels postoperatively of less than 90%. That child had a normal pulse oximetry level of 99% at the time the cast was changed 3 weeks later. I think that we can measure pulse oximetry and we can measure with Doppler's and so on, but I think we must also remember to look at the subcutaneous bleeding and at the capillary refill when the procedure is over.

The thing that has puzzled me in all of this is that, if indeed there are a vast number of anomalies such as absent anterior tibial arteries and so forth, why don't we have more major or even minor catastrophes following the very extensive releases that we are now doing? Indeed, if clubfeet do have an absent anterior tibial artery and a very deficient medial plantar arch, it seems that one should see many, many more problems than we do with wound healing, skin sloughs, partial amputations, and so on following clubfoot surgery.

Catterall: From your study, I perceive that you believe that the Doppler is more reliable as an indicator of abnormality than pulse oximetry. Is that correct?

Stanitski: No. Overall, I think that pulse oximetry is probably a more reliable test than the continuous-wave Doppler because it is less dependent on the operator. With the Doppler, one has to be exactly over the vessel and must not use a lot of pressure, etc., but with pulse oximetry, you either get a reading or you don't. If you don't, it's usually because it has been applied the wrong way or you're getting too much light from outside, etc. So I think pulse oximetry is probably more accurate than the Doppler.

Crider (San Francisco): There's probably a minimal caliber of vessel required to show on arteriography. With the color Doppler, one is probably going to be able to determine the caliber of the artery (and thus to quantitate the blood flow), which in turn will probably make it possible to determine the likelihood of a slough.

Hootnick (Syracuse): Schwartz' supposition is that recurrent vessels were measured by the Doppler on the dorsum of the foot, because the biphasic wave form of collateral flow was evident, rather than a triphasic wave form. This means that what Ellison and Hussein were measuring was, in fact, a vessel coming from the plantar surface rather than a direct flow through the anterior tibial artery. It's really not very helpful to use a continuous-wave Doppler on the dorsum of the foot because all it will tell you is whether you have a pulse; that pulse may very well be a reflection of the lateral plantar artery. A color Doppler avoids this shortcoming.

Stanitski: I think the Doppler gives a reflection of the blood supply that is getting into the foot, and that's the main thing we need to know.

Catterall: Did I understand you to say that, when you can't feel the pulse but can measure it with a continuous-wave Doppler, it is a retrograde flow coming through from below?

Crider: I think "could be" retrograde flow is more appropriate, because you simply can't tell how deep the vessel is. You can only tell whether it is systolic or diastolic by palpating elsewhere.

Stanitski: I think the point they made in the article is that it's probably retrograde flow.

Watts (Los Angeles): We all operate on many clubfeet and, as Stanitski has pointed out, the vast majority do well. However, there is a significant morbidity with arteriography. If everybody gets worried and performs an angiogram on every foot, we're going to have far more complications than we have had.

Crider: I personally would suggest not doing arteriography. I think the important point here is to treat the posterior tibial vessel as though it is the only vessel present. It might not be, but one should treat it like it is.

Riley (Ohio): We were concerned when some of our colleagues were using the pulse oximeter to monitor compartment syndromes and vascular injuries. Therefore, we did a study that proved it to be very unreliable in detecting vascular injuries or compartment syndromes. The pulse oximeter is an effective measuring device for arterial oxygenation, and it is probably more effective as a pulmonary measuring device than it is a profusion device. It doesn't measure profusion to a nail bed. Also, I would have to disagree with Dr. Sta-

nitski's final remark that its very reliable. We found that it was very unreliable.

Stanitski: Most of the data on pulse oximetry is in the anesthesia literature. What they are really measuring with the pulse oximeter is an oxygen disassociation curve. The amount of oxygenation of the net vascular bed is extremely reproducible and very accurate.

Editor's Comments

The enigma of the contradictory findings occurring with arteriography and those occurring with Doppler and pulse oximetry remains unanswered. The suggestion is made by **Crider et al**. that pulse oximetry measures retrograde flow in anastomic vessels that have an audible pulse or, less likely, that spasms are produced within the dorsalis pedis in the presence of contrast media.

The arteriographic techniques reveal a marked increase in the presence of abnormal vascular patterns, particularly of the dorsalis pedis and anterior tibial arteries. The study by **Stanitski et al.** revealed, however, that there was a very low incidence of diminished oxygen saturation by pulse oximetry and a very low incidence of pulselessness in a study using Doppler examination, with changes in flow occurring with changes in position. **Crider et al.** offered two possible explanations for the discrepancy between the Doppler readings and the arteriographic findings in their study.

However, as **Stanitski et al.** point out, probably the most puzzling question in this regard is that if the blood flow to the foot is vastly limited as is suggested by the arteriographic studies, why then are there not many more serious vascular complications associated with clubfoot surgery?

Finally, it would appear that the most accurate means of assessing vascular flow to the foot would be with the color Doppler technique. However, this is extremely expensive and not readily available in most centers. Nevertheless, this may become an important modality in the future in the assessment of clubfoot vascularity, particularly in the previously operated patient, or when there has been a vascular anomaly found in the first side operated upon in a patient with bilateral clubfeet.

6
Nonsurgical Treatment

Introduction

In the first of two papers presented at the congress on the nonsurgical management of clubfeet, **Seringe et al.** report the use of a new articulated splint for the gradual conservative correction of clubfeet. In one group this was used with manipulations and physical therapy; in the second group therapy and manipulations were not used.

In the second paper, **Zimbler** presents his experience with 90 feet personally treated over a period of 5 years, with 15 years' follow-up. **Zimbler** identifies what appears to be a spectrum of severity for children with "typical" clubfoot deformity. Finally, he describes the physical findings at the severe end of the spectrum. When these are found, the patient should be reclassified or the parents should be given a guarded prognosis.

A New Articulated Splint for Clubfeet

R. Seringe, P. Herlin, R. Kohler, D. Moulies, A. Tanguy, and A. Zouari

Most physicians agree that the initial management of clubfoot is conservative, by such methods as serial casts with or without manipulation, taping, and the use of various splints. We prefer the "functional" method with passive stretching of contracted soft tissues, active stimulations of peroneal muscles, and fixation of the foot on a sole plate by adhesive taping. We have participated in the design and the clinical trial of a prototype of a new articulated splint that we have tested in our orthopedic departments. The aim of this prospective multicentric study is to evaluate this new articulated splint.

Components of the Splint

The splint (Figure 6.1) features a flat sole in two parts: the posterior part supporting the calcaneus (1 on Figure 6.1) and the anterior part supporting the forefoot (2). Both of these parts are joined together by a mechanical part acting as a multidirectional hinge inferiorly (3).

The sole is joined to the inferior part of the posterior multidirectional hinge (3b) using a mechanical L-shaped part (4). The sole is fixed to this part (4) using a milled-edge screw (4b) situated approximately in the inferior pro-

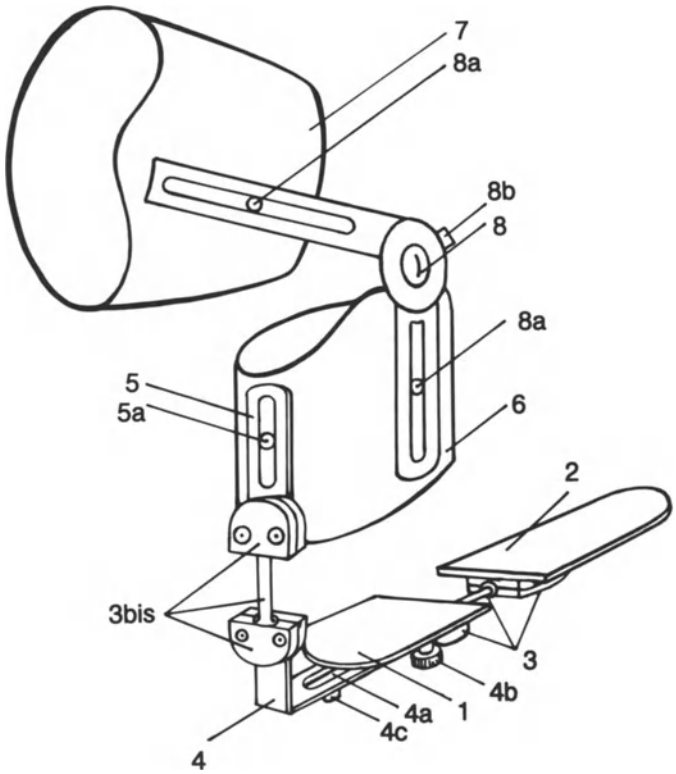


Figure 6.1. Components of new articulated splint: 1, posterior sole; 2, anterior sole; 3, anterior multidirectional hinge; 3b, posterior multidirectional hinge; 4, L-shaped part; 4a, sliding part; 4b, milled-edge screw; 4c, locking screw; 5, sliding arm; 5a, locking screw; 6, calf cuff; 7, thigh cuff; 8, knee adjustable locking system; 8, locking screw (a) and extension stop (b).

longation of the vertical axis of the interosseous ligament. Furthermore, the L-shaped part (4) is fitted with a sliding part (4a), which is locked and unlocked by the screw (4c).

The splint also features a calf cuff (6) hinged to the sole using the multidirectional hinge (3b). The superior part of this multidirectional hinge connects to the posterior portion of the leg strap using a mechanical part (5) that slides and is also loosened or tightened by using a screw (5a).

A fourth element of the splint is a thigh cuff (7) hinged to the leg at the knee using an adjustable locking system (8). Both the superior and anterior parts of this system slide and are locked and unlocked by screws (5a), controlling the degree of knee flexion.

The Principle

The four elements of the splint—the thigh cuff, calf cuff, posterior sole, and anterior sole—interconnect by a complex mechanical system that allows the splint to be adjusted according to the morphology of the lower limb under treatment. Each segment of the limb can then be fixed or be given controlled mobility in relation to the other limb in all three planes (apart from flexion-extension of the knee, which may be realized only on a sagittal plane). Thus a combination of corrections enables functional treatment of congenital talipes equrnovarus (CTEV).

Method of Fixing the Foot on the Sole Plates

The splint soles disconnect from the splint using a screw (4b) to make fixing the foot on this part easier. The foot is taped onto the soles with nonadhesive tape, according to the method preferred by the medical team, or by the taping method devised by the Hospital Saint Vincent de Paul, Paris. Avoid taping over the adjustment screws located under both plastic parts of the multidirectional hinge (3).

Method of Use

Correction of the adduction of the calcaneal-pedal block [calcaneus and forefoot (CFF)]* in the horizontal plane is controlled by turning the milled-edge screw (4b), which has its fixed point in the prolongation of the axis of the interosseous ligament.

The vertical axis of the interosseous ligament is adjusted in relation to the vertical axis of the tibial diaphysis by adjusting the sliding part (4a) and the screw (4c).

The multidirectional hinge (3) can be used to correct metatarsal adduction, supination of the forefoot, equinus [using the hinge and the sliding adjustment (5)], and varus of the calcaneus.

Course of Treatment

All newborn children with clubfoot are examined by the orthopedic surgeon. Physiotherapists perform the functional method of treatment. Patients are examined clinically and radiologically throughout the first year by the orthopedic surgeon and a decision to operate is reached by 10 to 12 months.

Passive Stretching

Treatment involves three types of manipulations. First, derotation of the CFF is carried out by a complex correction of the adduction and initial correction of the equinus by axial traction of the calcaneus. The distal part of the foot turns laterally; the heel turns medially around a central pivot, the interosseous ligament.

Second, the forefoot is corrected in relation to the midfoot. Third, residual equinus is corrected with vertical traction to push down the calcaneus.

Muscular Stimulations

It is only when reduction of the foot is started and when the contractures have decreased that the muscular stimulations will be efficient.

*This refers to all bones of the foot except the talus.—Ed.

Immobilization

Correct immobilization of the foot requires nonelastic adhesive tape to keep the heel on the sole of the splint. This is done by applying special bands around the ankle.

Evaluation of Treatment

As early as the first treatment, manipulations will allow progressive relaxation of the forefoot in relation to the hindfoot, using the multidirectional hinge (3), as well as correction of the adduction of the CFF, by using screws (4b and 4c). The neutral position of the CFF in relation to the leg should be obtained in approximately 3 weeks.

Correction of equinus is made progressively using the multidirectional hinge (3) and sliding adjustment (5), according to gains made by the manipulations.

By approximately 6 weeks, the foot should be realigned in relation to the leg; muscles should respond to stimulation and should even hold the position achieved by the patient's spontaneous correction.

At this stage, one may continue correcting equinus and start correcting pronation of the foot, which should still be moderate. Complete reduction of the foot should be achieved in 2 to 3 months.

At the 4th to 5th month, one may remove the thigh cuff (7). The splint adjustment can be set to 5° pronation, 10° abduction, and 15° to 20° dorsiflexion.

When the child begins to stand (around the 9th or 10th month), the foot may be fixed on the splint sole with a leather strap, which the parents can adjust themselves. This allows removal of the splint for a few hours each day. As soon as the child begins to walk, the splint is worn only at night.

Clinical Series

The splint has been used in 18 patients (15 males, 3 females) with 26 clubfeet (10 unilateral, 8 bilateral) from six different orthopedic departments. Two groups were studied.

Group A (initial treatment) consisted of 14 feet (10 patients) treated at birth with the splint. Initial reducibility of the deformity was noted by estimating the angles of fixed adduc-

tion and fixed equinus when firm pressure was applied toward the everted and dorsiflexed positions. The deformity was classified under three types: type 1, from 0° to 19° (one foot); type 2, from 20° to 39° (five feet); and type 3, above 40° (eight feet).

Group B (secondary treatment) consisted of 12 feet (eight patients) treated initially with another method (cast in five feet, Denis Browne splint in seven feet).

The clinical examination and roentgenograms were carried out at 6 to 8 weeks, at 4 to 5 months, and when the child was able to stand 10 to 12 months. The patients were followed an average of 13 months (minimum 10 months, maximum 17 months).

Results

The following features were assessed: morphology, spontaneous position, residual deformity, passive motion, standing position, and radiographic evaluation. The result was good if the morphology was nearly normal, the tibiocalcaneal angle was less than 70° on the lateral x-ray, and less than normal angular values on the anteroposterior (AP) x-ray (normal range is 25° to 40°). The result was fair if the morphology was unsatisfactory, the tibiocalcaneal angle was 70° to 90°, and the AP talocalcaneal divergence was 15° to 25°. The result was poor if the morphology was defective, the tibiocalcaneal angle was greater than 90°, and the AP talocalcaneal divergence was less than 15°. Feet with a poor result required a surgical release.

In group A, results were good in four feet, fair in five, and poor in five. In group B, results were good in four feet, fair in three, and poor in five.

Discussion

Our results, especially with the initial treatment group (group A), demonstrate that this new articulated splint combined with the manipulative method is effective in the treatment of clubfoot. Though it is a preliminary report, the results are encouraging because, in this small series, the feet were very rigid at birth.

The disadvantages of the new splint are the complexity of the system and the effectiveness of the splint, with its risk of overcorrection. The user must be prudent and carefully monitor the quantity of the correction.

The new splint has several advantages. It is applied to only one limb and therefore leaves the other limb unencumbered. It is well accepted by the parents, who did not like the Denis Brown splint with a bar joining the two feet. It allows the foot to be fixed with adhesive bands so that correction obtained by the manipulation treatment can be totally preserved.

The most important advantage, however, is the possibility of multiple adjustments with three-dimensional correction. This allows the orthopedic surgeon to control elementary movements of the splint according to the morphology of a specific deformity to meet the corrective goals the surgeon sets out to achieve.

Summary

The aim of this prospective and multicentric study is to evaluate a new articulated splint that is composed of four separate structures: a thigh cuff, a leg cuff, a posterior sole, and an anterior sole. These structures are interconnected by a complex mechanical system, allowing fixation of the foot in the best position of correction with nonelastic adhesive bands. The flexibility of this system allows functional treatment with passive manipulations and muscular stimulation.

The splint has been used in 14 patients (with 23 clubfeet). For 10 feet, the new splint has been used from birth and for 13 feet it has been used secondarily after another initial system. The patients were followed for a minimum of 1 year. The results were evaluated at follow-up using clinical and radiographic criteria. The preliminary results were good in 8 cases, fair in 8 cases, and unsatisfactory in 10 cases (required surgical release). The new splint has satisfied the parents and was well accepted by the family.

Nonoperative Management of the Equinovarus Foot: Long-Term Results

S. Zimbler

The purpose of this study was to determine whether foot position and functional ability deteriorate over time in children treated nonoperatively for talipes equinovarus. Orthopedic teaching during the period 1950 to 1970 stressed the importance of manipulation and proper application of corrective casts as the primary therapy for clubfoot deformity.[1] Surgical management was initially presented as a "fall-back" position when cast treatment failed. Poor plaster technique or delayed onset of treatment were frequently presented as causes for poor results and incomplete correction.[1] Modern clubfoot treatment (1970–1990)[2] has emphasized extensive surgical releases and new incisions. Follow-up of these patients reveals some of the same old problems seen with the older surgical procedures: (a) stiffness, (b) muscle atrophy, (c) extensive scarring, (d) recurrent deformity, (e) incomplete correction, and (f) overcorrection.

What type of treatment is best? What are the long-term functional results? Should certain types of deformity be approached differently? This review is an attempt to answer some of these questions.

Materials and Methods

Seventy-five patients have been included in this review (90 feet). All are clinically normal children except for the documented equinovarus deformity. These patients have been treated exclusively by one physician and growth is complete in all those presented. Follow-up averages 15 years in these patients. There was an equal distribution of males and females.

Treatment began in all patients within the first 2 days of life. Corrective long leg casts were applied every 2 to 3 days for the first 2 weeks and then weekly until the deformity was stable or corrected. All casts were of light plaster and applied over 1-inch or 2-inch cast padding (Webril). Vidrape* adhesive was used to prevent slipping of the cast. The knee position was 90° of flexion and the anterior thigh was molded to prevent the leg from moving inside the cast.

Gentle manipulation was carried out prior to each cast application as presented by Kite and others.[1,2] This stressed stretching of the forefoot into abduction to reduce the talonavicular dislocation. Subtalar eversion was also started initially. Passive dorsiflexion began at about 2 weeks of age. Great care was taken to mold under the anterior aspect of the calcaneus and the cuboid to prevent "rocker-bottom" deformity. Thin felt was placed over the anterior ankle and the distal Achilles tendon to prevent skin breakdown. These are areas of maximum pressure and potential irritation in the cast.

The period of serial cast applications was usually completed by 4 months of age. Surgical treatment was considered if the clinical and radiologic criteria did not show that neutral position had been reached.[3] Clinical criteria included (a) ankle dorsiflexion of 10°, (b) ankle plantar flexion of greater than 20°, (c) inversion greater than 10°, (d) eversion greater than 5°, (e) calf atrophy of 1 cm or less, (f) ability to wear normal footwear, (g) normal, painless gait, and (h) ability to participate in recreational sports without difficulty. X-ray criteria included (a) an anteroposterior (AP) talocalcaneal angle of at least 20°, (b) a lateral talocalcaneal angle of at least 30°, (c) neutral alignment of the talus and the 1st metatarsal, (d) alignment of the calcaneus and the fourth metatarsal, and (e) 15° of calcaneal pitch.[3,5]

Patients whose equinovarus deformity was corrected to the stated criteria were usually treated with an additional month of below-knee casts. The use of bivalved casts was begun at age 4 to 5 months. Casts were removed only for exercises and washing at first. Eventually, long-leg bivalved casts were used at night with braces during the day. All casts were constructed with the foot in a slightly overcorrected position.

Physical therapists taught the parents passive

*Deseret Medical, Inc., Parke-Davis, Division of Warner-Lambert Company, Morris Plains, NJ.

stretching exercises. Subtalar eversion, forefoot abduction, and hindfoot dorsiflexion were used only with stimulation of anterior tibial and peroneal function. Day support was originally provided by reverse last, open toe prewalker shoes and short-leg, single upright braces utilizing a posterior ankle stop and a lateral T strap. Articulated ankle-foot orthosis (AFO) braces in maximum correction are used now rather than the metallic braces and reverse last shoes.

By school age (5 to 7 years) all patients wore regular footwear or straight-last surgical shoes. Night casts were continued only if ankle dorsiflexion was below 5°. Braces were used for about 1 year following the completion of therapy.

Results

In this study, 75 patients were followed to cessation of growth. Although the author approached this group of patients with the premise that 50% of normal children with equinovarus deformity could be corrected nonoperatively, only seven children (10 feet) achieved that goal. All of the other children (80 feet in 68 patients) required operative intervention.

Careful scrutiny revealed that the type of equinovarus deformity and degree of rigidity determines the correctability. Fourteen children (17 feet) presented with relative flexibility and a long, thin foot (long 1st metatarsal). Ten of their 17 feet (seven children) were treated only with manipulation and corrective casts. These seven individuals have retained the function and range of motion reached during infancy. All feet show a neutral or slight valgus contour, ankle dorsiflexion to +10°, eversion to +10°, and abduction to +10°.[4] All of these patients wear normal footwear and participate in at least one recreational sport without symptoms. X-ray parameters of AP talocalcaneal angle to +20°, lateral talocalcaneal angle of +30°, and calcaneal pitch of 15° have also continued.

Patients requiring surgery had excellent results overall, but the nonoperative group showed a higher level of strength and motion. Patients presenting with a short, wide foot, deep medial and posterior creases, and a short first metatarsal should be considered as surgical candidates from the outset. A different prognosis can be provided to these families as well.

Discussion

It appears that there is a spectrum of severity within a typical group of patients with TEV. On the mild end of the spectrum, function was excellent, and the correction obtained by nonoperative means with manipulation and corrective casts was maintained. Unfortunately, the percentage of children amenable to this treatment is only about 10% of the total group. Function was excellent throughout the growing years and into young-adult life.

Summary

The purpose of this study was to determine whether foot position and functional ability deteriorate over time in children treated nonoperatively for talipes equinovarus. Seventy-five patients (90 feet) have been treated by one pediatric orthopedic surgeon from birth to at least maturity. Average followup is 15 years. Only seven children (10 feet) reached the desired clinical and radiographic criteria of complete correction via nonoperative means and maintained these for the entire growth period.

Clinical criteria included (a) ankle dorsiflexion of 10°; (b) ankle plantar flexion of greater than 20°; (c) inversion greater than 10°; (d) eversion greater than 5°; (e) calf atrophy of 1 cm or less; (f) ability to wear normal footwear; (g) normal, painless gait; and (h) ability to participate in recreational sports without difficulty.

The rigid radiographic criteria for complete correction included (a) anteroposterior talocalcaneal angle of at least 20°; (b) lateral talocalcaneal angle of at least 30°; (c) neutral alignment of the talus and 1st metatarsal; (d) neutral alignment of the calcaneus and 4th metatarsal; and (e) 15° of calcaneal pitch.

The type of equinovarus deformity and the degree of rigidity determined the correctability. Fourteen children (17 feet) presented with relative flexibility and a long 1st metatarsal (long thin foot). Ten of these 17 feet have maintained full correction through their entire life and growth period utilizing only casts and ma-

nipulation as described in this review. Eighty feet required one or more operative procedures to reach the same clinical result. It is this author's opinion that patients treated nonoperatively are functionally superior.

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Discussion

Bensahel (Paris): Dr. Seringe, what is the purpose of your above-knee splint? Don't you think that you could achieve the same results if you used a below-knee splint soon after birth?

Seringe (Paris): At the beginning of treatment, an above-knee splint is necessary to control the position of the foot in the horizontal plane because, if you use only a below-knee splint, the foot is in adduction and it is very difficult to maintain the correction of the horizontal rotation.

Goldner (Durham): What is the cost of the splint? How long does it take to make? Who puts it on? Who adjusts it? Can it be reused?

Seringe: No cost has been established yet because it is a prototype. It was made by a physical therapist, who also puts on the splint and readjusts it. It can be reused.

Paley (Baltimore): It appeared that there was a rocker-bottom in one of your patients. If you just manipulated a foot and didn't change the splint, you would probably not get a rocker-bottom; since the foot is held in that position for such a long time, it probably remolds into a rocker-bottom. What incidence of rocker-bottom do you have with this splint?

Seringe: I don't think the splint causes rocker-bottom deformity. The rocker-bottom that you saw was a complication of manipulative treatment. That is the reason that the patient did not have a good result but only a fair result.

Paley: Are the splint and the manipulation step A and B of the same treatment?

Seringe: The physical therapist manipulates the foot daily for 30 minutes and puts the splint on for 24 hours.

Paley: So the physical therapist obtains the correction and the splint maintains the correction.

Seringe: If you use only manipulations and no immobilization, the triple deformities persist and correction does not occur.

Alpis (Birmingham): Is it the consensus of the panel that every child with a clubfoot should have at least a period of splinting, casting, manipulation, or taping before surgery? Dr. Zimbler said that only 10% of the patients in his series benefited from this.

Zimbler (Boston): I believe that casts should always be applied first, even though the more severe feet will need surgical treatment. Manipulation and casts stretch the soft tissue. If a surgical procedure is later performed to give the foot a more corrected position, the skin is more adaptable to that corrected position. But I wouldn't persist with casts for more than 3 months, especially if the exam shows that foot is not correcting. Then I allow motion (for a short while before surgery) and use a part-time splint or a brace, whereas in children who have a good prognosis for conservative correction, I may persist with casts for 4 or 5 months.

Fahmy (Cairo): The splint is a retainer, with correction achieved either by manipulation or by operation. This retainer is applied until the peroneal tendons or the natural retainers take over. That's why, a few years ago, I devised an internal retainer using braided nylon suture, which I tie between the distal fibula and the 5th metatarsal. Initially, I thought that I would have to remove it because the foot would drift into valgus, but with growth the suture apparently gave way and none of my cases developed overcorrection.

Exner (Zurich): I think we can divide the conservative treatment into reduction and retention. We often see worsening of deformities. I think everybody has experience with repeated reduction and retention even after surgery. This is good evidence that casting and splinting are important.

Ryoppy (Helsinki): I have been operating on clubfeet for 16 years without any preliminary treatment, e.g., manipulation or physical therapy. Therefore, I have been interested to find a good functional splint that can be used very early, because our surgical treatment is completed by the age of 3 months, and then treatment is continued in a functional splint. Dr. Seringe, is it possible to use your splint before the age of 3 months?

Seringe: Yes, the splint was used at birth as the initial treatment.

Ryoppy: Is it possible to maintain the corrected position, because, in the neonatal treatment, it's very important that absolutely no loss of position occurs. You showed a picture where the position became worse in the splint, so is there a danger?

Seringe: The position may be modified everyday according to the degree of correction.

Watts (Los Angeles): We've learned from McKay that the calcaneus is rotated and we have to pull the heel medially.

Zimbler: Spinning of the calcaneus is very difficult to achieve without a soft tissue release. I don't think you can really push the calcaneus one way or the other without a release (because of the strong calcaneofibular ligament).

Catterall (London): If you are going to treat conservatively, the cast has to go above the knee. We have shown that the foot rotates as it goes from equinovarus to calcaneovalgus, and the only way to control this rotation is to control the knee.[2] I would like to make a plea that, if you're going to use a splint, it must be above the knee to control rotation. I think we need to review the classic teaching about the use of plaster in primary treatment. If 90% of cases come to an operation, could the primary treatment that produces swelling (and swelling implies injury) do harm? A paper from Adelaide[1] suggested that following their rationale, which was mainly manipulation and plaster, the body of the talus became wedge-shaped. Could this have been caused by the plaster?

Turco (Hartford): Having the opportunity to operate on a significant number of deformed feet that had never been treated, I noticed that, when I did surgery on patients of 3, 4, and 5 years of age, the heads of the tali were much better preserved than the talar heads of feet that I vigorously manipulated and treated with plaster for 1 or 2 years. Second, I was impressed that there was much less fibrosis. If one has not corrected the foot by 2 to 3 months, as determined by a good clinical and x-ray evaluation, you're going to be wasting your time—plan for surgery at a later date. In the meantime, remove the child's casts so that he can exercise the foot and there will be much less fibrosis and atrophy.

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Editor's Comments

Zimbler has provided a very extensive, long-term follow-up of conservatively treated clubfeet. In this interesting article, he states that he fully expected to see 50% good results with conservative treatment. However, following his final evaluation, he concluded that only 10% of his cases were successfully treated by conservative means alone.

This is currently the opinion held by a number of authorities in the field, although there is still quite a bit of controversy as to whether this number is too low. Furthermore, **Zimbler** identifies those feet that have a relatively good prognosis as opposed to those that have a poor prognosis. The feet with the good prognosis are the long, thin feet without marked skin creases. Short, wide feet with deep skin creases, particularly on the plantar surface, have an ultimately poor prognosis.

7
Surgical Indications, Incisions, and Techniques

Introduction

In this chapter, **Bensahel** and **Czukonyi** describe a form of treatment rarely used in North America. They propose the use of physical therapy as the initial form of treatment. When a plateau is reached, they perform selective surgical releases directed at specific residual deformities, and this is followed by further physical therapy. They avoid opening the subtalar joint, and they call the method the "à la carte" approach. This surgery is not done on patients under the age of 3 months.

Crawford describes multiple uses for the Cincinnati incision, in addition to its place in the treatment of clubfoot. He also describes its advantages and disadvantages and gives suggestions for avoiding complications.

Sodre, **Bruschini**, **et al.** report the results of their experience with the Cincinnati approach. Through this incision they perform complete subtalar release; however, they only release the lateral subtalar joint and interosseus talocalcaneal ligament if they consider it clinically necessary. The position of the foot, once corrected, is verified by clinical means, but not radiographically.

Kuo, in a brief article, compares the results of the posterior medial release performed through a straight medial incision with a posterior medial and lateral release performed through the Cincinnati incision.

Howard and **Dias** report the results of their cases in which posteromedial and lateral releases were used through the Cincinnati incision. In addition, they used Carroll's technique of rotation of the talus within the mortise with a Kirschner wire and the complete release of the calcaneocuboid joint. They report the results of their cases on a yearly basis, over an 8-year period.

Barnett describes the use of a complete subtalar release through a Cincinnati incision; however, his technique of deep soft tissue dissection differs from that described by other surgeons.

Klaue and **Filipe's** paper on a long-term review of juvenile congenital talipes equinovarus (CTEV) treated by posteromedial release (PMR) describes the shortcomings of that procedure in the typical clubfoot.

Indications for Limited Soft Tissue Release in Congenital Talipes Equinovarus

H. Bensahel and Z. Czukonyi

Most surgeons are in agreement that initial treatment of congenital talipes equinovarus (CTEV) should be conservative. CTEV should be considered a neonatal orthopedic emergency and, consequently, treatment should be started as soon as possible. Several techniques of conservative treatment have been described, ranging from manipulations followed by plaster casts to gentle progressive manipulations without rigid retention. The type of conservative treatment used influences the type and timing of surgery.

We developed a progressive technique of daily physiotherapy in babies that elicits active participation of the child. With this technique, we achieved 77% acceptable results. However, not all cases responded favorably to physiotherapy, and surgery had to be undertaken in the "fair" and "poor" cases.

Indications

Three major questions must be answered when considering surgery for correction of CTEV: (a) What type of CTEV does the patient have? (b) When should surgery be undertaken? (c) What type of surgical procedure should be performed?

Nature of the CTEV Deformity

The decision to operate must be made after considering that potential indications for surgical release are also influenced by the type of clubfoot encountered. CTEV can, in many cases, be treated adequately by physiotherapy, except when stiff fibrosis has set in. Clubfoot secondary to neurological or generalized malforming conditions, such as arthrogryposis multiplex congenita, will respond to some degree to physiotherapy; however, it always requires some form of surgical release. Special consideration should be given to recurrence of clubfoot following successful initial treatment. The presence of latent neurological disease must be fully evaluated. Treatment in these cases should be surgical.

Timing

The timing of surgical correction has been the subject of much controversy between proponents of early and late operation. Our experience with the treatment of clubfoot over the last 25 years has shown that 3 months of correctly applied physiotherapy was necessary before a decision concerning surgical correction could be made. Therefore, we believe that neonatal surgery is not indicated. On the other hand, a child as young as 3 months old could benefit from surgical release.

Type of Surgical Procedure

Descriptions of surgical procedures for treating clubfoot abound in the literature. In our opinion, extensive procedures are not indicated in young patients. Underlying physiological mechanisms must be well understood when planning surgery. We believe that CTEV is the consequence of contracture of the tibialis posterior muscle, leading to a fibrous zone located medially in the midfoot. The origins of this retraction can be quite different, ranging from neuromuscular disease to muscle contracture consequent to in utero malposition. It is as if all the different components of CTEV converged at this point like the spokes of a wheel. Limited posteromedial release is aimed at breaking these spokes without altering the bony structure.

We developed a technique that achieves this result through lengthening of the tibialis posterior, opening the talonavicular joint space associated with occasional plantar release, and then lengthening the heel cord by a posterior release, and opening the tibiotalar joint but without release of the subtalar joint. It is essential that the existing deformities be assessed and the technique adapted "à la carte" to the foot, not the foot to the technique.

The technique must be limited in nature so that bone development and muscle tone are not altered. Overlengthening of the tibialis posterior muscle or the Achilles tendon will invariable lead to overcorrection, quite often with catastrophic results in young patients.

Do more extensive procedures have a place in surgical treatment of clubfoot? We feel that the answer is no! When CTEV has been treated by a combination of correctly applied physiotherapy, followed by limited posteromedial release, and again by physiotherapy, 96% of our patients have "good" or "fair" results based on morphological and functional criteria. Procedures on bones or tendon transfers should be used only in patients for whom these procedures were initially intended.

Summary

Limited posteromedial release can be performed in young patients in whom progressive physiotherapy has yielded incomplete correction. The procedure should be limited in nature, addressing itself "à la carte" to residual deformities that remain after initial physiotherapy.

The Cincinnati Incision: An Approach for Extensive Dissection of the Foot and Ankle

A.H. Crawford

The orthopedic surgeon is frequently challenged with the problem of obtaining adequate exposure of the posteromedial and posterolateral aspects of the foot and ankle while avoiding complications that are secondary to the incision itself.

The Cincinnati Incision

The incision is generous, extending from the medial aspect of the foot in the region of the naviculocuneiform joint, curving beneath the distal end of the medial malleolus to the Achilles tendon. It continues in a gentle curve over the lateral malleolus to a point just distal and slightly anterior to the sinus tarsi, on the lateral aspect of the foot. It can be extended at either end, depending on the needs of the surgeon (Figure 7.1).

Advantages

Longitudinal, oblique, and hockey-stick–shaped incisions used for the treatment of foot deformities in children have been used for decades, so why propose another incision? I consider the main goal of the surgical incision in CTEV to be uninhibited visualization of the pathologic anatomy. The Cincinnati incision provides improved visualization so that no portion of the surgical anatomy is excluded. The structures that, if damaged, could result in permanent serious disability, i.e., vessels, nerves, tendons, and articular surfaces, are more easily avoided and protected.[3] A good surgical approach also avoids violation of surrounding structures, thus minimizing morbidity. Very important is the easy access to all soft tissue and osseous structures in the posterior aspect of the foot and ankle, which may be contracted and, ultimately, the cause of preoperative deformity or disability.

For the management of clubfoot deformities, the Cincinnati incision allows excellent four-bone exposure with direct visualization of all three compartments. The incision allows a direct approach to the posterolateral structures responsible for medial spin, such as the posterotalofibular and calcaneofibular ligaments that can be released under direct vision. The Cincinnati incision allows complete alignment

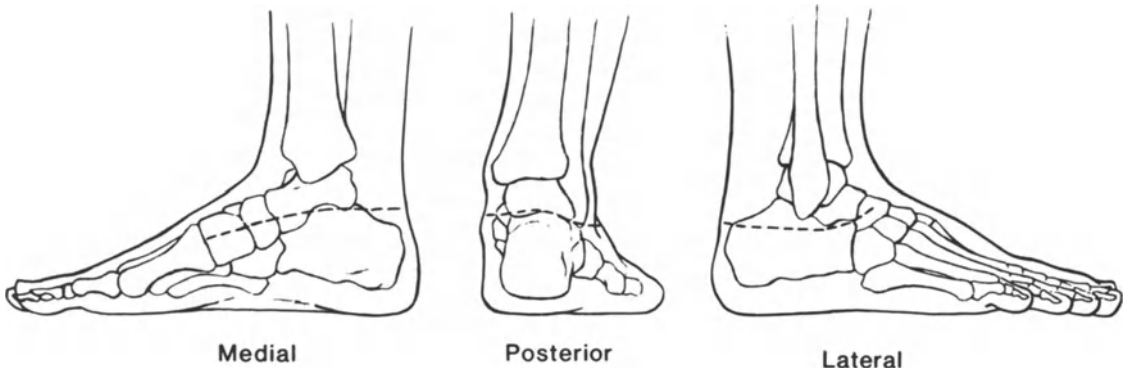


Figure 7.1. A line drawing showing the possible medial extent of the Cincinnati incision, superimposed over the tarsal bones and malleoli. The incision may be extended laterally to the same extent as medially, depending upon the needs of the surgeon. (Reprinted with permission from Crawford et al.[3])

of the foot in all planes, i.e., talonavicular, talocalcaneal, and calcaneocuboid, and there is excellent visualization of the talar head for talonavicular pinning.

Skin closure of the Cincinnati incision is obtained with minimum tension on the suture line.

The incision is advocated for revision surgery, allowing the surgeon to approach those segments of the anatomy that may have been inadequately corrected at the time of the initial surgery. The incision can be used safely in children under 7 years of age with a complete subtalar release procedure. Problems associated with other operative approaches, including inadequate visualization, tender and cosmetically unacceptable scars, and pressure associated with shoe wear, have not been a factor and have been avoided with the use of this incision.

The incision has, in some instances, been made across scars from previous incisions and across scars following severe trauma. The quality and uniformity in appearance of the healed scar has been particularly gratifying, even though a wide variety of suture materials and closure types have been employed.

Use of the Cincinnati Incision for Other Conditions

Giannestras,[5] in his textbook on the foot and its disorders, described a transverse incision for heel cord lengthening. The author personally assisted Giannestras in the use of a transverse incision for the treatment of congenital vertical talus. Many procedures can be performed through the Cincinnati incision, including complete and limited subtalar release for CTEV, split posterior tendon transfer (SPLOTT), one-stage posterolateral/anteromedial release for congenital convex pes valgus, extensive posterior release for paralytic equinus contracture, excision of medial or lateral coalitions, and triple arthrodesis.

Complications

Complications do occur, but have not presented significant morbidity. Most of the complications had to do with the surgeon immobilizing the older child's foot in dorsiflexion following closure and experiencing minor skin sloughs. All wounds have healed without grafting and correction has been maintained. Surgeons in the Middle East have managed clubfeet through the use of the Cincinnati incision and simply placed the foot in a cast without closing the wound, allowing it to granulate. I do not advocate this technique; however, a review of some of those cases has shown excellent results.

Avoiding Complications

There are several recommendations for avoiding complications with the Cincinnati incision:

1. The posterior transverse limb of the incision should be 1 to 2 cm above the junction

of the skin of the leg and the weight-bearing skin of the heel.
2. One should incise the tissue perpendicularly to the skin—without skiving the skin or subcutaneous tissue, because this compromises the closure.
3. Use sharp dissection of the subcutaneous tissue rather than continuously spreading with scissors, as this tends to violate the tissues.
4. A self-retaining retractor, if used, should be released after 30 minutes.
5. Extension of the incision for heel cord lengthening or lengthening of other tendons should be done by elongating the incision anteriorly on the medial or lateral aspect and then spreading the limbs of the incision (similar to the visor of a knight's hood).
6. The tourniquet should be released after Kirschner wires are inserted.
7. A two-layer closure should be used. Repair the deep layer with interrupted sutures; this is followed by a subcuticular closure.
8. If there is tension on the incision following skin closure when the foot is in dorsiflexion, the foot may be placed in plantar flexion until perfusion improves. Internal fixation is used by most surgeons to hold the deformed bone in the corrected position and, therefore, it is not important for the foot to be immobilized in dorsiflexion following surgery. As a result, we leave the foot in a neutral or slightly plantar-flexed position if there appears to be any tension-blanching of the skin at the time of closure. Skin perfusion should be evaluated in several positions before the foot is immobilized in the cast, if greater than 10° to 15° degrees of plantar flexion is required to prevent blanching of the skin; the foot should be repositioned into more dorsiflexion in 2 weeks when the skin is relatively well healed.
9. Place a small diameter Jackson-Pratt drain in the wound of children over 2 years of age to prevent hematoma following extensive surgery to the foot.
10. Place an abdominal gauze pad over the dorsal and plantar aspect of the foot before wrapping it in Webril to decrease compression of the cast on the foot.

Conclusions

The Cincinnati incision offers direct visualization of medial, posterior, and lateral foot and ankle anatomy. It utilizes the natural skin creases; which allows easy closure. It is cosmetically superior to any of the previously performed incisions for extensive exposure of the foot and ankle.

I advocate the Cincinnati incision for primary, as well as revision, procedures in the management of CTEV. It facilitates resident education by allowing a broader exposure of the pathology of CTEV. The Cincinnati incision's superiority to other incisions has been well documented in the literature.[1] Furthermore, there have been no reports of adverse sequelae in any series utilizing this incision.

Finally, my recommendation for the treatment of CTEV is to approach the foot through the Cincinnati incision. The decision of which technique to utilize (i.e., Goldner,[6] Carroll.,[2] Handelsman and Badalamente,[7] Brougham and Nichol,[1] Cummings,[4] McKay,[8–10] Turco,[12] and Simons[11]) is the surgeon's to make. The Cincinnati incision has been utilized for all of these techniques. I highly recommend its use.

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The Cincinnati Approach in Clubfeet

H. Sodre, S. Bruschini, C. Nery, and J. Mizusaki

Until 1985 at Escola Paulista de Medicina in São Paulo, Brazil, the surgical treatment of CTEV was performed using the Codivilla incision.[6] In October 1985, McKay visited São Paulo and introduced his theory and techniques for the treatment of clubfoot, including the Cincinnati approach described by Crawford et al.[2] in 1982. Since that time, we have used this approach with Turco's procedure.[15,16] The goal of this paper is to report our experience with this approach in terms of visualization of the medial and posterolateral aspect of the foot and ankle, as well as to discuss the healing of the wound and its cosmetic appearance.

Materials and Method

Of 65 patients operated on (103 feet), 56 had idiopathic clubfoot, three had arthrogryposis, two had myelomeningocele, one had Down syndrome, one had Freeman-Sheldon syndrome, and two had other anomalies. There were 38 bilateral deformities, 27 unilateral. Only 15 patients were female; 50 were male. The average age at the time of surgery was 9 months, with a range of 5 to 60 months. Forty-five patients have been previously treated with casts; 20 had no previous treatment. There were 58 white and 7 nonwhite patients with consanguinity present in 6 cases and familial accumulation in 10.

Surgery is performed under general anesthesia with the patient in a prone position with a pneumatic tourniquet applied over the middle third of the thigh.

The incision begins at the medial aspect of the foot at the base of the 1st metatarsal and runs proximally in the direction of the tibial malleolus. It then bends transversely 1 cm above the insertion of the Achilles tendon on the calcaneus and passes under the tip of the fibular malleolus.

The sural nerve must be protected. The subcutaneous tissue is dissected, the Achilles tendon is exposed, and z-lengthening is performed.

The capsules of the posterior tibiotalar joint and the posterior talocalcaneal joint are incised. The calcaneofibular ligament and the sheaths of the peroneal tendons can be seen (Figure 7.2). If necessary, the lateral portion of the talocalcaneal capsule may be incised.

The posterior tibial tendon is z-lengthened and incisions are made in the talonavicular capsule, the dorsal talonavicular ligament, the plantar calcaneonavicular ligament (spring), and Henry's knot. The capsules of the naviculocuneiform joint and the 1st metatarsal–cuneiform joint are also incised.

Dissecting carefully the sheaths of the flexor digitorum longus and flexor hallucis longus, the sustentaculum tali, and the medial aspect of the talocalcaneal capsule are incised, and, if necessary, the interosseous talocalcaneal liga-

ment. The plantar structures that arise from the calcaneal tuberosity must be incised near their insertion.

At this time, we test the correction of the deformity and the talonavicular joint is fixed with a Kirschner wire from posterior to anterior. The varus and equinus are corrected and two Kirschner wires are used to fix the talocalcaneal joint without fixing the ankle joint (Figure 7.3).

The tendon sutures must be inserted with the foot at 90°. Subcutaneous and skin sutures are placed with the foot in equinus. Dressing and wide padding are applied followed by an above knee cast with the foot in equinus and the knee in flexion. After 2 to 3 weeks, equinus is corrected gradually with cast changes.

Results

The results were analyzed only in relationship to the aesthetic aspect of healing of the scar, since it is too soon to analyze the functional results of the clubfoot itself.

Satisfactory results (Figure 7.4) were obtained in 94 feet (91.3%) and unsatisfactory results in 9 feet (8.7%).

Among the results considered unsatisfactory, we had five superficial deficiencies (dehiscences) in three patients consisting of dermis and epidermis that varied from 1 to 3 cm in length (Figure 7.5). Of these, three were located in the medial retromalleolar region and two in the posterior region. In four feet we observed profound dehiscences with tendon exposure in the medial and posterior retromalleolar areas. In these cases, the presence of infection was verified through clinical and laboratory tests.

These results were analyzed statistically through Fisher and Mann-Whitney tests as to sex, age, skin color, consanguinity, socioeconomic conditions, and associated anomalies. The analysis showed that the healing of the surgical wound was not significantly altered by these factors (Table 7.1).

A female patient with Freeman-Sheldon syndrome developed necrosis of the skin over the posterior calcaneal region, 1 cm below the surgical incision, with exposure of the calcaneus in one foot. Infection was not found by clinical and laboratory tests, nor was cicatrization of the surgical wound observed.

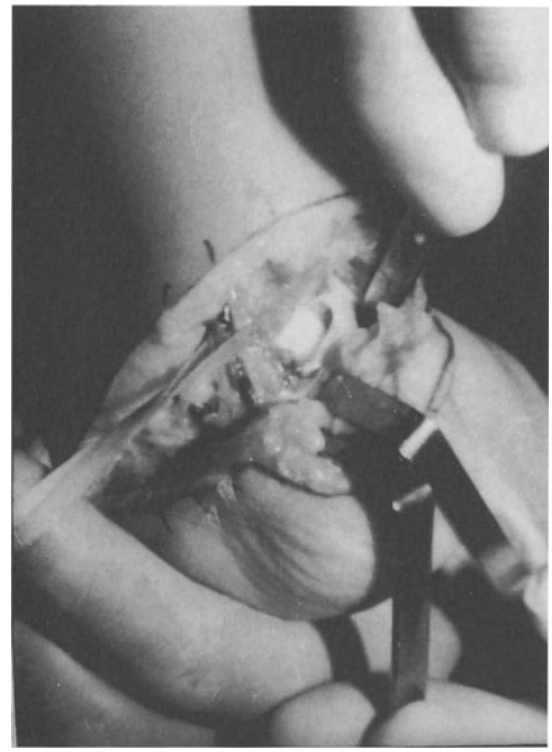


Figure 7.2. Posterior aspect of the foot showing the calcaneofibular ligament exposed through the Cincinnati incision.

Discussion

Codivilla's incision permits good exposure of the medial structures of the foot and ankle, as well as good exposure for lengthening of the Achilles tendon.[1] However, access to the posterior capsules requires excessive tension when retracting the margins of the surgical wound.

McKay stresses the ease of exposure of the medial, posterior, and lateral structures through the Cincinnati approach.[7–9] Simons[11,12] has given his reasons why only a wide subtalar liberation allows correction of the deformities. He stresses the need for incision of the calcaneofibular ligament and the difficulty in reaching this ligament through Codivilla's incision. In children over 3 years of age, he prefers to use two approaches: the lateral and the medial.

The Cincinnati approach is a good incision because it allows a wide approach of the foot and ankle, making it easier to see and liberate

Figure 7.3. Two Kirschner wires fixing the subtalar joint, although only one can be seen within the joint.

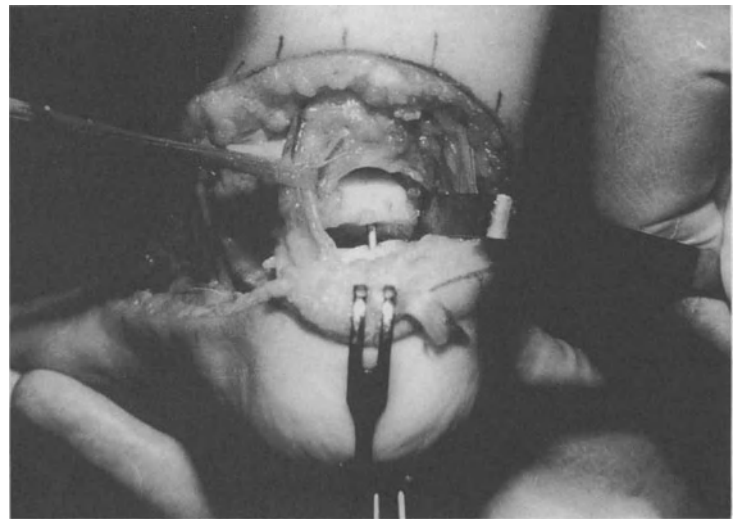


TABLE 7.1. Analysis of results of study.

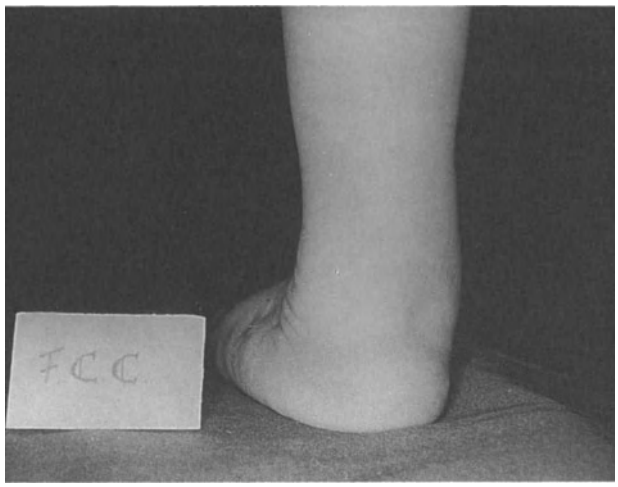
	Unsatisfactory	Satisfactory	Total number of patients	Percent unsatisfactory
Sex*				
Male	5	45	55	10.0
Female	0	15	15	0.0
Total	5	60	65	7.7
Median age†	15.6 months	13.1 months		
Color*				
White	3	55	58	5.2
Nonwhite	2	5	7	28.5
Total	5	60	65	7.7
Consanguinity*				
Yes	2	4	6	33.3
No	3	55	58	5.2
Total	5	59	64(+)	7.8
Socioeconomic situation*				
Private	0	11	11	0.0
Public	5	49	54	9.3
Total	5	60	65	7.8
Etiology*				
Idiopathic	4	52	56	7.1
Syndromes	1	8	9	12.5
Total	5	60	65	7.8

* Fisher test not significant.
† Mann-Whitney test not significant.

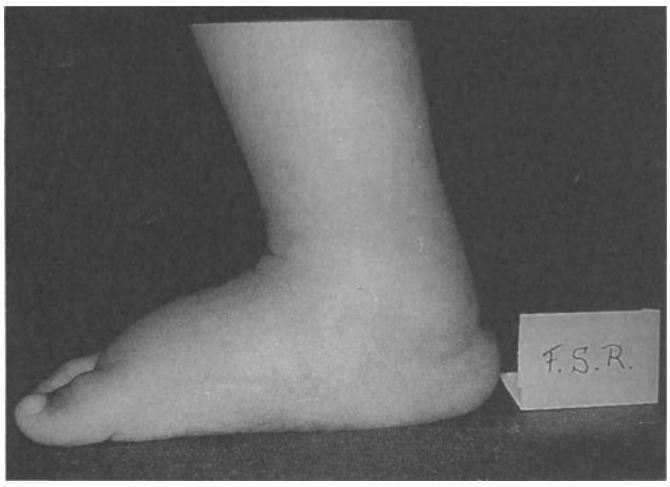
the posteromedial and posterolateral structures.

The cicatrization of surgical wounds in patients with CTEV has always been a matter of concern, due to the possibility of necrosis, dehiscence, and the subsequent formation of hypertrophic, retractile, or keloid scars (Figure 7.6).[1,3,5,14] The process of skin healing in CTEV's surgical wounds depends fundamentally on two factors: cutaneous vascularization and the tension exerted on the skin.

The cutaneous region that covers the medial



A



B

Figure 7.4. A: Scar with a good aesthetic appearance (posterior view). B: Another patient with satisfactory healing (medial view).

malleolus is supplied through branches of the anterior tibial artery and through branches of the medial plantar artery, which originates from the posterior tibial artery. On the lateral side, the arterial supply is through the lateral calcaneal artery, a branch of the lateral malleolar artery, and the lateral plantar artery, which originates from the posterior tibial artery and from the posterior perforating trunk, derived from the peroneal artery.[10]

The study of CTEV's vascularization has shown that arterial alterations were present in 93% of the cases.[13] Anterior tibial arterial hypoplasia was observed in 90% of the feet studied arteriographically. These studies did not show alterations of posterior tibial and fibular arteries. Based on these findings, we can suppose that cutaneous perfusion of the medial and lateral malleolus is deficient in a great number of CTEV cases, and that every incision that surrounds the malleolus posteriorly may interrupt important cutaneous branches, causing necrosis of the wound's margins that directly affect its cicatrization.

In Codivilla's incision, which is made perpendicular to the skin's force lines, tension caused by muscular action on the wound's margins may result in retraction, hypertrophy, or keloid formation. These factors may produce the recurrence of deformities (Figure 7.6). On the other hand, the Cincinnati incision is parallel to the skin's force lines which contributes to better healing (Figure 7.7A and B).

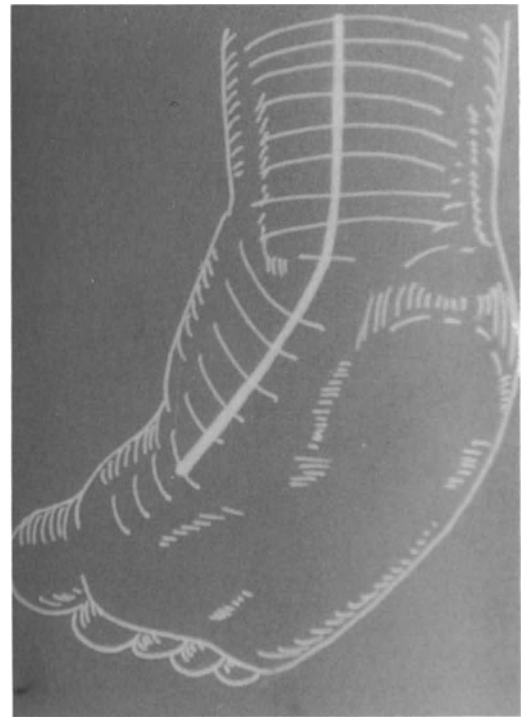
Another factor that influences wound heal-



Figure 7.5. Superficial dehiscence with an unsatisfactory result.

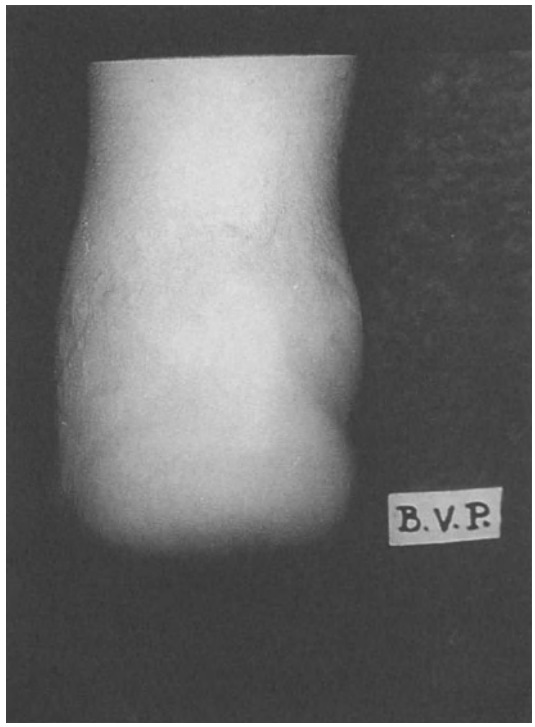


A

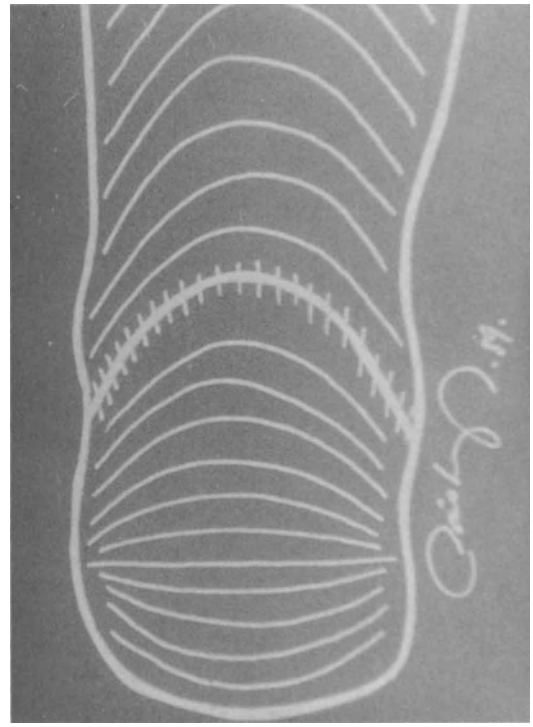


B

Figure 7.6. Keloid formation (A) following Codivilla's incision is perpendicular to the skin's force lines (B).



A



B

Figure 7.7 Cincinnati incision does not cross the skin's force lines.

ing is age. Children's scars have longer erythematous and hypertrophic phases, leading to less satisfactory results.[4]

In Brazil, there are differences between private and public patients that reflect their socioeconomic situation. The private patients are treated significantly earlier and, consequently, the desired functional results were worse in older patients. In our study, the results of scar healing were not significantly different according to age, as proved by the Mann-Whitney test.

According to parental opinion, in a later evaluation, 99 feet (96.1%) were considered satisfactory, contrasted with the 94 feet (91.3%) we considered satisfactory. Results of the Fisher test classified by color and by etiology were also insignificant. The same results were seen according to consanguinity, sex, familial accumulation, previous treatment, and associated anomalies, as seen in Table 7.1.

The patient with the Freeman-Sheldon syndrome presented with necrosis of the skin and of the subcutaneous tissue, with bone exposure of the complete posterior portion of the calcaneum in one foot. During the immediate postoperative period, we observed an ischemic area on the posterior face of the hindfoot, distal to the surgical incision. Despite the local care, necrosis developed with bone exposure, but without infection. The area needed cutaneous covering with skin grafts to allow healing.

We suspect that interruption of the blood supply of the affected area during surgery may have occurred due to regional vascular anomalies similar to those we discovered through the arteriographic study in CTEV patients. The contralateral foot healed without any complication, which excludes the incision as a cause of skin necrosis.

The incidence of complications related to the surgical wound's cicatrization in our cases was not greater than that reported in the literature, and the aesthetic aspect of the scar was considered good, especially when compared to the results obtained with longitudinal incisions in the posterior region of the foot and ankle.

Summary

The Codivilla approach to the surgical correction of clubfeet was used until 1985, at which time the authors discontinued its use in favor of the Cincinnati approach. This approach has been used in 103 feet since that time. The authors express their satisfaction with the visualization of the medial, posterior, and lateral structures, and also with wound healing. The incidence of poorly healed wounds by the Cincinnati approach was no higher than with the Codivilla incision. Sex, skin color, and consanguinity may influence the healing of wounds.

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A Comparative Result of Posteromedial Release Versus Posteromedial and Lateral Release for Idiopathic Talipes Equinovarus Using the Cincinnati Incision

K.N. Kuo

The surgical management of CTEV deformity has continued to evolve since Brockman[1] first published his monograph on congenital clubfoot in 1930. In 1974, when I returned from my pediatric orthopedic fellowship under Lloyd-Roberts in London, I continued the quest for the betterment of clubfoot correction. My personal experience can be divided into my first 8 years of experience with posterior[5] and posteromedial[13] releases performed through a posteromedial straight line incision as advocated by Lloyd-Roberts,[5] and my next 8 years of experience with posteromedial and lateral releases using the Cincinnati incision originally described by Giannestras,[3] popularized by Crawford, et al.,[2] and detailed by McKay[6–8] and Simons.[10–12]

The advantages of the Cincinnati incision are its excellent exposure, especially for the posterior and lateral aspects through one incision, excellent skin healing with minimum keloid formation, and versatility for a variety of procedures. The visualization of the lateral structures is enhanced.

The disadvantages of the Cincinnati incision are inadequate length for the Achilles tendon exposure, a problem with skin tension, especially in older children, and an upside-down view of the medial structures.

A complete release of medial and lateral subtalar structures is necessary to achieve rotation of the calcaneus under the talus. Without the lateral release, the only way to correct the heel varus is to open the medial subtalar joint, and this often causes lateral translation of the calcaneus under the talus without correcting the rotational deformity.

Between March 1984 and July 1987 at the Shriner's Hospital for Crippled Children and Rush-Presbyterian Medical Center in Chicago, a total of 70 children with 92 congenital clubfeet were operated on by a one-stage posteromedial and lateral release,[6–8,11,12] utilizing the Cincinnati incision.[1] None of the feet had previous surgery. All surgeries were performed or supervised by myself. The clinical evaluation was based on Turco's[13] criteria and the radiologic evaluation consisted of measuring the talocalcaneal angles and the first tarsometatarsal angles by Simons'[9,12] criteria. The average age at the time of surgery was 7 months. The length of follow-up averaged 2 years, ranging from 12 months to 56 months.

The progression of surgery was from posterior to lateral, to plantar, and to the medial side. The interosseous ligament was left intact unless it was too tight. Internal fixation was used on all recent cases.

The clinical results were excellent in 55 (60%), good in 18 (20%), fair in 15 (16%), and poor in 4 (4%). The radiological measurement of the talocalcaneal angle preoperatively and postoperatively did not show a significant difference between excellent, good, and fair results; however, there was a definite failure of correction in the poor group. There was a significant difference in the first tarsometatarsal angles postoperatively.

In comparison with our previous series of posteromedial releases using the posteromedial incision between 1974 and 1978, with an average 3-year follow-up,[4] our current series is far superior. We did not see any difference in functional results between posterior tibial tendon release and the z-lengthening of the tendon. The Kirschner wire fixation of the talonavicular joint to maintain position obtained better results than those without fixation. Ninety-five percent of patients with clinically absent peroneal tendon function before surgery had return of function postoperatively.

Summary

Overall, the Cincinnati incision gives excellent exposure to the deformed foot; therefore, greater attention may be given to the detailed corrective surgery of the clubfoot. A comparison of posteromedial release (PMR) and posteromedial and lateral release (PMLR) performed with the Cincinnati incision revealed superior results with the latter technique.

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Medial Rotation of the Talus and Complete Calcaneocuboid Release—Its Effect on the Surgical Results in Idiopathic Clubfoot

P. Howard and L. Dias

Treatment for congenital idiopathic clubfoot (CTEV) ranges from nonoperative serial casting to radical surgical procedures such as the triple arthrodesis. Most physicians agree that conservative manipulation and casting is the appropriate initial treatment for management of clubfoot. When such therapy fails, however, the proper treatment plan is the subject of much debate. This study examines our experience with the complete posteromedial and lateral release (PMLR) on idiopathic clubfeet resistant to nonoperative therapy. Included is the presentation and evaluation of a simple technique for derotating the talus into a more anatomically appropriate position. Also presented is a breakdown of results obtained when the calcaneocuboid joint was opened versus when left undisturbed.

A thorough understanding of the pathoanatomy of talipes equinovarus is crucial to the development of an effective surgical treatment plan. Differences in surgical approach often originate from divergent opinions about the pathology of a given condition. The name

talipes equinovarus proves to be quite descriptive. Clinical evaluation reveals equinus, varus, and adduction of the forefoot, often accompanied by a cavus deformity.

Numerous bony deformities and soft tissue contractures are responsible for the extensive range of abnormalities. CTEV is marked by subluxation of the talonavicular joint. Dissection of congenital clubfeet by Carroll et al.[1] revealed (a) the lateral malleolus directed posteriorly, (b) the talus head directed laterally, and (c) the navicular subluxated medially toward the medial malleolus. The external rotation of the talus puts pressure on the anterior part of the calcaneus, causing it to drop into varus and to be abnormally internally rotated.

The success of surgery relies upon a proper rotational correction of the talus. Medial derotation of the talus is a critical component of the procedure. Only then can proper realignment of the calcaneus be achieved (Figure 7.8).

As surgical procedures have evolved, attention has been focused upon the more subtle pathological abnormalities causing forefoot adduction in talipes equinovarus. Drawing from information gained by digitizing histological sections of a clubfoot and a normal foot, Herzenberg et al.[3] discuss the implications of malalignment of the calcaneocuboid joint. They assert that the joint's sloped articular facet is in part responsible for the internal rotation of the midfoot. They advocate release of the ligaments binding the calcaneocuboid joint.

Understanding the pathological deviations makes clear the rationale forming the basis for the three approaches to surgery that have been used in the past and present: (a) the posteromedial release (PMR) of Turco,[6] (b) the posteromedial and lateral release with two incisions (PMLR2) of Carroll,[1] and (c) the posteromedial and lateral release (PMLR) utilizing the Cincinnati incision as described by McKay[4] and Simons.[5]

Posteromedial and Lateral Release

Crawford[2] introduced the use of the Cincinnati incision for clubfoot surgery. The incision runs transversely from the calcaneocuboid joint, under the lateral malleolus, just above the heel crease, under the medial malleolus, then toward the head of the first metatarsal. One advantage of the approach is that it allows excellent visualization of the pathology.

The resulting scar is aesthetically pleasing—the line of the incision closely follows Langer's lines of the foot. The only disadvantages noted by McKay were (a) difficulty in dissecting the Achilles tendon for lengthening, and (b) problems in closing the skin in older children due to tightness.

Method

This study reviews the results of surgical treatment for idiopathic clubfeet of 97 children (137 feet). The original patient population included an additional 12 children (17 feet) who were lost to follow-up. The minimum follow-up was 12 months (range 12 to 98 months, average 40.8 months).

Every effort was made to schedule surgery when the child reached 6 months of age. Age at surgery ranged from 3.5 to 90 months, average 8.0 months, median 6.0 months. Those children older than 12 months (7.2%) were generally those who had been treated (nonoperatively) elsewhere prior to coming under our care.

Children who had previously undergone unsuccessful surgical treatment were excluded. Such feet present a set of problems unique from those of virgin clubfeet (e.g., scarring, uncertainty in the extent and mode of prior treatment, and loss of anatomical structures). Such problems cause difficulties interpreting the results of the surgical procedure we advocate.

All cases were performed by the senior author (L.D.) at the Children's Memorial Hospital (CMH) in Chicago between 1981 and 1988. Examining the results obtained by a single surgeon controls much of the inconsistency that occurs due to differences in the technical skills and intraoperative judgment of different individuals. The fact that all the procedures were performed at a single institution provides an additional control, increasing the likelihood that the children receive similar postoperative care.

Preoperative Treatment

Preoperative treatment involves serial casting, manipulation, and use of an ankle-foot orthosis (AFO). For the past 3 years, we have been using the Wheaton brace to maintain the partial correction obtained with conservative treatment. The prerequisites for PMLR are a foot that is rigid and resists nonoperative attempts at correction. Radiographic and clinical evaluation form the basis for the determination of a rigid clubfoot. With the foot in forced dorsiflexion, the lateral talocalcaneal angle in the uncorrected CTEV is typically less than 25°. Clinical signs of a resistant foot include persistent hindfoot equinus and varus and forefoot adduction.

Surgical Method

The general outline of the PMLR is the same as that described by McKay[4] and Simons.[5]

Tendon Lengthening

McKay[4] lists one of the disadvantages of the Cincinnati incision as difficulty in dissecting the Achilles tendon sufficiently to allow lengthening. We have used, on a few occasions, a second incision proximally (superior to the posterior aspect of the transverse incision) to allow a more extensive access to the heel cord. Thus, a z-lengthening can be performed with greater ease. The tibialis posterior tendon is lengthened similarly in a z fashion. The distal tendon and muscle fibers of the abductor hallucis brevis are incised. If the toes show a tendency for clawing, z-lengthening of the flexor hallucis longus and the flexor digitorum longus are performed.

Ligamentous Release

With the neurovascular bundle, sural nerve, and the peroneus longus and brevis well retracted using elastic tapes, the calcaneofibular ligament is divided, entering the subtalar joint posterolaterally. The release of the subtalar joint is then completed posteriorly, medially, and laterally. The interosseous ligament is divided, leaving the talus and calcaneus hanging by its most anterior capsule. Next, the ankle joint is widely opened posteriorly, including the posterior talofibular ligament. The deep deltoid ligament is preserved. The talonavicular joint is opened medially, superiorly, and inferiorly with the navicular only hanging laterally on the head of the talus.

Opening the Calcaneocuboid Joint

Using the most lateral part of the Cincinnati incision, the peroneus longus and brevis tendons are well retracted. The muscle origin of the short toe extensors are lifted from the cuboid. The calcaneocuboid joint is opened under direct vision superiorly, medially, laterally, and inferiorly.

Plantar Release

When the foot has a significant cavus component, a small incision is made on the plantar aspect of the foot and a plantar release is performed. The short plantar muscles are not divided.

Fixation

Since 1984, we have used a temporary small Kirschner wire driven into the posterolateral aspect of the talus to aid in the proper medial derotation. The wire is trimmed to a length of about 5 cm and used as a lever arm to rotate the talus into a more anatomically correct position. With the talus in its proper position, a second wire is inserted through the posterior aspect of the talus, driven into the reduced talonavicular joint, then out through the posterior portion of the foot. The temporary wire is removed at this time (Figure 7.8).

Another threaded Kirschner wire is placed through the plantar aspect of the calcaneus into the talus in order to hold the calcaneus reduced under the talus. Thus, two Kirschner wires hold the foot in the corrected position. The talonavicular and talocalcaneal wires are trimmed and intraoperative radiographs are taken to insure that appropriate alignment has been achieved. The foot is also clinically evaluated.

Postoperative Care

A posterior long leg splint is applied immediately after surgery. Barring complications, the child remains hospitalized overnight and is discharged the following day. Approximately 2 weeks postoperatively, the posterior

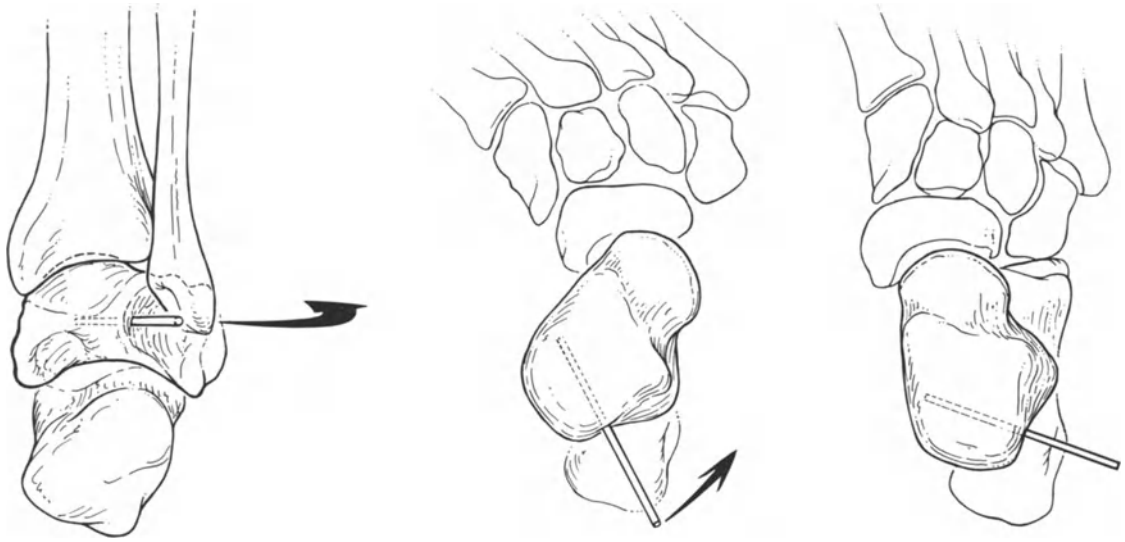


Figure 7.8 A: Posterior view of the ankle and talus. The Kirschner wire is inserted in the posterolateral surface of the talus. Note the external rotation of the talus in the ankle mortise. B: The abnormal rotation of the talus is seen. The Kirschner wire is used to derotate the talus to its normal position. C: With the talus in a normal alignment and the talonavicular joint reduced, a second Kirschner wire is then used to maintain this correction.

splint is changed to a short leg cast. Four weeks later, the cast, Kirschner wires, and stitches are removed. Radiographs are taken at this time to assess correction. The child is fitted in a night splint (Wheaton) and the parents are instructed to start range of motion exercises. Additional follow-up is at 2 months, 6 months, and 12 months postoperatively. Yearly follow-up continues until maturity.

Denis Browne Bar

Use of the Denis Browne bar is reserved for cases of persistent internal tibial torsion.

Evaluation

The literature on talipes equinovarus presents many rating systems for the results of clubfoot surgery. We find Turco's cosmetic, functional, and radiographic evaluation methodology to be the most useful of those reviewed.[6] It follows in brief with a few modifications:

Excellent:
1. Plantar grade foot
2. Full correction of the deformity obtained at time of surgery
3. Only minor residual deformities
4. Cosmetically pleasing appearance
5. Pliable subtalar motion
6. Normal ankle dorsiflexion
7. Strong triceps
8. Good push-off and gait
9. Normal tarsal relationship radiographically

Good:
1. Plantar grade foot
2. Complete correction obtained
3. Normal tarsal relationship on radiographs
4. Presence of one or more mild, but still cosmetically acceptable, residua (e.g., mild pes planus, mild metatarsus adductus, slight limitation of subtalar motion)

Fair:
1. Plantar grade foot
2. Acceptable functionally but less so cosmetically
3. Overcorrection or some loss of initial correction
4. Minor forefoot surgery necessary to correct residual deformities

Poor:
1. Loss of initial correction

2. Surgery (other than minor forefoot procedures) necessary to correct the deformities that recurred.

At follow-up visits, the foot is examined by a variety of means to insure a critical assessment of the results of surgery. Preoperative and postoperative photographs are a rather recent addition to assist in clinical evaluation. These photographs have proven invaluable in providing an objective record of cosmetic results. The photographs also help us at the time of subsequent visits to detect subtle changes that may indicate that the deformity is recurring.

Radiographic assessment forms another component of the evaluation process. In the lateral view, lines are drawn marking the inferior borders of the talus (rather than its longitudinal axis) and calcaneus in order to measure the talocalcaneal angle. The angle is considered normal if it falls within the 25° to 45° range.

The anteroposterior (AP) radiograph provides little more information than merely looking at the foot. We do, however, examine the calcaneocuboid relationship in the AP view. If one line can accurately describe the long axes of both bones, the calcaneocuboid relationship is recorded as normal. Any deviation marks the relationship as abnormal. The importance of radiographs is rather minor for our purposes because the range of angle values for even normal feet is quite large. A more important component of our exam involves testing the foot's motion at the subtalar joint. Passive and active dorsiflexion and plantar flexion are tested and recorded.

We also try to identify qualities that help to describe functional abilities and restrictions. For those who had a bilateral deformity, we ask which foot they prefer postoperatively. Shoe wear is examined, complaints are elicited, and problems explored for cause. The patients are observed standing and walking to identify possible functional dificulties.

TABLE 7.2. Surgical result for entire series (137 feet).

Result	Number of feet	Percent
Excellent	78	56.9%
Good	41	29.9%
Fair	7	5.1%
Poor	11	8.0%

Results

For this series, PMLR on 137 feet yielded the results shown in Table 7.2.

The results are shown in Table 7.3, categorized by year of surgery. The yearly breakdown by graded category demonstrates a trend toward improved results from 1981 to 1988. Outcome is significantly associated with year of surgery, $p < 0.1$.

Inherent to the definition of a poor result is the need for future surgery to correct severe residual deformities. Thus, all 11 feet in the poor category required further surgery.

Table 7.4 shows the surgical results in children, divided into two groups, based on whether the additional procedures of using an extra Kirschner wire and opening the calcaneocuboid joint were performed. Children in group I (55 feet) had surgery prior to the addition of these procedures to the standard PMLR, whereas in group II (47 feet) both of these procedures were used.

TABLE 7.3. Surgical results by year of surgery.

Year	Excellent	Good	Fair	Poor	Total
1981	1 (20.0%)	1 (20.0%)	2 (40.0%)	1 (20.0%)	5
1982	3 (30.0%)	6 (60.0%)	1 (10.0%)	0 (0.0%)	10
1983	9 (37.5%)	10 (41.7%)	0 (0.0%)	5 (20.8%)	24
1984	13 (76.5%)	1 (5.9%)	1 (5.9%)	2 (11.8%)	17
1985	10 (47.6%)	8 (38.1%)	2 (9.5%)	1 (4.8%)	21
1986	15 (75.0%)	3 (15.0%)	1 (5.0%)	1 (5.0%)	20
1987	8 (53.3%)	7 (46.7%)	0 (0.0%)	0 (0.0%)	15
1988	18 (72.0%)	6 (24.0%)	0 (0.0%)	0 (0.0%)	24

TABLE 7.4. Surgical results group I versus group II.

Result	Group I ($n = 55$)	Group II ($n = 47$)
Excellent	25 (45.5%)	33 (70.2%)
Good	19 (34.5%)	12 (25.5%)
Fair	3 (5.5%)	1 (2.1%)
Poor	8 (14.5%)	1 (2.1%)

TABLE 7.6. Forefoot alignment at last postoperative follow-up.

Alignment	Group I	Group II
No adduction	34 (61.8%)	35 (74.5%)
Mild adduction	17 (30.9%)	11 (23.4%)
Moderate adduction	0 (0.0%)	1 (2.1%)
Severe adduction	4 (7.3%)	0 (0.0%)
Supination (not exclusive of adduction)	6 (10.9%)	4 (8.5%)

Age at Surgery

Age at surgery was not found to be significantly associated with results obtained.

Complications

Complications occurred in 15 feet (10.9%). Minor pin-tract infection requiring early removal of the offending Kirschner wire (usually at the talonavicular joint) was the most common complication (12 feet, 8.8%). Cellulitis was seen in 2 feet (1.5%). Wound dehiscence occurred in 1 foot (0.7%).

Shape

Postsurgical hindfoot and forefoot shapes were recorded for each foot according to the criteria established by Turco.[6]

Table 7.5 shows the hindfoot shape by category as recorded at last follow-up (or at last follow-up prior to surgical treatment) for group I versus group II. No cases of increased valgus or fixed equinovarus occurred in group II.

Table 7.6 reports the results of examination of postsurgical forefoot shape at last follow-up visit for group I versus group II. Only three of seven feet with moderate or severe postoperative adduction had the calcaneocuboid capsulotomy.

TABLE 7.5. Hindfoot alignment at last postoperative follow-up.

Alignment	Group I	Group II
Normal valgus (5°–7°)	34 (61.8%)	37 (78.7%)
Abnormal (increased valgus (>7°)	2 (3.6%)	0 (0.0%)
Neutral	11 (20.0%)	7 (14.9%)
Varus	2 (3.6%)	2 (4.3%)
Equinovarus	1 (1.8%)	0 (0.0%)
Cavus	5 (9.1%)	1 (2.1%)

Discussion

This review of 137 feet constitutes a substantial series with results supporting the effectiveness of the PMLR for treatment of idiopathic clubfoot resistant to nonoperative management. Excellent and good results were obtained in 86.9%, fair results in 5.1%, and poor results in 8.0%. The breakdown of results by year of surgery shows a trend toward improved results from 1981 to 1988 (see Table 7.3). The incorporation of the extra Kirschner wire and calcaneocuboid joint release in the operative procedure is responsible for this trend.

Table 7.5 demonstrates the substantially better results for hindfoot correction obtained in group II versus group I. Excellent and good results were seen in 80% of group I patients versus 95.7% of group II patients. A poor result was obtained in only 1 of the 47 cases in group II (2.1% versus 14.5% for group I).

Postoperative analysis of the shape of the hindfoot and forefoot supports the release of the calcaneocuboid joint and the use of an extra Kirschner wire for talus derotation in clubfoot surgery. As shown by Table 7.5, 2 cases of valgus (3.6%) occurred in group I, whereas no cases of valgus were seen in group II. Cavus deformities occurred in 9.1% of group I feet versus 2.1% (one foot) in group II. For the entire series, only one foot had fixed equinovarus posturing postoperatively—a group I foot. These results support the use of the extra Kirschner wire for improving hindfoot correction.

Forefoot correction, too, proved to be better in group II feet when compared to that obtained for group I (see Table 7.6). Of the 47

feet in which the joint was opened and the wire was used, only one had more than a mild adduction deformity and none had a severe adduction deformity at last follow-up. There was no residual deformity in 61.8% of group I feet versus 74.5% of group II feet. Thus, opening of the calcaneocuboid joint is associated with improved forefoot correction.

Shape of the corrected foot is a cosmetic variable that reflects functional ability as well. Function is the ultimate criteria for determining success or failure of clubfoot surgery. As the children included in the study mature, time will tell whether their surgically corrected clubfeet will hinder their activities. Observations of the children with long-term follow-up reveal few obvious limitations in movement.

All of the complications noted were treated successfully with no sequelae. Currently, fixation is maintained for 6 weeks barring complications. Of the 12 feet in which pin-tract reactions occurred, 5 (41.7%) had excellent results, 6 (50%) had good results, 0 had fair results, and 1 (8.3%) had a poor result. Thus, the pin-tract reactions do not appear to be related to increased incidence of fair or poor results, despite early removal of internal fixation.

Wound dehiscence was a problem in one foot. Special attention is directed to avoiding wound dehiscence at the time of surgery. Often the foot is splinted in slight plantar flexion to avoid excessive tension on the wound.

Conclusions

Analysis of 8 years of experience with the complete posteromedial and lateral release through the Cincinnati incision has shown promising results. Two modifications of the procedure, namely (a) use of a temporary Kirschner wire for correction of the abnormal external rotation of the talus, and (b) release of the ligaments binding the calcaneocuboid joint, are useful adjuncts to the original surgical plan as presented by McKay[4] and Simons.[5]

Proper hindfoot correction is imperative in obtaining functionally and cosmetically pleasing results in clubfoot surgery. We believe that this correction can be achieved only if the talus is medially derotated in proper position in the ankle mortise. Use of a temporary Kirschner wire as an aid to the alignment of the talus with the navicular prior to insertion of wires for internal fixation is a simple and efficient means of obtaining this crucial hindfoot correction and, thus, a better operative result.

Forefoot correction is the second critical component to successful clubfoot surgery. Residual forefoot adduction deformities tend to be much milder, if present at all, when the release of the calcaneocuboid joint is performed. These results support Carroll's assertion that release of the ligaments binding this joint is imperative in avoiding severe residual adduction deformities.[1]

On the basis of the results obtained with these modifications, we recommend their use.

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Surgical Release and Reduction of Congenital Talipes Equinovarus

R.M. Barnett, Sr.

In the course of the past 30 years, I have developed a philosophy for the treatment of clubfeet that is now the surgical method used at the Twin Cities (Minneapolis–St. Paul) Unit of the Shriner's Hospitals.

The teachings of Kite[3] indoctrinated most of us (in the United States) into a nonoperative attitude toward clubfeet. These teachings are fundamental and important, but late results have dictated a change.

Over the years, the surgical philosophy has grown, to which many have contributed. Of the most recent teachers, we look to Turco,[9,10] McKay,[4–6] Carroll,[1] Simons,[7,8] Crawford,[2] and others. Their contributions have led us to the belief that the most conservative treatment for clubfeet that resist serial cast correction is the operative approach to accomplish complete release of all components of the clubfoot and to allow reduction of the skeletal deformities to a near-normal position. These surgical advancements, have, in my judgment, led us to a point in time in which we must determine the best method for accurate reduction of a clubfoot in reference to *anatomical landmarks*. This reduction must then be taught to younger surgeons so that it can be reproduced with accuracy. It is no longer good enough to say "it looks good," "it feels okay" "the heel position is about right," etc.

Purpose

It is my intention in this discussion to describe my surgical exposure and to point out what I believe to be the *accurate anatomical landmarks* to be used for the reduction of the foot once it is released. In the course of this discussion, I shall describe a method of treatment of the posterior tibial tendon that does not violate the tendon sheath or the gliding mechanism of this structure and does not require tendon lengthening, yet provides a generous release of the posterior tibial insertions, thereby removing its control over the clubfoot deformities.

Surgical Technique

I believe that the clubfoot release is best accomplished prior to the age of walking. Probably the most desirable time is between the ages of 3 months and 9 months. In this time period, the foot is large enough to provide comfortable surgical exposure and the cartilaginous bones are small enough that adaptive changes occur quite rapidly to the newly positioned skeletal parts.

The patient is anesthetized and placed in the prone position, the leg is exsanguinated, and a tourniquet is inflated to 150 mm of mercury.

Incision

The Cincinnati incision[2] is made with the exposure beginning medially over the mid- or the distal one-third of the 1st metatarsal, extending posteriorly to a point slightly below the tip of the medial malleolus, then curving over the heel cord at a level of about $\frac{1}{2}$ cm above the single transverse heel crease. From the heel cord laterally the incision curves down under the lateral malleolus, follows the line of the sinus tarsi and the subtalar joint, and extends into the forefoot overlying the interspace between the 3rd and 4th metatarsal bases. The deep tissues are then exposed by scissor dissection, avoiding the inclination to "spread" the tissues with the scissors.

Lateral Side

Dissection begins with the lateral part of this incision as the heel cord is identified and is freed from its surrounding tissues upward for a distance of about 2 cm. It is lengthened in a Z fashion as long as possible. The sural nerve is identified and isolated adequately to allow for protection throughout the procedure. The peroneal tendon sheaths are transected slightly below the tip of the lateral malleolus leaving the proximal sheath intact, preventing, it is

hoped, anterior subluxation of these tendons as the child grows. The peroneal tendons are retracted distally to expose the underlying fascia that extends from the peroneal tendon sheath to the heel cord. This fascia is divided in a line between the lateral malleolus and the heel cord. Deep to this, one can easily identify the calcaneofibular ligament, which is one of several major tethering structures in the clubfoot. This ligament is divided immediately below the lateral malleolus permitting easy entry into the posterolateral corner of the posterior facet of the subtalar joint. Having identified this joint space visually, the posterior capsule of the subtalar joint is divided transversely to a point approximately opposite the heel cord, but stopping short of the crossing of the flexor hallucis longus tendon. The peroneal tendons are retracted posteriorly and the release of the lateral capsule of the subtalar joint is continued from the posterior facet through the sinus tarsi to the interspace between the beak of the calcaneus and the junction between the navicular and the talar head. The calcaneocuboid joint is not opened at this time. The talonavicular joint is then opened with the scissors on the inferior, lateral, and superior surfaces, with care taken to divide the capsule near the navicular, leaving the talar neck with as little surgical dissection as possible. With the lateral and posterior parts of the subtalar joint now released, the heel can be placed into a varus position under moderate tension. This allows access for complete transection of the interosseus ligament.

Medial Dissection

Rotating the lower extremity externally allows access to the medial half of the incision through which the neurovascular bundle is identified and is dissected free of surrounding tissue over a distance of about only $1\frac{1}{2}$ cm, where it overlies the subtalar joint.

The flexor hallucis longus tendon sheath is identified and opened longitudinally from the subtalar level down to the medial face of the calcaneus, which thus allows this tendon to be retracted away from the subtalar joint while the underlying capsule is opened beginning at the point of capsular opening, which was made from the lateral exposure. Retracting the neurovascular bundle posteriorly, the flexor digitorum communis tendon sheath is opened longitudinally in the same fashion to a point just inferior to the sustentacular process of the calcaneus.

The posterior tibial tendon is identified by palpation extending from the medial malleolus to the medial prominence of the navicular. This, in most instances, is a very short distance. The tendon is exposed on its anterior or dorsal surface from the medial malleolus to its navicular attachment. At this point, blunt-nosed dissecting scissors are used to remove the navicular attachment of this tendon. Dissection proceeds distally under the navicular, the first cuneiform, and the 1st metatarsal base, staying next to the bone all the way, so that the tendon insertions are released from their underlying skeletal attachments. Proceeding across the plantar surface of the midfoot, the posterior tibial tendon attachments are visualized, and released from their skeletal attachments into the cuneiforms, and 1st, 2nd, and 3rd metatarsal bases. A slip of the tendon is released from its attachment on the sustentaculum (Figure 7.9). One must be careful not to incise the sustentaculum inadvertently. The posterior tibial tendon release and plantar dissection are carried laterally to visualize the peroneus longus tendon in its sheath crossing from the cuboid to the 1st metatarsal. All posterior tibial tendon slips into this sheath and extending slightly beyond into the forefoot are also released. At this point, the medial face of the cuboid is visualized.

With the posterior tibial tendon released but allowing its intrasheath portion to remain undisturbed, the tendon can be elevated along with the flexor digitorum communis to allow access to the remaining part of the capsule of the subtalar joint. The subtalar capsule is then divided with scissors from the flexor hallucis longus, crossing over the top of the sustentaculum, under the talar neck and head to the talonavicular joint. The talonavicular capsulotomy is then completed from the medial side to provide a complete release on all surfaces of that joint.

At this point, a complete subtalar release has been accomplished, including the interosseous ligament, as well as a complete release of the talonavicular joint. There has also been a complete release of the posterior tibial tendon attachments into the hindfoot, midfoot, and the forefoot. With this accomplished, one turns the leg to visualize the lateral surface of the foot again. By dislocating the calcaneus

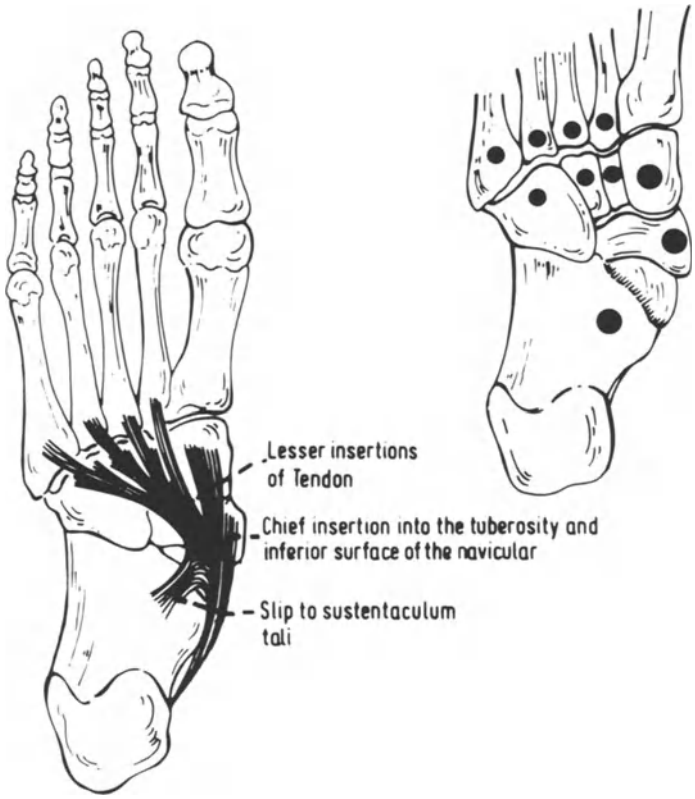


Figure 7.9. Posterior tibial tendon insertions into hindfoot, midfoot, and forefoot.

medially from under the talus, the navicular is simultaneously dislocated medially. This allows complete visualization of the plantar surface of the talus throughout its entirety.

Sustentaculum Tali

One can now visualize the small, hypoplastic sustentaculum of the calcaneus with its small articular face and, opposite this, the articular counterpart on the neck of the talus (Figure 7.10). The sustentaculum in the clubfoot articulates with the medial inferior edge of the talar neck. I consider this articulation to be abnormal in that the sustentaculum tali is hypoplastic and is located too far medially to provide a normal relationship between the talus and the calcaneus. In other words, the radiographic anteroposterior talocalcaneal angle is maintained in parallel alignment through the abnormal articulation of the sustentaculum. This relationship, I believe, is of considerable importance and will be discussed in detail below.

Calcaneocuboid Joint

At this point, the calcaneocuboid joint must be evaluated for subluxation and thus the need for a capsulotomy of this joint should be determined. If the cuboid, either clinically or by preoperative radiographic evaluation, appears to be medially displaced more than 10° away from the long axis of the calcaneus, the calcaneocuboid joint should be opened in its entirety and the subluxation reduced.

Reduction Techniques

Subtalar Reduction

With the hindfoot and midfoot completely released, the first joint to reduce is the sustentacular portion of the calcaneus to a point on the middle third of the plantar surface of the talus, when relating to the medial and lateral edges of the neck (Figure 7.11). Once this joint has been reduced to this position, one is no

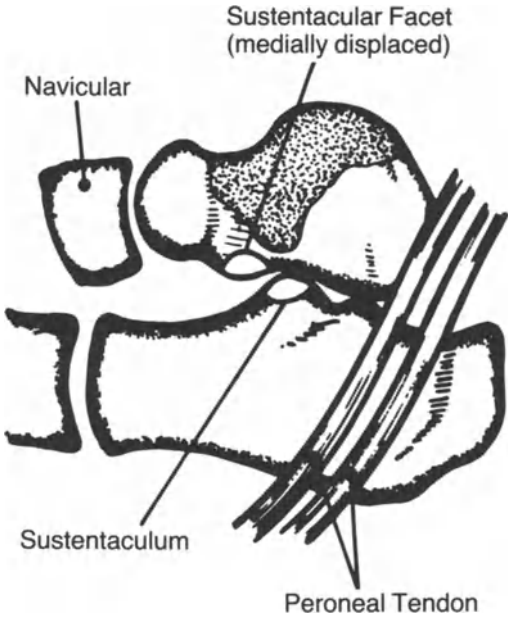


Figure 7.10. Subtalar joint dislocated to show the sustentaculum tali of the calcaneus and its talar facet. The sustentaculum is hypoplastic and its facet is located too far medially on the talus.

longer able to visualize the accuracy of the reduction. Therefore, I use a suture of absorbable material, which is passed through the sustentaculum and the long axis of the calcaneus. The two ends are then brought up through the midpoint of the neck of the talus in its middle third, exiting dorsolaterally on the talus (Figure 7.12). Thus, when this suture is tightened, one is assured that the sustentaculum is placed on the middle third of the neck of the talus.

Talonavicular Reduction

The navicular must be reduced in such a way that the maximum length of the medial column of the foot is obtained irrespective of the shape or direction of the talar head or neck. It must also be placed in such a way that the inferior border of the navicular is flush with the subtalar joint and not resting superior to this. A second suture of 2-0 Vicryl can be passed with a curved needle through the navicular, across the joint exiting on the medial side of the talar neck, then brought back through the talar neck to exit from the navicular parallel with the first leg of the suture (Figure 7.13). Thus, when



Figure 7.11. Drawing showing an anteroposterior view of the foot. Reduced ("de-spun") subtalar joint. The sustentaculum is repositioned onto the middle third of the talar neck.

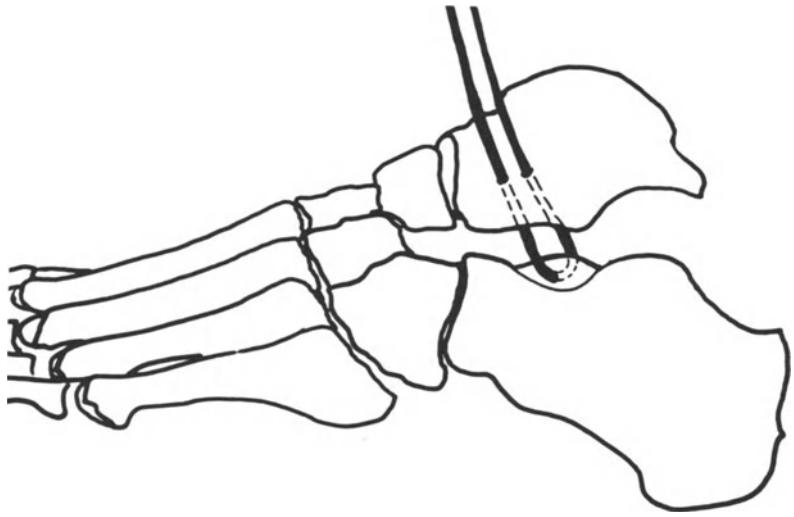


Figure 7.12. A lateral view of the foot. The sustentacular suture passes through the sustentaculum, then up through the middle third of the talar neck and out dorsolaterally (an absorbable suture is used).

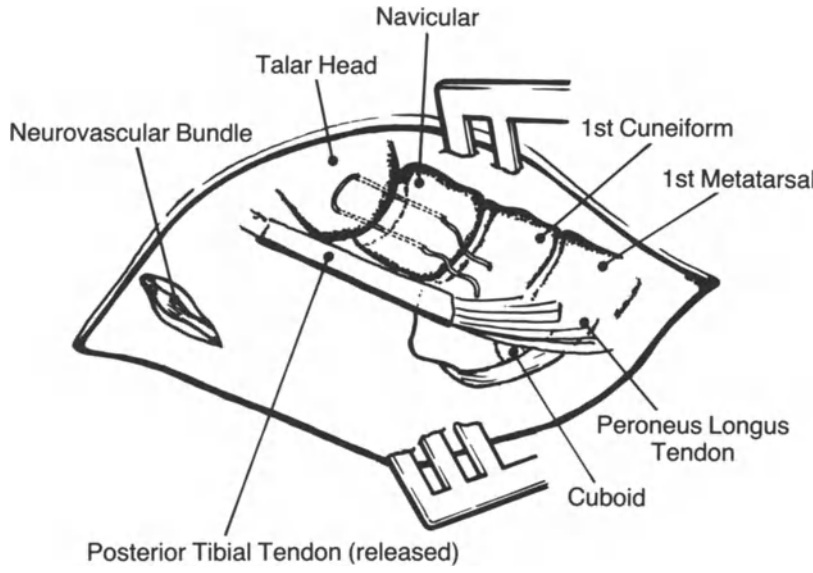


Figure 7.13. The talonavicular suture as viewed from the medial side. An absorbable suture passes through the navicular, across the talonavicular joint, out of the talar neck, and returns to exit out of the navicular. (I have stopped using this suture and now use a Kirschner wire for fixation of this joint, as this suture has proved unreliable.)

this suture is tightened, the navicular is held in the predetermined reduced position.

(I recently have found reason to be discouraged by the performance of the talonavicular suture as described. I have had a few cases of early subluxation of the navicular from its reduced position on the talus, which I presume to be due to premature lysis of the suture material or to the suture's cutting through the cartilage. As a result, I have resumed transfixing this joint with a Kirschner wire, which is left in place 6 to 8 weeks. The sustentacular suture continues to be accurate and trustworthy.)

The navicular must show absolutely no tendency to spring back into a dorsally subluxated position. Thus the navicular must rest comfortably with its inferior margin at the level of the subtalar joint. If it does not, additional release is required to free the medial column of the foot from the lateral column. (This separation of the two columns is usually performed in only previously operated feet.)

Tibiotalar Capsulotomy

Having reduced and sutured the talocalcaneal joint and talonavicular joint, the ankle is dorsiflexed gently to its limit. If the dorsiflexion range is less than 10°, the posterior capsule of the ankle joint is opened from the tip of one malleolus to the other. This release should allow the talus to rotate into dorsiflexion easily and also to translate posteriorly under the tibia.

After this part of the procedure has been completed, one will note that the cuboid almost always slides laterally to orient itself correctly with the distal end of the calcaneus. No internal fixation is used at this joint.

Closure and Cast Application

The only tendon that requires repair is the Achilles tendon. The Achilles tendon is reattached with the ankle at 90° and is under tension to such an amount that, with doriflexion of the ankle, it should appear that the sutures retaining the heel cord are under considerable tension. The penalty for overlengthening the heel cord is devastating, permanent, and irreparable. The flexor hallucis longus and the flexor digitorum longus tendons are not lengthened even though the toes may be in a position of acute flexion as the ankle is dorsiflexed. If ankle dorsiflexion is clearly restricted by these contractures, then lengthening is indicated. No subcutaneous closure is needed. The skin is closed with an absorbable suture. The tourniquet is released prior to closure.

At the end of the procedure, the bimalleolar axis of the foot should be at 90°.[4–6] The foot progression angle should be about 10° or 15° external and dorsiflexion should be possible without strain up to 10° to 15°.

The incision is covered with a strip of Owens gauze or other nonsticking substance; a strip of cotton approximately the width of the forefoot and about a half-inch in thickness is cut to extend from the toes to the upper tibial level. This is applied directly to the skin. Cast padding is used to encircle the leg, ankle, and foot in such a way that there is no compression of the cotton padding as it crosses the anterior part of the foot and the ankle. Attention to details at this point will enable the patient to be much more comfortable and will minimize, if not eliminate, the need for spreading or splitting the cast during the first postoperative days. With the patient still in the prone position, the short leg portion of the cast is applied with the ankle at 10° or 15° of dorsiflexion. There should be no attempt to improve the position of the foot during the cast application. One must accept what has been achieved surgically. Once this section of the plaster has set, the patient can be turned to his back and a long leg extension of the cast applied to the upper thigh with the knee at 60° to 90° of flexion.

Postoperative Care

The long leg cast is changed at approximately 2 weeks, attempting to gain further dorsiflexion with the use of anesthesia if necessary. The second long leg cast is removed at approximately 6 weeks. Following cast removal, a posterior Orthoplast splint is used to maintain the knee in flexion and the foot in dorsiflexion and eversion during the sleeping hours. During the day, no splinting or special shoes are used. The parents are instructed to stretch the foot into dorsiflexion and eversion six or more times at each diaper change. When the child has reached walking age, standard shoes of any variety are recommended with no special adaptations.

Results

Using this technique, we have been able to achieve a repeatable, accurate correction of the foot, to correct the bimalleolar axis, to restore the lateral border to a straight line, to create normal depth of sinus tarsi, to create the "normal" talocalcaneal (TC) angles, and to achieve an accurate talonavicular reduction without interfering measurably with any of the surfaces of the gliding tendons that cross the ankle and hindfoot.

A review of 181 primary complete peritalar releases in the past 5-year period of 1985 to 1989 reveals a 3.6% recurrence rate leading to secondary surgery. The reoperation rate prior to the complete peritalar release was 18%.

Discussion

In the future, more information is needed regarding the gliding and stretching characteristics of the posterior tibial tendon and the gastrocsoleus, as neither of these have very much excursion at the time of the initial operative procedure. This lack of excursion may be due to the absence of any opportunity to develop elasticity prior to treatment, or it may be due to an intrinsic muscular contracture. The question still is unsettled as to whether the abnormalities of these two muscles in particular are of an arthrogrypotic nature.

We also need to determine by magnetic resonance imaging (MRI) scans the degree of incongruity in the posterior facet of the subtalar joint that is created by the reduction of the talocalcaneal angle and the bimalleolar axis. Further, we need to know how long it takes for a young foot to adapt to this incongruity by producing a congruous joint. Additional knowledge in either of these areas may dictate a change in our postoperative program.

Summary

A method of extensive surgical release of the CTEV deformity performed through the Cincinnati incision is described. This procedure stresses the importance of releasing the multiple tendinous insertions of the posterior tibial tendon. The author also describes a method of reduction of the calcaneocuboid and talonavicular joints using specific anatomical landmarks. This surgery is performed at between 3 and 9 months of age. The order of reduction of the joints is as follows: the subtalar joint, the talonavicular joint, and the calcaneocuboid joint. The first joint is internally fixed by a strong absorbable suture and the second by a Kirschner wire, whereas the calcaneocuboid joint is not internally fixed. The results of surgery show that the reoperation rate prior to complete soft tissue release was 18%; following the adoption of this newer technique in 1985, the reoperation rate has fallen to 3.6%.

Acknowledgment

I am deeply indebted to the Twin Cities Shriner's Hospital for Crippled Children for providing me with the opportunity and the patient volume over the past 30 plus years to develop these concepts of clubfoot surgery.

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Long-Term Review of Juvenile Clubfoot Correction by Posteromedial Release: Clinical and Radiological Results

K. Klaue and G. Filipe

Today, the surgical treatment of congenital clubfeet (CTEV) is still very controversial. Compared to other reconstructive surgical procedures, this treatment is variable and must be adapted individually to the severity of each case. The three demonstrable deformations of clubfoot to be released surgically (varus and equinus of the hindfoot, and adduction at the tarsometatarsal joints) are more or less pronounced and fixed. The surgeon must avoid insufficient release producing recurrence and excessive release producing overcorrection.

It seems that a consensus presently exists that the simple posterior release with lengthening of the Achilles tendon is insufficient in most cases. Nevertheless, the age of the patient at the time of surgery and the extension of the release (by means of a defined hierarchy of intact functional structures necessary for subsequent stability of the foot) is not accepted by all authors. Published long-term results of surgically treated clubfeet suggest a consensus for performing a posteromedial soft tissue release and, in some cases, an occasional lateral approach to shorten and abduct the lateral column of the foot.[2,3,7,8,10] If one assumes that the essential deformity in the clubfoot is located within the midtarsal joint, reduction of the medial subluxation of the navicular seems to be critical for optimal correction.[6] Logically, on the lateral side, the calcaneocuboid joint should be reduced as well. However, this part of the deformity is often treated by intra-articular wedge resection of the calcaneocuboid joint[5] even though extra-articular bone resection is also possible. The transposition and/or lengthening of the tibialis anterior tendon is also a described means for improving the ankle function. However, this method is not accepted by many authors.

Soft tissue release for clubfoot deformity was performed following constant principles at our institution from about 1967 to 1985. This study reviews the results of this soft tissue procedure.

Materials and Methods

Thirty-five children and young adults (representing 44 feet) could be contacted and were examined clinically and radiographically 7 to 22 years (mean ± SD: 11 ± 3 years) after having primarily undergone soft tissue release for clubfoot deformity at the pediatric orthopedic department of the University of Paris VI (Hospital Trousseau). Selection of patients was performed using the following criteria: (a) no neurological disorders present, and (b) no other orthopedic problem present.

All newborns presenting with a clubfoot deformity were treated by manipulations and corrective splints for at least 6 months. Primary

surgical correction in this series was performed between 6 months and 2.5 years of age. Twenty-five children had unilateral involvement, whereas the remaining patients required bilateral surgery. The charts and operative reports were reviewed. Preoperative radiographs with anteroposterior (AP) and lateral views (taken in a manually corrected position of dorsiflexion) were available in all but two feet. This allowed preoperative assessment of the talocalcaneal angle as well as the talometatarsal angle.

The surgical procedure consisted of a soft tissue release performed through a hockey-stick posteromedial approach. In only four cases was a separate lateral approach done. Nevertheless, no calcaneocuboidal resection was performed primarily. The ankle joint was always released in its posterior aspect, while the subtalar joint capsule remained more or less untouched. The interosseous ligament was cut through a medial subtalar approach in two feet. The Achilles tendon was lengthened in all cases. The tibialis posterior tendon was always lengthened and the tibialis anterior tendon remained untouched. In 12 instances the flexor hallucis longus was also lengthened.

The abductor hallucis was detached from its posterior and superior insertion. The deltoid ligament was not released. The talonavicular joint was opened after having removed the pseudojoint between the medial malleolus and the navicular. The head of the talus was released in all cases. The spring ligament was cut in 13 cases, kept intact in 18, and there was no reference made about this structure in the remaining 13 cases. On the lateral aspect of the Achilles tendon, the lateral ligaments of the ankle and subtalar joint were not visualized and were inconsistently released. The mobilized hindfoot was fixed in a corrected position with one Kirschner wire within the first ray. A new short leg cast was applied every 5 to 7 days after the operation and maintained for 2 months.

At follow-up, the patient was checked clinically by one independent examiner. Standing AP and lateral x-ray films were taken and the interosseus angles were compared with normal values.[1,11] Additionally, a footprint and photographs were taken. The footprint was evaluated with regard to the width of plantar contact at the midfoot, and the adduction of the forefoot was considered at the angulation (convexity) of the lateral border of the foot (Figures 7.14 and 7.15).

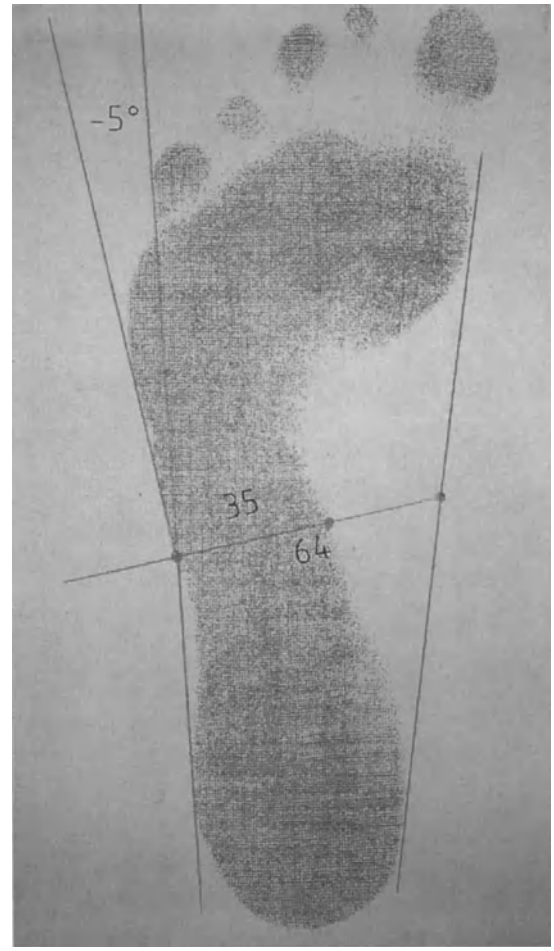


Figure 7.14. Normal footprint achieved after posteromedial release in an 8-year-old boy. This finding was exceptional in our series. The width of the plantar contact about the midfoot was measured at right angles to the 5th metatarsal at its base. This width (35 mm) was expressed in relation to the width of the midfoot measured on the same axis and limited by the medial tangential line to the footprint (64 mm). The adduction of the forefoot was measured through the angulation of the lateral border of the foot at the base of the 5th metatarsal (5° abduction).

Results

Upon reviewing the patients' histories, we found 21 of the 44 feet required at least one

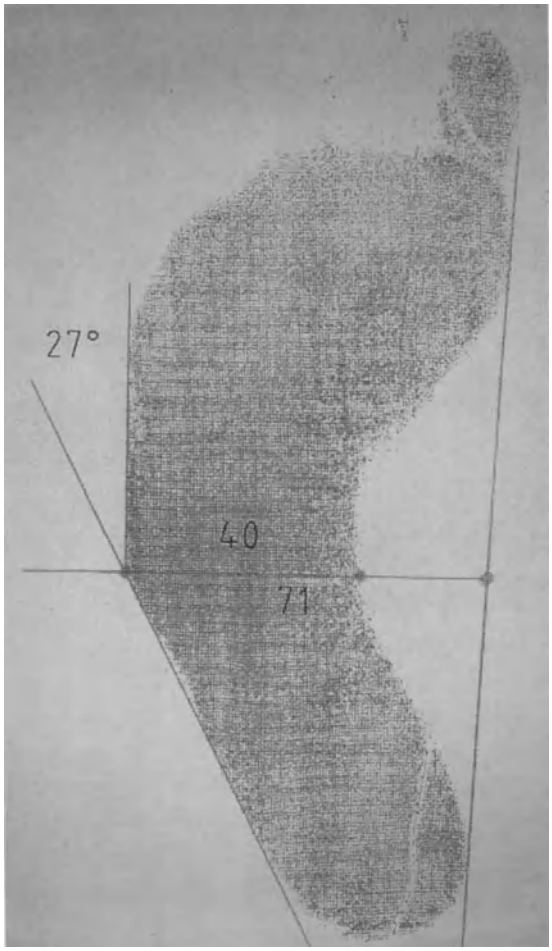


Figure 7.15. Marked residual adduction of the forefoot after posteromedial release in a 12-year-old boy. No reintervention was performed. Although the width of the plantar contact about the midfoot is normal, the adduction of the 5th ray measures 27°. The patient is asymptomatic.

secondary surgical intervention. The age at which this procedure was performed varied between 3 and $11\frac{1}{2}$ years. In all cases, a soft tissue release was performed as described above. Additionally, in seven feet an intra-articular shortening of the calcaneus was performed. A lateral transfer of the tibialis anterior tendon was performed in five feet. A triple arthrodesis was performed in one case.

By questioning the patient, we learned that 11 feet were without any functional limitation, including sports, there were 30 feet with a slight limitation occurring under extreme physical activity; there were three feet that caused daily limitation. No feet demonstrated continuous limitation.

Three visible deformities persisted in a more or less pronounced manner in the 44 controlled feet: (a) the heel was lateralized beneath the ankle joint (hindfoot valgus) (Figure 7.16), (b) the bimalleolar angle was increased in external rotation in relation to the 2nd metatarsal; and (c) there was a remaining "bean-shaped" appearance of the forefoot.

Functional tests demonstrated a general limitation in flexion (mean + SD: 27° + 13°) and extension (mean ± SD: 8° ± 7°) of the ankle joint (Figure 7.17). In 32 feet, the subtalar mobility was reduced. Walking tiptoe was feasible in 38 feet. A gradually decreasing number of cases were able to walk on their heels, jump on one leg, and finally, to stand tiptoe on one foot. The latter was possible for only 18 feet. Absence of an anteromedial buttress [metatarsophalangeal (MTP) one joint] was found in 22 feet. The footprint demonstrated an increased adduction of the 5th metatarsal (mean ± SD: 16° ± 7°).

Radiologically, in only 15 cases was the talar dome normal, whereas in the remaining 29 it was flattened. The talocalcaneal angles in both planes were diminished compared to normal values. The talometatarsal angle within the sagittal plane (on the lateral radiograph) was found to be increased in flexion (mean ± SD: 13° ± 9°). The first ray axis within the sagittal plane was broken by a malalignment of the navicular between the talus and the first cuneiform in 16 feet (Figure 7.18). This was an indication of dorsal subluxation of the navicular.

Discussion

The number of cases that required reoperation in this series (21 of 44) demonstrates that the surgical release was globally insufficient and led to this high recurrence rate. However, when comparing the objective findings of the morphology of the feet and the subjective results expressed by the patients, we were astonished that these residual deformities are tolerated without major limitation.

The final result of this long-term review suggests that, even after extensive surgical release,



Figure 7.16. The lateralized (valgus) heel of a 10-year-old girl who underwent posteromedial release at age 2. No reintervention. The heel cord is thinned due to lengthening. The lateral border of the foot is straight. The girl is asymptomatic, but is unable to walk tiptoe [maximum ankle (plantar) flexion is 5°] or jump on one foot.

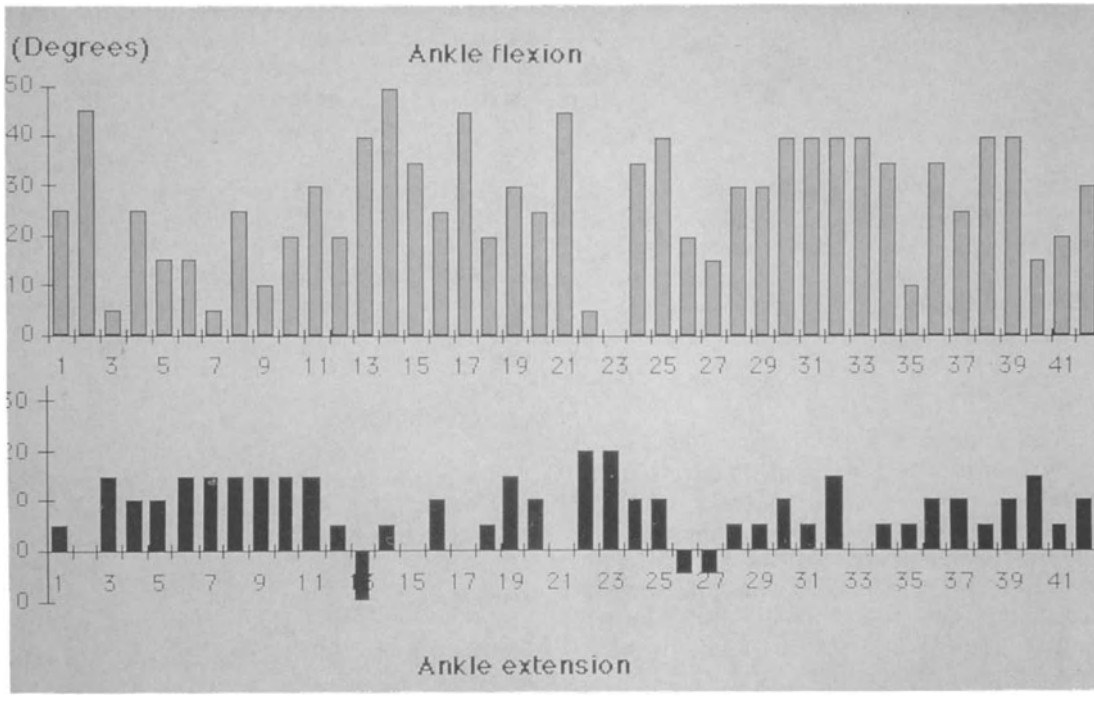


Figure 7.17. Ankle motion at follow-up. Mobility was reduced in both flexion (plantar flexion) and extension (dorsiflexion). The lack of extention (dorsiflexion) is currently explained by insufficient lengthening of the heel cord. In our series, six feet had ankle (plantar) flexion of 10° or less.

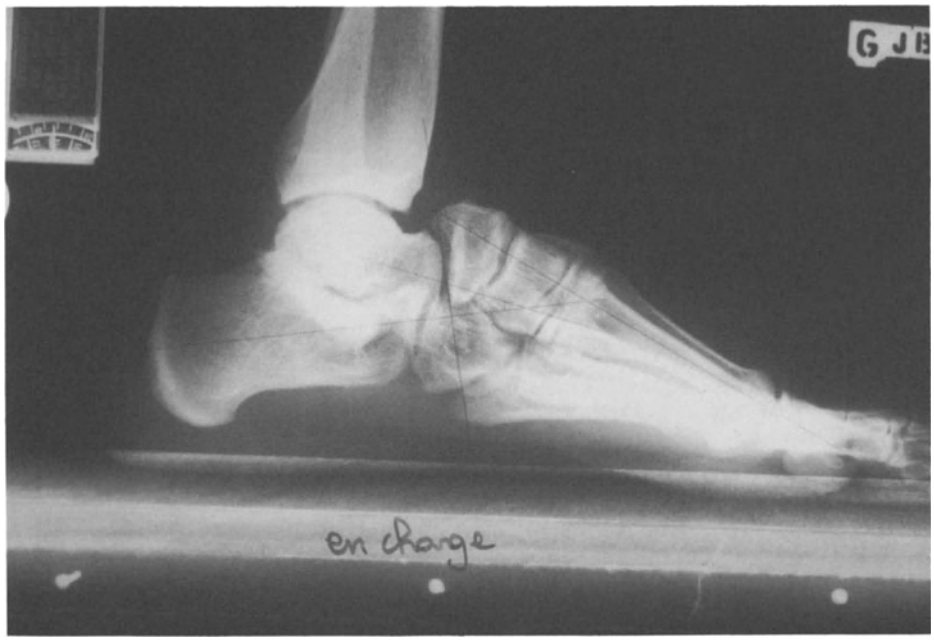


Figure 7.18. Lateral weight-bearing radiograph of the foot of an 18-year-old boy. First operated on at 1 year 3 months of age. Reintervention was performed at age 6. The navicular is subluxed dorsally. This patient is limited under extreme conditions like football or athletics. The triangular shape of the navicular was a very common finding in this series.

these feet are on the "undercorrected" side. This statement, however, needs to be clarified because of the complexities of the deformities. In fact, the deformities must be described within three distinct planes. There is probably a mutual influence of the different steps of the release on the morphology within those planes. For example, one can imagine that a limited (not released) excursion of a joint in one plane overloads the soft tissue structures within another plane by weight bearing. It is therefore not correct to talk simply about over- or undercorrection of the clubfoot release.

The fact that many feet showed a lateralized heel (15 cases) seems to be a sign of excessive release on the medial side of the hindfoot (tibionavicular joint, tibialis posterior tendon). It might also be due to the limited release on the posterolateral aspect of the foot, which is poorly controlled with the single posteromedial approach.

The fact that the plantar flexion was generally limited is probably due to a lack of release of the anterior structures, e.g., tibialis anterior tendon.

The dorsal subluxation of the navicular within the sagittal plane may be due, in turn, to an insufficient fixation after a complete release.

The adduction of the forefoot measured at the 5th metatarsal may demonstrate an insufficient mid-tarsal release that was performed on the medial side only, leaving the lateral structure in its original medially subluxated position. The intraarticular shortening of the calcaneus seems to be an easy way to correct the adduction of the forefoot.[9] Our feeling, however, is that although this procedure may protect the foot to a certain degree from recurrence, it certainly stiffens the hindfoot significantly by impeding midtalar motion.

There is probably a danger of overcorrection secondary to sectioning the interosseous ligament. Two cases showing markedly pathological footprints and malalignment were associated with sectioning of the interosseous ligament. We believe this hindfoot structure should not be altered. Our aim is the horizontal, external rotation of the calcaneus, together with the physiological valgus alignment of the hindfoot. This external rotation of the calcaneus should be performed until the interosseous angle between the talus and calcaneus (on

the AP projection) is normalized and is held without any recoil due to strained soft tissue. One can easily understand that, without the central pivot of the subtalar joint, no structure stops the hindfoot from sliding laterally, thus severely altering the hindfoot stability.

Besides the possibility of local overcorrection, which should be avoided, another crucial point to consider is the posterolateral release. The talocalcaneal ligaments, the so-called posterolateral knot, and the calcaneocuboid joint must be visualized and released. Direct visual control is also necessary for precise release of the fibula from its posterior position and the heel from its lateralized position.

Tibialis anterior tendon lengthening is a procedure that should be performed primarily to avoid the very limited tibiotalar motion seen in our series. Its eventual transfer toward the lateral part of the foot should be achieved early, before deficiency of the anteromedial plantar buttress becomes established.

Malalignment of the navicular seems to be related to inadequate reduction of the first ray and to the extensive release. Additional or altered fixation to avoid dorsal subluxation should be performed.

For several years we have routinely used the Cincinnati approach[4] for the juvenile clubfoot release. This approach permits a perfect view of the posterior and lateral structures. The lateral release should be performed together with the medial midtarsal release. Additionally, it should be performed within the soft tissue exclusively and/or within the bone. Thus, the calcaneocuboid joint is preserved, which avoids stiffening of the foot, and complete release and reposition of the midfoot can be achieved. By better control of the posterolateral structures, tensionless reduction of malrotation about the hindfoot is possible. We believe that an individually adapted technique of release is much easier to perform with the Cincinnati approach. The lateralized heel should be avoided, the bimalleolar angle in relation to the second ray corrected, and the lateral border of the foot made straight.

Summary

Today, surgical treatment of congenital clubfoot deformity through simple posterior release with lengthening of the heel cord is known to be insufficient in the long term. Although posteromedial release has been widely used for a number of years, the critical aspects of the release and the possibilities of undercorrection and overcorrection in the long term are not yet clear. Based on our clinical experience with a posteromedial approach and a clinical and radiological evaluation with a mean follow-up of 11 years (SD 3 years), we can conclude from this series that undercorrection was the most common end result. Nearly half of the cases required reoperation. The posteromedial approach does not permit optimal visualization of all the structures to be released. Our review suggests that the tight structures responsible for the deformities should be released more precisely where they are tethered. Although the mutual influence of the different releases is difficult to predict, the release performed must be individualized to the patient.

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Discussion

Dimeglio (Palavas-les-Flots, France): I would like to take a poll of the audience to see what incisions are being used. [The poll showed approximately 60% used the Cincinnati incision; 30% used two incisions; and 10% percent preferred a single medial incision.—ED.]

Handelsman (New Hyde Park, New York): I prefer a serpentine incision; this allows for a little extra increase in length, which prevents contractures. I like to lengthen the tendons above the pulley mechanism behind the medial malleolus so that they don't become adhesed later. I lengthen the tibialis posterior and the long toe flexors.

Gould (Milwaukee): I think its important to plan one's incisions. I hear people say, "there are feet in which we know we'll have skin problems." This suggests a failure to appreciate that there are ways of making skin incisions to deal with these severe feet. Although many routine incisions, including the now-standard Cincinnati incision, would be appropriate, there are those feet in which other types of incisions, e.g., transitional flap incisions, would prevent problems with healing.

Crawford (Cincinnati): The Cincinnati incision is a comprehensive approach and is nothing more than an approach. If one wishes to perform a limited medial surgery, one can do it through this incision or, alternately, one can make a posterolateral approach through a portion of this incision. I would much prefer to use a direct approach to the anatomy and to be able to concisely incise any pathoanatomical structures, rather than to attempt to incise them blindly through an incision that does not allow me to fully visualize the articular structures, resulting in possible damage to them. I anticipate that there would be less scarring and less fibrosis by meticulous surgery performed through an adequate incision than through several incisions, none of which allows adequate visualization as does the Cincinnati incision.

Dimeglio: In France we have avoided the Cincinnati incision. We perform a limited dissection of the subtalar joint. Therefore, we usually make only one incision on the medial side.

Kinoshita (Osaka): I think extensive releases may provide good results, but they sometimes lead to excessive scar formation, which may result in relapses.

Dias (Chicago): I have reported the results of 137 feet operated on through the Cincinnati incision without one case of wound healing problems. If one leaves the foot in equinus, then gradually brings it into dorsiflexion with repeated cast changes at 10 to 14 days, one should not have any problem with this incision. It is possible to have complications, of course, but if one is careful, this should not happen.

Bruschini (São Paulo, Brazil): We had a 5% complication rate. In my opinion, severe equinus is the main contraindication to the Cincinnati approach. I think that this was the cause for most of our complications.

Goldner (Durham): Dr. Bruschini showed us an example of a deep slough and reported a 5% complication rate in 60 patients using the Cincinnati incision. That's a greater complication rate than I would be willing to accept, and

I think that this was due to the tension on the incision.

Goldner: I believe that magnification should be used in CTEV surgery. The cartilage can be easily damaged if one doesn't see what one's doing. One should use microsurgery with large magnification and small instruments.

Watts (Los Angeles): A few years ago I presented a paper entitled, "Circumcision as the Treatment for Clubfeet." By that I meant that the Cincinnati incision was used but, rather than extending both of its arms distally, the arms were carried circumferentially around the foot and ankle. Instead of going three-quarters of the way, I went 360° to possibly bring the excess skin on the lateral side around to the medial side to help closure. I did not have any complications, but I didn't really think that it helped much. On the other hand, Lindseth from Indiana is now doing this.

Kling (Indianapolis): Lindseth has used circumferential incision in feet with myelomeningocele (without CTEV). He makes a 360° incision, mobilizes the dorsal skin proximally, rotates it about 60°, and then uses that to close the wound. This has been very satisfactory on some very tight feet following posteromedial release. He's reviewing these now, and it's my understanding that he has not had any complications.

Handlesman: I would like to discuss the treatment of the tibialis posterior and long toe flexor tendons. In a monkey or a baboon, the tibialis posterior tendon does not have an attachment to the navicular. It sweeps past the navicular in the foot and attaches to the bases of the 2nd, 3rd, and 4th metatarsals. Only in man does it attach to the navicular. We forget about these digital projections of the tibialis posterior in man. It often passes as a discrete tendon beneath the sole of the foot. In my opinion, it is important not to transect the tendon distal to the attachment of the tuberosity of the navicular. I leave the tendon attached to the tuberosity, because I don't want to ultimately lose the function of the tibialis posterior with a resultant flatfoot. Thus, I do the actual z-lengthening above the malleolus.

In my early cases, I did not lengthen the long toe flexors; I now believe, unlike Catterall, that this has been a significant cause for recurrent deformity. I would like to ask Dr. Turco if he lengthens the flexor hallucis longus?

Turco (Hartford): I have never lengthened either the flexor digitorum longus or the flexor hallucis longus. I only see significant deformity of the great toe when I'm dealing with what I call an "atypical" clubfoot. With this exception, I don't lengthen the tendons and I don't think they are a cause of recurrent deformity.

Handelsman: In addition to performing flexor hallucis longus lengthening, I also perform a volar capsulotomy at the metatarsophalangeal (MTP) joint if there is fixed deformity present there.

Campos da Paz (Brasilia, Brazil): The interosseous talocalcaneal ligament is a very important structure. It triggers muscle contraction on and off during gait. So I wonder what's going to happen when patients have this ligament resected, as it is such an important structure.

Dias: I don't think the (proprioception) sensation of the interosseous talocalcaneal ligament is an issue. I routinely release the interosseous ligament and I have performed gait studies before and after and have noticed no difference whatsoever. If we're going to rotate the calcaneus, we need to release the interosseous ligament. This is still a debatable issue, and some surgeons may achieve the same good results that we have without releasing it.

Handelsman: If there is a good result from cast corrections preoperatively and only the residual of equinus of the hindfoot remains as a deformity, one can perform a limited posterior approach. The Achilles tendon, the tibialis posterior, and the long toe flexor tendons can be lengthened, as well as posterior capsulotomy of the subtalar and ankle joints performed. All that may be required then is to assess the need for further surgery. On the other hand, if deformity still exists, then the incision can be extended down the medial side of the foot and a formal posteromedial approach may be used.

Editor's Comments

In the Discussion section of this chapter, **Handelsman** makes a strong argument for the *posterior release* as an alternative procedure to the posteromedial release. He states that a posterior release is adequate for the correction of the hindfoot deformity of equinus when no other significant hindfoot deformity is present.

Although I would agree with this as far as the clinical appearance of the foot is concerned, radiographically in a study involving multiple interoperative radiographs taken following each stage of a soft tissue dissection, it was discovered that the release described by **Handelsman**, commonly referred to as a posterior release, was not adequate for the complete correction of equinus deformity as proven by interoperative x-rays.[2] In addition to the conventional posterior release, which involves Achilles tendon lengthening, posterior tibial tendon lengthening, posterior capsulo-

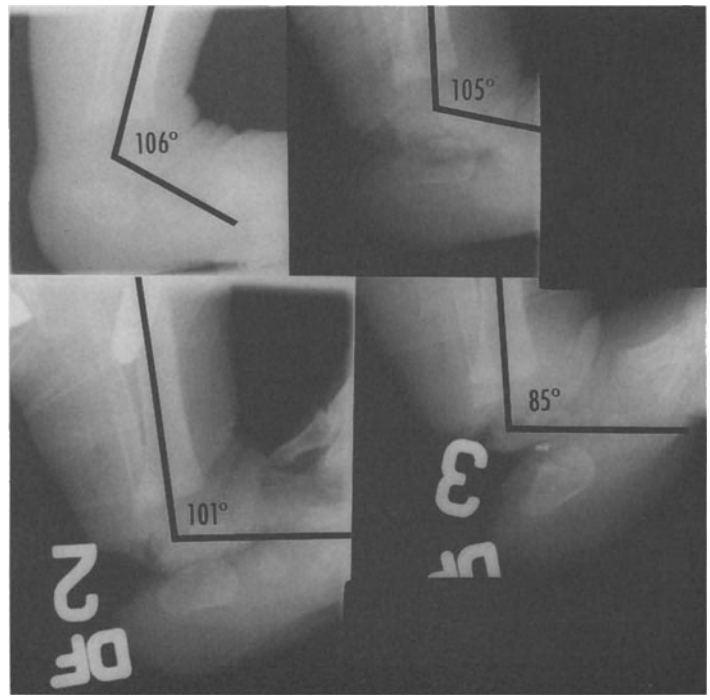


Figure 7.19. A series of lateral views of the foot and ankle that demonstrate a progressive increase in ankle and subtalar range of motion (as determined by the lateral tibiotatar and lateral tibiocalcaneal angle and the talocalcaneal angle—the latter not drawn) in each stage of the soft tissue release. These x-rays show that *the conventional posterior release does not correct equinus deformity*. Top left: Preoperatively. Top right: Following Achilles tendon lengthening (TAL). Bottom left: Following conventional posterior release (i.e., TAL, posterior tibial tendon lengthening, posterior capsulotomy of the ankle and ankle joint, and posterior capsulotomy of the subtalar joint. Bottom right: Following "partial subtalar release" (i.e., extension of the medial ankle capsulotomy to the level of the posterior tibial tendon sheath and lateral extension to the posterior talofibular ligament, medial and lateral extensions of the subtalar capsulotomy to the midlevel of the subtalar joint, and release of the posterior talofibular and calcaneofibular ligaments. (Note that the clip on the interosseous talocalcaneal ligament is intact.) Only when these structures are released does the ankle and subtalar range of motion become normal. Rarely, with severe contracture of the interosseous talocalcaneal ligament, this ligament must also be released to achieve normal range of motion at the subtalar joint.

tomy at the ankle and subtalar joint levels, the following releases must be performed: The incision of the posterior capsule must extend medially to the level of the posterior tibial tendon sheath and laterally to the posterior talofibular ligament, which must be released. In addition, the subtalar capsulotomy must be extended halfway forward to the anterior part of the subtalar joint, on both the medial and lateral sides. This is particularly important on the lateral side, as the calcaneofibular ligament must be released in order to achieve the correction of the equinus deformity. In addition, the calcaneofibular ligament release is necessary for the important derotation of the calcaneus beneath the talus, as described by **McKay** (Figure 7.19).[1,2]

In my experience, the important pathology of CTEV is seen more completely through the *Cincinnati incision* than through any other incision. Once the release is complete, and the foot pinned in the correct position, the ankle joint should be viewed posteriorly; the talus can be seen to dorsiflex and plantar flex through a good range of motion while no evidence of rotation within the ankle mortise can be seen (either around the vertical axis or around the horizontal axis), if there is no anterior ankle contracture or flattop talus (which may markedly restrict plantar flexion). I believe this is substantial evidence in favor of **McKay's** concept.

In the paper by **Sodre, Bruschini, et al.,** the authors report a 5% incidence of *skin necrosis* of which two cases were severe, with exposure of the Achilles tendon and subsequent skin grafting. It has been our experience that in young children, given enough time, epithelialization will cover the defect even in severe cases.

Kuo's comparison of the posteromedial incision and approach used prior to 1984 with the posterior, medial, and lateral release through the Cincinnati incision showed that the latter provided far superior results. He also states that 95% of the patients with clinically absent peroneal tendon function before surgery had a resumption of function postoperatively, and, finally, that the Cincinnati incision gives excellent exposure and, therefore, permits greater attention to detail during the surgical correction.

Howard and **Dias** report their results using a combination of two techniques—those of **Carroll** and those of **McKay**. Although they release the calcaneocuboid joint routinely in all patients, they do this primarily for forefoot correction not primarily for the correction of calcaneocuboid subluxation.

Whereas **Carroll** performs a partial calcaneocuboid release through the medial wound, **Howard** and **Dias** perform it through the lateral arm of the Cincinnati incision.

Our studies of calcaneocuboid subluxation have demonstrated that only approximately 25% of the patients have calcaneocuboid subluxation of a magnitude significant enough to justify release at the joint for the sole purpose of correction of deformity at this level. Some authors (e.g., **Carroll**) perform partial capsulotomy at this level to produce a secondary corrective effect on the forefoot. However, I perform the calcaneocuboid joint release only for deformity at this level.

I have almost always used a *plantar release* in addition to the calcaneocuboid release for correction of the calcaneocuboid subluxation. This enhances the corrective effect of straightening of the lateral column, as it removes the bowstringing effect of the medial column. Thus, I use the plantar release for three problems: (a) calcaneocuboid subluxation, (b) forefoot adduction, and (c) cavus deformity. If there is no forefoot deformity and the calcaneocuboid joint reduces without increased tension on the medial column, following calcaneocuboid release, I will not perform a plantar release. If plantar release and calcaneocuboid release result in correction at the midfoot with residual forefoot deformity, metatarsal capsulotomies or in the older patients combined cuneiform and cuboid osteotomies are indicated (see Chapters 8 and 13).

Barnett detaches the posterior tibial tendon from its multiple insertions on the plantar surface of the foot rather than proximally and performs the medial subtalar dissection in a unique fashion. In addition to the complete subtalar release, he performs a talonavicular release and complete release of the interosseous talocalcaneal ligament. His technique and order of reduction of the joints differs from what I have used. He stresses the reduction of the talocalcaneal joint first, giving greatest importance to the sustentacular position over the talonavicular reduction. Finally, he describes the use of a suture for fixation of the talocalcaneal joint rather than a Kirschner wire.

However, recently having experienced loss of reduction at the talonavicular joint with subsequent dorsal talonavicular subluxation, he has abandoned suture fixation at this level in favor of Kirschner wire fixation of the talonavicular joint.

Klaue and **Filipe** report that almost 50% of their patients who had only a PMR required a second surgical procedure. This is in keeping with earlier observations by **Stevens** and **Meyer** and by **Barnett** in Chapter 3 that a subsequent operation was required in 40% to 50% of patients who initially had inadequate surgery, such as a posterior release or PMR. **Klaue** and **Filipe** go on to point out that most of these patients were relatively asymptomatic; however, these feet had three persisting deformities: lateralization of the heel beneath the talus (hindfoot valgus), an increased bimalleolar angle, and a bean-shaped appearance of the forefoot.

They reported that the number of reoperations demonstrated that their PMR was insufficient. The great majority of these feet were undercorrected.

Finally, **Klaue** and **Filipe** point out that the anterior tibial tendon should be lengthened in cases where there is a marked restriction of plantar flexion preoperatively. It has been our experience that the anterior capsule of the ankle may need to be opened and the extensor tendons of the toes may also require lengthening. If this can be determined preoperatively, anterior capsulotomy should be performed (along with anterior tendon lengthening) as the first stage of a two-stage procedure. I believe that it is contraindicated to open extensively the anterior capsule as well as the posterior capsule of the ankle at the same operative intervention.

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8
Wound Healing/Postoperative Care/ Calcaneocuboid Subluxation

Introduction

In the first paper by **Grant** and his colleagues, the history of tissue expanders is briefly presented. They describe the types and variations of tissue expanders including those with internal and external ports. The technique for insertion and the determination of proper location are outlined as are the complications that can occur with this technique.

Breed presents his technique of leaving the wound open following surgery in order to obtain full correction of all deformities. This approach is based on the observation that the circulation to the skin is compromised when a severely deformed foot is corrected, the foot placed in dorsiflexion, and the wound closed. When wound closure causes inadequate blood supply to the skin flaps, **Breed** uses this technique rather than primary grafting or placing the foot in plantar flexion and gradually bringing it into dorsiflexion during subsequent cast changes.

Malan describes the presence of calcaneocuboid joint deformity in virtually all of his cases. He describes complete release of the calcaneocuboid joint along with a standard extensive subtalar release. He points out that failure to recognize and correct this deformity leads to hindfoot valgus. With correction of the deformity and proper muscle balance (between the anterior tibial and the peroneals), the foot may then grow and develop normally.

Carroll describes his technique for calcaneocuboid joint release as well as his technique for plantar release. These are used for correction of forefoot adduction.

Thometz and **Simons** describe a radiographic classification of calcaneocuboid subluxation. This is a practical classification, as treatment is predicated upon it. The indications and technique for calcaneocuboid joint release are presented along with their results.

The Use of Tissue Expanders in Clubfoot Surgery

A.D. Grant, D. Atar, W.B. Lehman, and A.M. Strongwater

Primary skin closure after completion of the surgical correction of clubfoot may be difficult or even impossible, especially with severe deformity or in revision clubfoot surgery.[10] There are several solutions to the problem:

1. Close the skin primarily in the undercorrected position, followed by weekly manipulations and casting (under general anesthesia).[13,18]
2. Perform a lateral release and local flap.[5,19]
3. Perform a myocutaneous or fasciocutaneus flap.[10,14,27]

The decision as to which alternative to use is usually made in the operating room. Factors to consider in this decision include the orthopedic surgeon's familiarity with skin flaps, the availability of a plastic surgeon, and the added risk of repeated general anesthesia.

An alternative to these three possibilities is tissue expansion using a silicon tissue expander before the surgical correction of the clubfoot. This allows primary skin closure without tension at the time of correction. It is important that the tissue expander be positioned under the skin without scar tissue, and sufficiently close to the area where the skin is to be used, so that rotation of skin is easily accomplished at the final operation.

Case Reports

Case 1

A 1-year, 3-month-old boy was born with severe bilateral clubfeet and ulnar deviation of both hands. The child's diagnosis was arthrogryposis, probably inherited as an autosomal dominant. The patient's feet were initially treated with serial casts. The hands were treated with splints. At 21 days, closure of a patient ductus arteriosis (PDA) and bilateral inguinal herniorrhaphies were performed. At 6 months, he was referred for further orthopedic treatment. At 9 months, an extensive soft tissue clubfoot release was performed on the left foot. After the release, a huge skin gap prevented primary wound closure in the corrected position. Therefore, the skin was closed with the foot in the originally deformed position, followed by weekly manipulations for 4 weeks under general anesthesia, until the fully corrected position was achieved. At the fourth manipulative session (anticipating the same skin problem), a tissue expander was placed in the operated leg after carefully planning its location. The skin and subcutaneous flap used for closure of the anticipated skin deficit was designed as a long anterior rectangular flap. The expander* was inserted to expand this flap area using an incision along what was to be the posterior edge of the flap. The expander was inserted between the skin and fascia (Figure 8.1). A proximal medial incision was used for the filling valve (Figures 8.1 and 8.2).

Saline (5 cc) was left in the expander and the wounds were closed with no drains. Every 1 to 2 weeks, 10 to 15 cc of saline was added percutaneously through the filling valve with a 23-gauge needle (Figure 8.3). The amount of filling was based upon the color and tension of the underlying skin. When a total of 120 cc saline had been added, sufficient expansion had been achieved (Figure 8.4). The child then had surgery. The tissue expander was removed (Figures 8.5 and 8.6). An extensive soft tissue release was performed. Primary closure of the wound was achieved with the foot in the fully corrected position without tension (Figure 8.7) and healing was uneventful.

Case 2

A child with severe congenital talipes equinovarus (CTEV) of the right foot was referred for treatment at 6 months of age. The tissue expander was placed in the medial side of the leg close to the ankle joint. After 2 months of weekly injections, the tissue expander was removed and complete subtalar release followed. The skin was closed primarily in the fully corrected position and healing was uneventful.

*Mentor Care, Goleta, California (custom-made rectangular expander 7 × 3 cm with microfill valve).

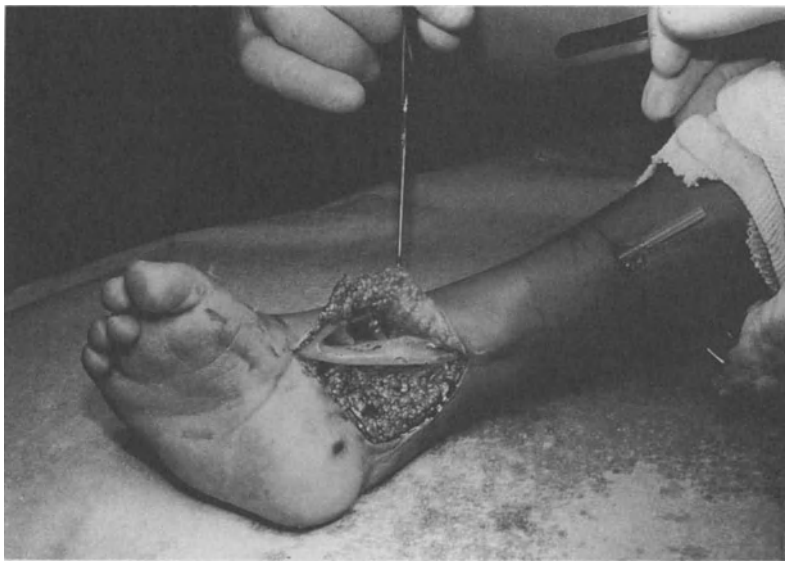


FIGURE 8.1. Insertion of the tissue expander into the subcutaneous pocket (distal longitudinal incision). The expander tube is seen through the proximal transverse incision.

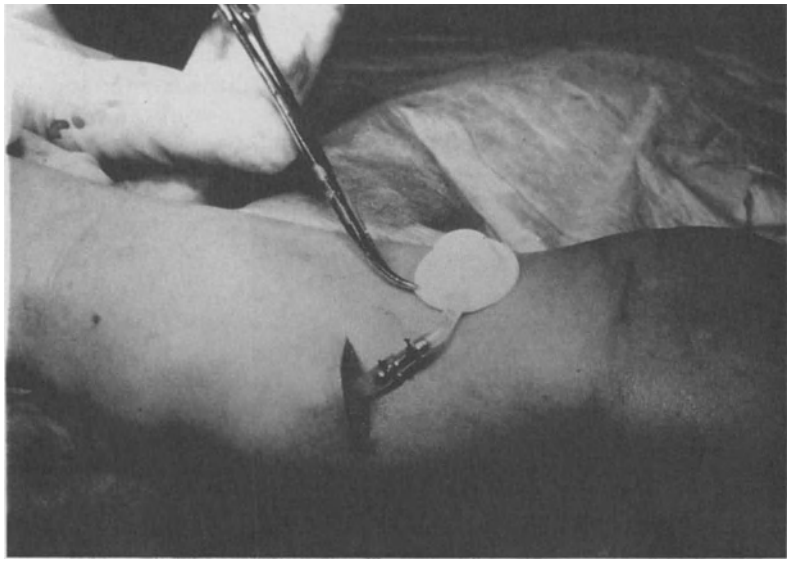


FIGURE 8.2. The injection port (filling valve) connected to the expander tube before insertion into the subcutaneous pocket.

Case 3

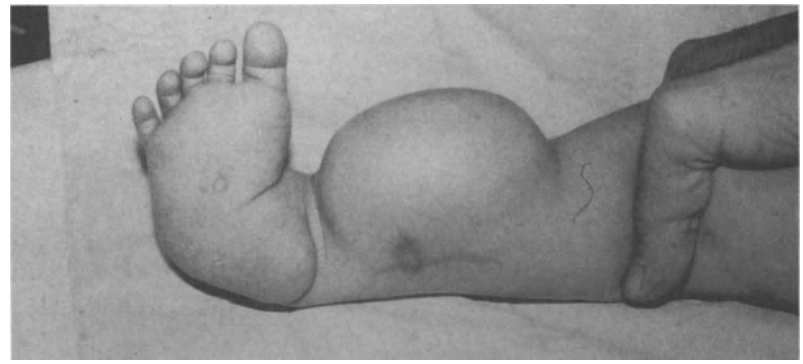
A child with partial tibial hemimelia whose foot was in severe equinovarus position was referred at 6 months of age. Prior to centralizing the fibula into the talus, the skin over the medial distal leg and dorsum of the foot was expanded. The final procedure permitted primary closure in the corrected position.

Discussion

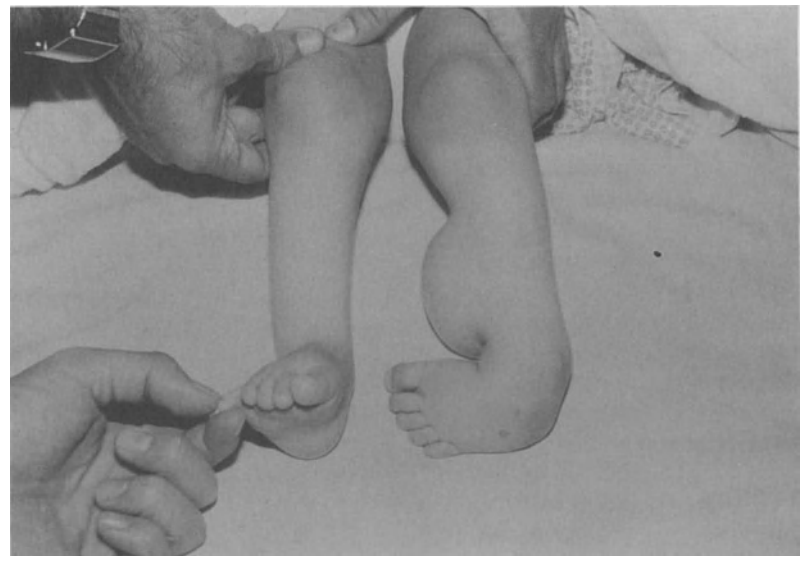
Soft tissue expansion is a physiological process. For example, the surface area of the abdomen may double during pregnancy as the result of underlying uterine enlargement.[8] Similarly, the skin of the developing breast increases its surface area to accommodate for the growth



FIGURE 8.3. Percutaneous test injection in the operating room. Weekly injections were done in the same manner in the outpatient clinic for 9 weeks.



A



B

FIGURE 8.4. A: Medial view of the leg and foot before the operation with total volume of 120 cc in the tissue expander. B: Front view. Note the severity of the deformity and the excess skin created by the tissue expander.



FIGURE 8.5. The inflated tissue expander before removal during the soft tissue clubfoot release.



FIGURE 8.6. The fibrous capsule formed around the tissue expander.

of the underlying glandular and adipose elements. The first person to recognize the importance of tissue expansion and to use it therapeutically was Planas (quoted by Jackson et al.[15]) who inflated a subcutaneous balloon in the ear region of a patient with congenital absence of the ear and used the expanded skin to reconstruct an ear.

In 1957, Neuman[24] used a subcutaneous rubber balloon with an external tube for injection of air to reconstruct an amputated ear. Credit for initiating tissue expansion as we know it today goes to Radovan,[28] who, in 1976, designed a silicone expander that was inflated by way of a filled remote injection port placed under the skin. Since then, the procedure for expansion of skin has been widely utilized in breast reconstruction,[29,30] head and neck reconstruction[1,6] for the removal of lesions, and for the repair of defects in the upper and lower extremities.[11,15,20–22]

Most tissue expanders utilize subcutaneous

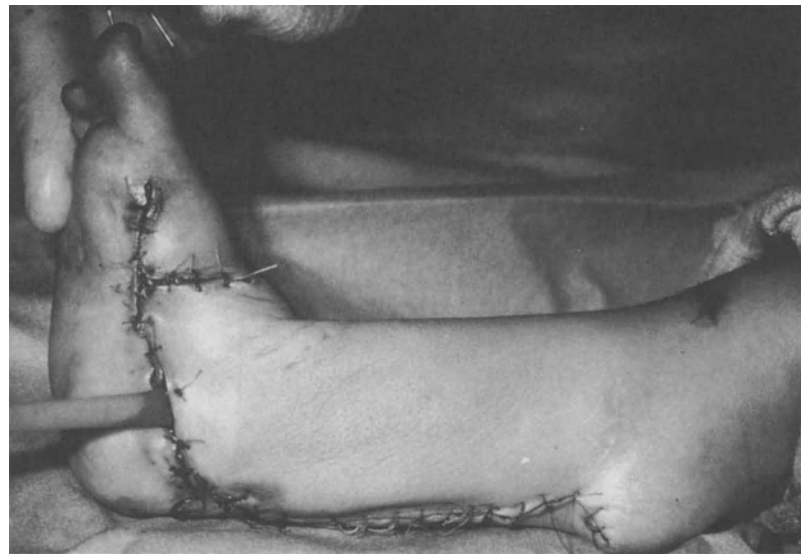


FIGURE 8.7. Primary skin closure with the foot in the fully corrected position. Note that the skin is not under tension.

remote injection ports connected to the expansion envelope (silicone) by a tube. The ports are placed through a separate incision in a subcutaneous pocket that is dissected at the time of expander placement. They are anchored locally by sutures to prevent malposition with movement of the limb, which may make it difficult to locate the port for injections. Several modifications have been suggested. Lapin et al.,[17] in 1985, used a tissue expander with a self-contained injection port. Difficulty in palpating the injection port through the distended skin can cause inadvertent puncture of this type of expander.[7] Therefore, further improvement was attempted by including a magnet at the base of the injection port. Injections were then performed through a special device that included a magnetic finder.[9] In 1982, Austad and Rose[3] developed a self-inflating soft tissue expander by including a hypertonic solution inside a semipermeable envelope (silicone). An osmotic gradient across the membrane caused slow expansion without the need for periodic injections. Recently the use of tissue expanders with external injection ports has been described.[15,16]

Injections are usually performed weekly. During each session the distended skin is observed for tension, blanching, or discomfort.[2,23,26,31] In some instances, family members are taught how to do this. The most effective and safest way to fill tissue expanders is still being investigated.[12,24] There are now more sophisticated ways to monitor the intraluminal pressure in the expander, such as the microcirculation and the oxygen saturation of the distended skin.[12,24] The tension created at the time of injection gradually dissipates as the skin stretches, accommodating to the increased pressure.

The tissue expanders have been positioned in several locations. The most common location is the medial leg. This has a sufficiently large area that the expander and injection site can be easily accommodated. However, initially it was felt that the area was too far away from the site for correction of the clubfoot. A second expander was placed over the dorsum of the foot. This was found to be too small and it had no advantages. One device was placed over the medial malleolar area without any problems or complications resulting. Our present preference is the medial leg, just above the medial malleolus. Previous incisions and scars should not be crossed.

Histopathological studies on guinea pigs[4] and humans[25] show a thick epidermis, a thin dermis, and formation of a fibrous capsule around the expander (Figure 8.6). These changes were not associated with significant changes in expansion time, expansion volume, location of the expander, or age of the patient. After a 2-year follow-up, the capsule totally resolved: the epidermis, dermis, and subcutaneous tissue returned to their preexpansion thickness.

The complication rate reported in patients with tissue expanders is quite variable, ranging from 5% to 25%.[15,22] Certain areas of the body (breasts) have a lower complication rate than others (lower extremities). Complications include seroma, hematoma, infection, implant puncture, and reservoir leakage. Skin necrosis and implant exposure were also reported. These were related to unrecognized overexpansion.[12] The expanders should not be placed under scars or previously operated sites as necrosis may occur.

Summary

Soft tissue expansion, now in use for more than one decade, provides us with a tool that can be used in a variety of fields. The successful use of this method is reported in the treatment of CTEV. Surgical correction was performed in several feet with severe deformities, using tissue expanders. This method should be reserved for the most severe deformities, where significant difficulty in skin closure is anticipated. In such instances, the additional surgery and protracted postoperative care is warranted. The ability to obtain a primary closure without tension is a major factor in avoiding incomplete correction or recurrence of deformity. The use of tissue expanders provides a way to achieve this goal.

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Partial Wound Closure Following Clubfoot Surgery

A.L. Breed

The major emphasis in the surgical treatment of the clubfoot has been correction of the existing deformities. Although surgical wound management has received only passing attention by most authors, wound problems have been recognized as a cause of compromised results.[2,6] Proper wound healing is essential for lasting correction of the deformity with good foot function.

The accepted practice of wound management following surgical treatment of the clubfoot has been to close the skin immediately after the operative procedure with the foot in the fully corrected position. This is the ideal method. However, the closure of the wound has often resulted in compromise of the correction achieved at surgery because of loss of blood flow to the skin. This may result in wound necrosis and recurrence of the deformity.[6]

When the best surgical correction cannot be maintained without compromising skin circulation, it is necessary to make a choice of wound management. Either the wound is closed primarily in a position of full correction with the probability of skin loss, an alternative method of skin closure is used (e.g., skin graft or tissue expander[1]), or the wound may be left open to close secondarily.

Purpose

This report discusses the treatment and results of seven clubfeet whose surgical wounds were left open at the end of surgery rather than compromise the position of full correction to achieve skin closure.

This approach was devised as a result of a child with diastrophic dysplasia whose initial clubfoot release resulted in a large open wound when the foot was placed in the corrected position. An extreme loss of correction would have been necessary to achieve viable skin closure. A plastic surgeon was consulted and the wound was closed with a full-thickness skin graft. After a prolonged healing period, the resulting scar was wide and irregular (Figure 8.8A). When the second foot was treated, the wound was left partially open and allowed to close by secondary intention. The wound closed in about 3 weeks with better scar formation than the first foot and with good foot function (Figure 8.8B).

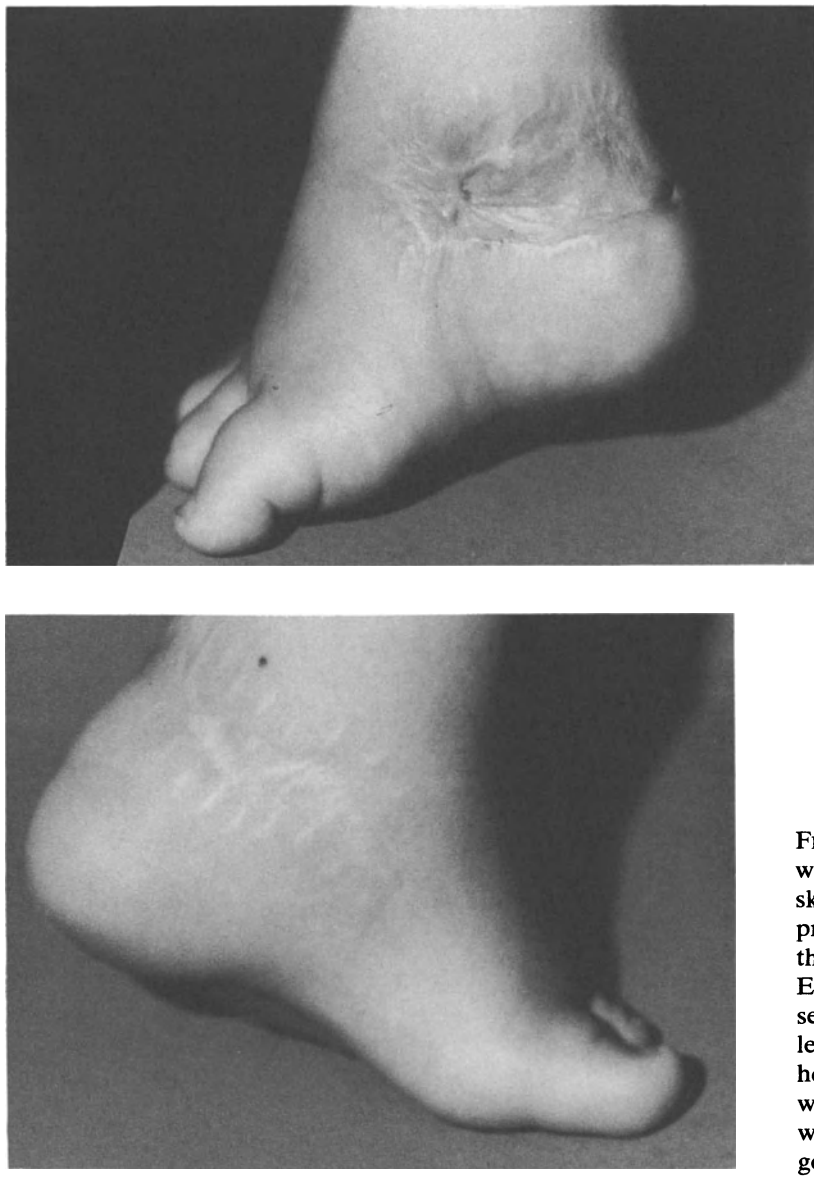


FIGURE 8.8. A: End result of a wound treated by full-thickness skin graft. The wound required a prolonged time for healing and the scar is wide and irregular. B: End result of a wound on the second foot of the same patient left open partially and allowed to heal by secondary intention. The wound closed in about 3 weeks with better scar formation and good foot function.

Materials and Methods

Over a period of 3 years and 9 months, 17 patients with clubfoot deformity (24 feet) were surgically treated by posterior medial and lateral release through a Cincinnati incision.

Of the 24 feet, 18 had no underlying cause for the deformity, two feet were in a patient with diastrophic dysplasia, two feet were in a child with Larsen's syndrome, and one foot was associated with congenital constriction band syndrome. One patient was referred for treatment because previous surgery had resulted in residual deformity of the foot.

In seven of these cases, the incision was left open to close by secondary intention. Those patients ranged in age from 2.5 months to 9 years 5 months.

The decision to leave the wound open was made (a) if closing the wound with the foot in full correction might compromise circulation to the skin of the foot, or (b) if closing the wound

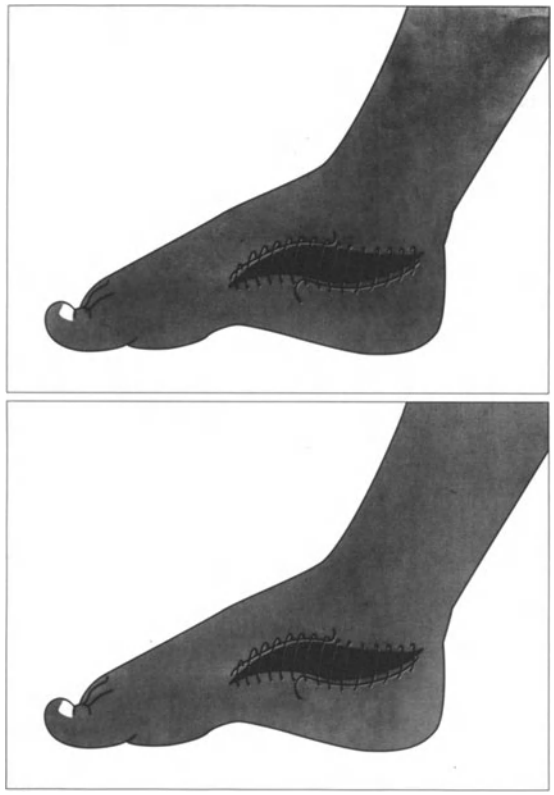


FIGURE 8.9. Suturing technique used in wounds that were left open. A running single suture using simple 2-0 nylon was placed through the skin, subcutaneous tissue, and investing fascia. The suture was tightened only to the point where no blanching of the skin was noted under the suture. No knots were tied. The desired tension of the suture was maintained by friction of the suture ends passed back under the loops of the sutures.

required compromising the position of correction. All wounds were left open to the extent that good circulation was maintained to the skin with the foot in full correction.

Using 2-0 nylon suture, a running single suture was applied through the skin, subcutaneous tissue, and investing fascia (Figure 8.9). The suture was kept loose by tightening it only to the point where there was no blanching of the skin under the suture. Knots were not tied; because knots are large, they can cause pressure areas underneath. Also, when sutures are tied, the tension constricts the skin and compromises circulation. The friction of the suture (passed back under the loops of the sutures) was sufficient to maintain the desired tension. The large suture acted like a spring and placed mild tension on the skin, drawing the wound edges together. Because of their greater area of surface contact, large size sutures do not cut into the tissue as much as smaller sutures.

A gauze dressing and a cast were applied with the foot in full correction. The first cast was changed under anesthesia, 1 to 2 weeks after surgery. The time of the cast change depended on the degree of wound opening. The wider the opening, the earlier the cast change. During the first cast change, the wound was debrided down to healthy granulation tissue with removal of all fibrinous debris. The suture was tightened to the extent that circulation remained uncompromised. A new cast was then applied. Casts were changed every 1 to 2 weeks until the patient's wound had closed. The greatest number of cast changes was five (in the child referred after previous surgery).

Results

All seven wounds had gaps greater than 3 mm. Wounds with gaps less than 3 mm were considered to be closed primarily. The maximum recorded wound gap at the time of the first cast change was 1.2 cm. However, since the wound gap decreases significantly during the first week, the gap had been greater than 1.2 cm at the end of surgery.

All wounds healed within 6 weeks. The scars were similar to those seen in feet whose wounds were closed at the time of initial surgery (Figure 8.8B).

Although the range of movement of the foot is difficult to assess after clubfoot surgery, it did appear compromised in these patients and was similar to patients who had their wounds closed at the end of the surgical procedure.

Discussion

When skin circulation is maintained at the expense of a compromised position of correction, the patient may be left with a partially corrected deformity because the correction achieved at surgery cannot be recovered. When skin circulation is compromised because of tight wound closures, wound infection,

wound dehiscence, or skin necrosis may occur. These problems are initially treated as an open wound with healing by secondary intention.

In his paper that popularized the one-stage posterior medial release of the clubfoot, Turco[5] listed foot correction in the initial cast to "avoid tension on the skin and subcutaneous tissues." He changed the cast at 3 weeks "bringing the foot up into further dorsiflexion." In a similar manner, Simons[4] positioned the foot in the first cast so that capillary refill of the proximal skin edge was achieved. At the time of the first cast change, he manipulated the foot to achieve further dorsiflexion.

In a later article in which he evaluated his failures with the one-stage correction technique, Turco[6] determined that surgical correction was lost during the postoperative period after the internal fixation was removed. He also observed a recurrence of deformity when one foot was placed in equinus position for plastic surgery. Although the ability to recover the position achieved at surgery during cast changes had been assumed, the corrected position was not always achieved. He therefore emphasized the need to obtain complete correction of all components of the deformity at the time of surgery. However, subsequent wound dehiscence and skin necrosis was observed and, when such complications did occur, he allowed the wound to heal by secondary intention.

Surgeons are familiar with the indications for leaving wounds open. Open treatment of contaminated traumatic wounds to minimize infection is well accepted. Surgical wounds that become infected are often left open to heal by secondary intention. Hand surgeons also use open treatment for Dupuytren's contracture.[3] Infection is possible in open wounds if they are neglected. If complications do occur, the wound is left open to heal by secondary intention.

I have elected to leave the wound partially open after clubfoot surgery rather than risk the loss of surgical correction. Scar formation and foot function have been similar to those observed in patients in whom it was possible to close the wound with the foot in full correction.

This approach is based on the observation that circulation to the skin is compromised when a severe deformity is maintained in full correction and the wound is closed. When the position of the foot is returned toward the deformed posture to allow adequate circulation, the fully corrected posture may not be recovered by manipulation at a later cast change. If the surgeon is not able to manipulate the foot back to the fully corrected position, a compromised result may have to be accepted and full correction permanently lost.

Summary

The primary objective of wound management is to avoid compromise of circulation to the skin with the foot in full correction. When the adequacy of circulation is in question, open treatment of the clubfoot wound is an alternative to closing the wound.

Seven cases of CTEV are reported in which the surgical wounds were left open partially and allowed to heal by secondary intention, rather than compromise the position with full correction to allow for skin closure. All wounds healed within 6 weeks. Scar formation and foot function were similar to those observed in patients in whom it was possible to close the wound with the foot in full correction.

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The Role of the Calcaneocuboid Joint in Clubfeet

M.M. Malan

In 1980, I became aware of a rigid deformity of the lateral ray at the level of the calcaneocuboid joint in rigid idiopathic clubfeet (CTEV). It was present in the vast majority of clubfeet in all age groups. This calcaneocuboid deformity was recognizable in most published photographs and x-rays of clubfeet but was seldom reported or discussed.

The radiographs of 100 consecutive idiopathic clubfeet presenting between the ages of 6 and 52 weeks were studied clinically, radiologically, and during surgery. Computed tomography (CT) and magnetic resonance (MR) images were obtained in some instances. Radiologically, the deformity was a fixed medial displacement of the cuboid from the normal position directly anterior to the long axis of the calcaneus. Displacement was marked in 85% and moderate in 15% of the feet. Clinically and at operation, the magnitude and rigidity of this deformity was easily demonstrated.

Complete correction of the cuboid position is only possible once all fibrous connections between the calcaneus and the cuboid are severed. The lateral and dorsal ligaments, although stretched, have abnormal secondary attachments necessitating division before complete correction occurs. The strongest structure preventing correction is the long plantar ligament, which is well developed in clubfeet and normal neonatal feet. Division of the long plantar ligament, which is mandatory for calcaneocuboid correction, is also important to minimize cavus and forefoot adduction.

The addition of calcaneocuboid correction to a standard posteromedial release allows congruent reduction of the talocalcaneal joint, since the position of the calcaneus is no longer determined by its midfoot and forefoot connections. This enhances the advantages of complete subtalar joint release and eliminates the risk of subtalar joint collapse, because excessive valgus and lateral rotation of the calcaneus is eliminated. Soft tissue tension is decreased since the natural calcaneal eversion that can now occur is coupled with slight posterior movement of the calcaneus. A calcaneus directly under the long axis of the tibia is the keystone to stable and lasting hindfoot correction.

The bony correction and stability obtained can be maintained without external corrective forces in the immediate postoperative period when deforming muscle force is simultaneously eliminated. This aspect of the procedure is discussed in the paper Tibialis Anterior Lengthening in Chapter 9. The absence of abnormal force preserves joint shape and cartilage function resulting in rapid and lasting recovery of motion once postoperative immobilization is discontinued.

Complete calcaneocuboid correction was used in over 1,500 clubfeet procedures performed at the Medical University of Southern Africa since 1981. Ninety-eight rigid clubfeet that were operated upon between 6 and 52 weeks of age were reassessed after a minimum of 6 years postoperatively. In 87 of these feet, growth and movement patterns were nearly normal and painless function was present. In four feet recurrent deformity necessitated repeat operation. In four feet valgus of the hindfoot was present, but there was little functional disability due to the valgus. In three feet there was postoperative infection resulting in severe limitation of movement in all three. One of the septic cases also developed growth disturbance in the distal tibia. No special shoes or splints were used. The operation did not correct all forefoot adduction. Residual forefoot adduction was recorded in 14 feet after 2 years but observed in only 8 feet after 6 years. It never caused functional disability.

The operation and result obtained fully satisfied the objectives set for rigid CTEV management at the Medical University of Southern Africa and is continuing unchanged. The observed growth toward normality and the excellent painless function of the majority of feet support the concept that the basic pathology in CTEV is joint contracture. The prin-

ciples of (a) complete release of all fibrous restraints to correct the contractures and (b) balancing muscle action (see Chapter 9, Tibial is Anterior Lengthening) eliminates the suggested pathology. The foot and ankle tissue can then grow and develop normally and provide the patient with unrestricted function.

Technique of Plantar Release and Calcaneocuboid Joint Release in Clubfoot Surgery

N.C. Carroll

In addition to tight tendons, capsules, and ligaments, my early pathoanatomic studies demonstrated that in a severe clubfoot the lateral malleolus was positioned posteriorly. The prominence on the lateral side of the untreated foot represented the lateral edge of the head of the talus while the navicular was subluxated medially toward the medial malleolus. The body of the talus was *externally* rotated in the ankle mortise. The talus and the calcaneus were parallel. It was apparent that the equinus deformity of the calcaneus could not be corrected until normal divergence between the talus and the calcaneus was restored.[4] In these early studies I did not pay enough attention to either the cavus component or the lateral column in the severe CTEV. This became apparent when I reviewed my early results.[28]

Cavus

Contractures of the plantar fascia, flexor digitorum brevis, and the abductor digiti quinti muscles as well as overactivity of these muscles can contribute to varus, cavus, and adduction deformity in a clubfoot.[20] Thompson et al.[23] found that feet with recurrent deformity or incomplete correction usually have pes cavovarus with uncorrected or recurrent contractures of the plantar structures.

In a recent study performed on CTEV presenting for reoperation,[22] failure to release the plantar fascia and short plantar muscles correlated with a high level of statistical significance with residual cavus deformity ($p < .015$) and with residual adduction deformity ($p < .05$). In this study, 64.2% of feet presenting for reoperation required a plantar release. Green and Lloyd-Roberts[9] extended their early limited posterior release to include a plantar fascia release with stripping of the abductor hallucis and small plantar muscles from the calcaneus. Turco[24] attributed the presence of severe cavus deformity to an abnormal origin of the abductor hallucis arising more dorsally from the posterior tibial tendon sheath, and occasionally, the navicular tuberosity. He recommended releasing the muscle from its abnormal origin rather than sectioning the muscle in children over 4 years of age. Turco would perform a Steindler plantar release at the time of his major soft tissue release through a small separate medial plantar incision. Many authors have added a plantar release to Turco's posterior medial release on all of their clubfeet.[6,7,17,21,23] McKay[15,16] and Carroll[3] routinely perform a complete plantar release in which the abductor hallucis is freed proximally from the calcaneus and the plantar fascia, and the flexor digitorum brevis and abductor digiti minimi are all sectioned under direct vision.

Forefoot Adduction

Adduction of the forefoot has been recognized as a component of clubfoot deformity but historically has received little attention, as seen, for example, in the comment "the forefoot will

walk itself straight with growth."[26] In the last two decades, however, more and more authors have recognized the problem of residual forefoot adduction following clubfoot surgery. Turco views CTEV as a congenital dislocation of the talocalcaneonavicular joint complex with the basic deformity being a medial displacement of the anterior end of the calcaneus and navicular around the talus.[24,25] His posteromedial release gained wide popularity since its introduction in 1971. It appears, however, that forefoot adduction with an in-toeing gait is a frequent residuum.[5,13,17,18,27]

Attenborough[1] reported that 15 of 19 feet had residual forefoot deformity after his operation; four needed reoperation, whereas there were only two feet with residual hindfoot deformity. Lowe and Hanson[12] reported a 52% incidence of residual forefoot adduction in a series previously subjected to a variety of operations, whereas Main and Crider[14] reported a 69% incidence in a group of 63 feet. Otremski et al.[18] reported that residual adduction was present in 48% of feet after a one-stage posteromedial release, but 91% correction of forefoot adduction could be achieved following a Turco posteromedial release that was modified to include a full release of the abductor hallucis and short plantar muscles and fascia. Brougham and Nichol[2] found the major residual deformity in a series corrected through a Cincinnati incision to be forefoot adduction, which developed in 16 out of 24 feet. Adduction deformity, persisting after initial clubfoot surgery, tends to increase as a child grows.[19] Why is residual forefoot adduction so common following initial clubfoot surgery?

New Pathoanatomic Studies

In our three-dimensional computer modeling studies of a normal foot and a clubfoot, we showed that the long axis of the cuboid was parallel to the long axis of the calcaneus in the normal foot, but tilted 55° medially in a clubfoot.[10] Grant[8] pointed out that there are two columns to the foot. The lateral column consists of the calcaneus, cuboid, and 4th and 5th metatarsals. The medial column consists of the talus, navicular, three cuneiforms, and the 1st, 2nd, and 3rd metatarsals. One of the main problems with clubfoot surgery in the past was that the medial displacement of the navicular in relation to the head of the talus was addressed, but the lateral column of the foot and the calcaneocuboid joint was left undisturbed. It follows that, if the distal portion of the medial column (the navicular) is displaced medially, the distal end of the lateral column (cuboid) must be displaced medially as well. Porat and Kaplan[19] found that a calcaneocuboid release was essential for successful alignment of the forefoot on the hindfoot. In our recent study of children with clubfeet presenting for reoperation, we showed that failure to release the calcaneocuboid joint was associated with a significant incidence of residual forefoot adduction deformity ($p < .01$).

Many advocates of Turco's posteromedial release have realized the importance of the calcaneocuboid joint and have modified his operation to include a full release of this joint through a separate straight lateral incision[11,21] or through the same medial incision.[6] McKay[15,16] sees the major deformity in clubfoot to be an inward rotation of the whole foot on the talus, involving all three components of the subtalar joint complex: the talocalcaneal, the talonavicular, and the calcaneocuboid joints. The cuboid is displaced medially on the calcaneus and lies under the navicular and cuneiform bones. A normal-appearing foot cannot be achieved without correction of all three components of the subtalar complex.

Technique of Plantar Fascia Release

A severe clubfoot will require a complete plantar, lateral, medial, and posterior release. My technique uses a medial incision that (a) gives an excellent exposure of the anatomy; (b) allows protection of the neurovascular structures; (c) preserves the tendon sheaths of the tibialis posterior, flexor digitorum, and flexor hallucis behind the medial malleolus; and (d) promotes good healing with minimal scarring and good cosmesis. The landmarks for the medial incision are the center of the calcaneus, the front of the medial malleolus, and the base of the 1st metatarsal (Figure 8.10A). These three points define a triangle. The incision is parallel

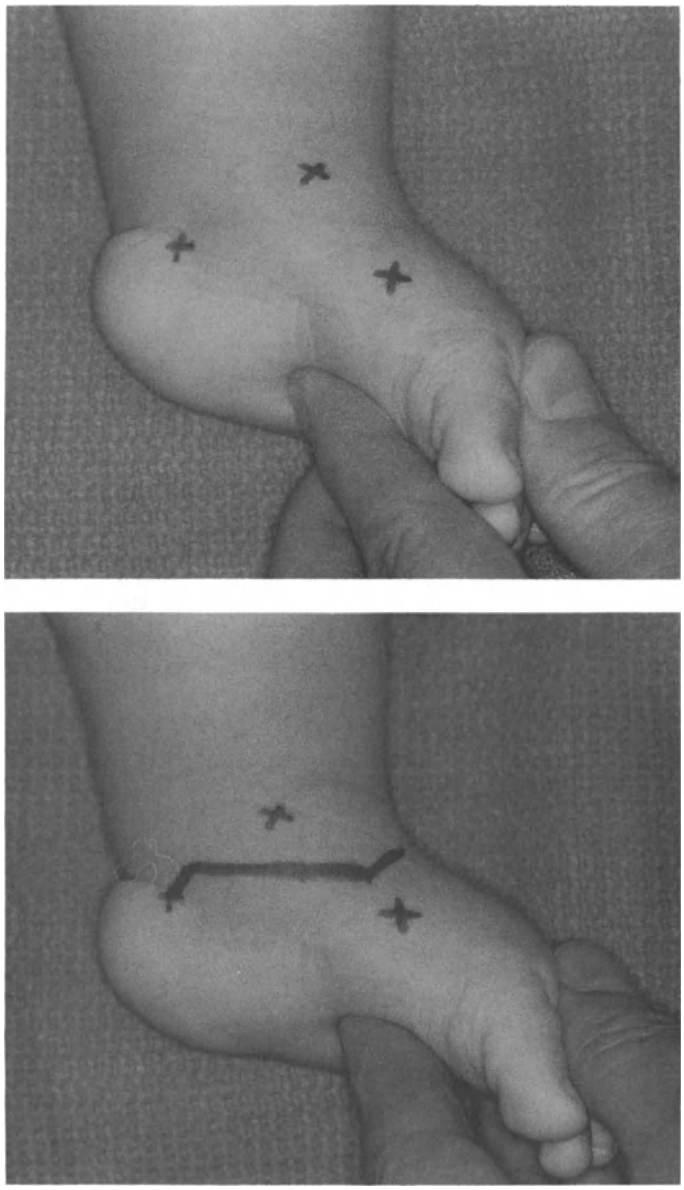


FIGURE 8.10. Carroll's medial skin incision. A: Medial side of the left foot. The landmarks for the medial incision are the center of the calcaneus, the front of the medial malleolus, and the base of the 1st metatarsal. B: The incision is parallel to the base of the triangle formed by the three Xs but angulated in the plantar direction proximally and in the anterior direction distally.

to the base of the triangle but angulated in the plantar direction proximally and in the anterior direction distally (Figure 8.10B). Through this incision, the abductor is exposed and freed proximally from the calcaneus and the accessorius fascia (Figure 8.11A,B). A plane is then developed between the plantar fascia and the fat beneath the sole of the foot (Figure 8.11C). The accessorius fascia is opened to expose the lateral plantar artery and nerve (Figure 8.11D). These two structures occupy a tunnel that passes toward the lateral side of the foot. Under direct vision the plantar fascia, flexor digitorum brevis, and abductor digiti minimi are freed from the calcaneus by placing one blade of a scissors in the tunnel for the lateral plantar nerve and artery and one blade superficial to the plantar fascia.

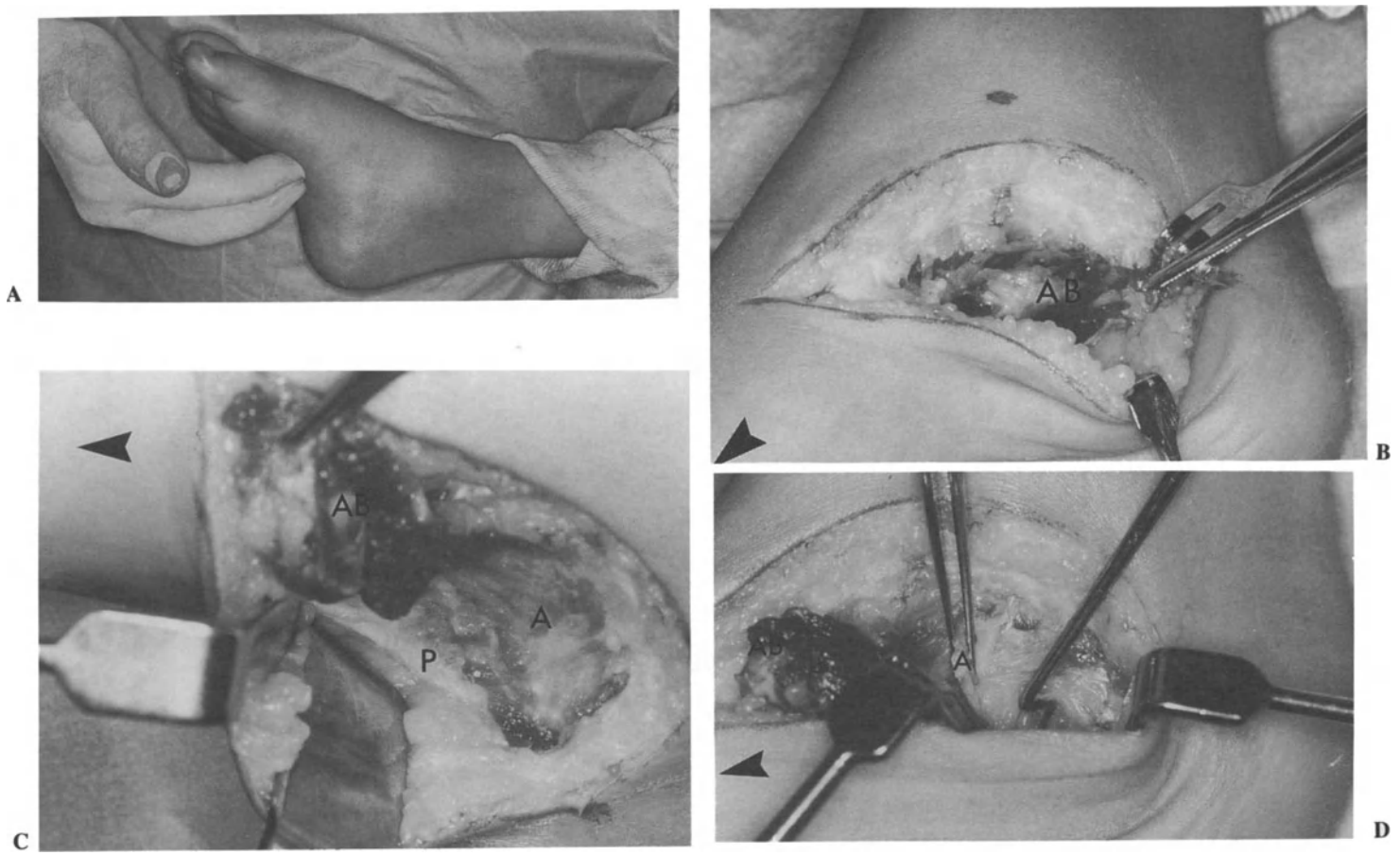
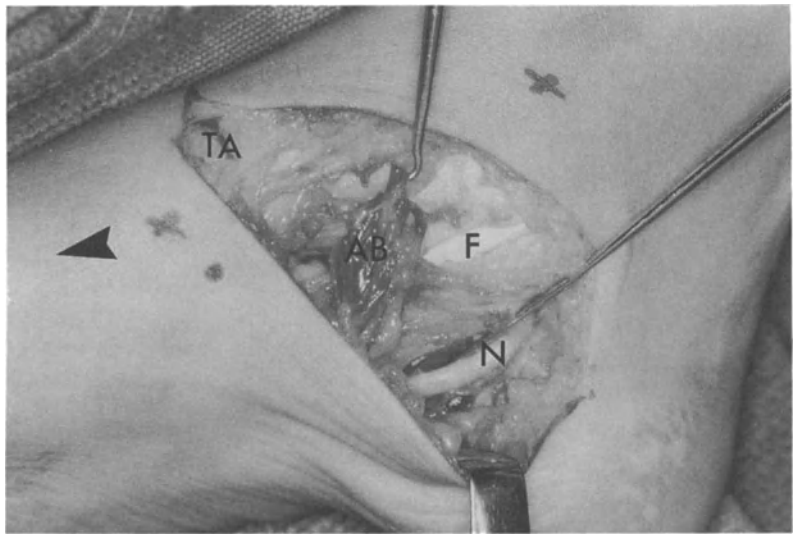
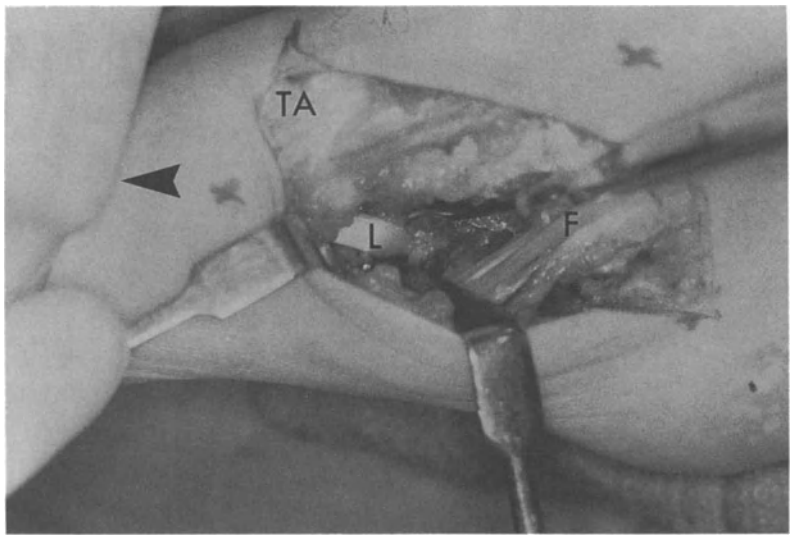


FIGURE 8.11. The technique of plantar fascia release (right foot). (The black arrow points toward the toe.) A: A 5-year-old boy's right foot demonstrating residual forefoot equinus and cavus after only a posterior release. B: The abductor is being elevated off of the calcaneus. C: The abductor hallucis has been reflected distally, exposing the accessorius fascia (A), and the dissection has been carried deep beneath the plantar fascia (P). D: The abductor hallucis is reflected. The accessorius fascia (A) has been divided and is being elevated with the forceps. A nerve hook outlines the lateral plantar nerve and artery.



A



B

FIGURE 8.12. The technique of calcaneocuboid joint release (right foot). A: At the tip of the medial malleolus the sheath of the flexor digitorum longus (F) has been opened and followed distally to Henry's knot. TA, the insertion of the tibialis anterior into the base of the 1st metatarsal; AB, abductor hallucis, N, lateral plantar nerve. B: The insertion of the tibialis anterior (TA) into the base of the 1st metatarsal has been identified. The sheath of the peroneus longus has been opened so that the tendon (L) can be identified.

Technique of Calcaneocuboid Joint Release

At the tip of the medial malleolus the sheath of the flexor digitorum longus is opened and followed distally to Henry's knot where the flexor hallucis longus is identified (Figure 8.12A). Both of these tendons are protected while the dissection is continued distally. The tibialis anterior is identified on the dorsum of the foot and traced to the base of the 1st metatarsal. The flexor hallucis and flexor digitorum together with the neurovascular structures are retracted in a plantar direction (Figure 8.12B). The sheath of the peroneus longus tendon is identified and opened; the tendon is traced proximally to the point at which it curves around the lateral border of the foot. The peroneus longus tendon is protected while the long and short plantar ligaments are divided. The calcaneocuboid joint is identified (Figure

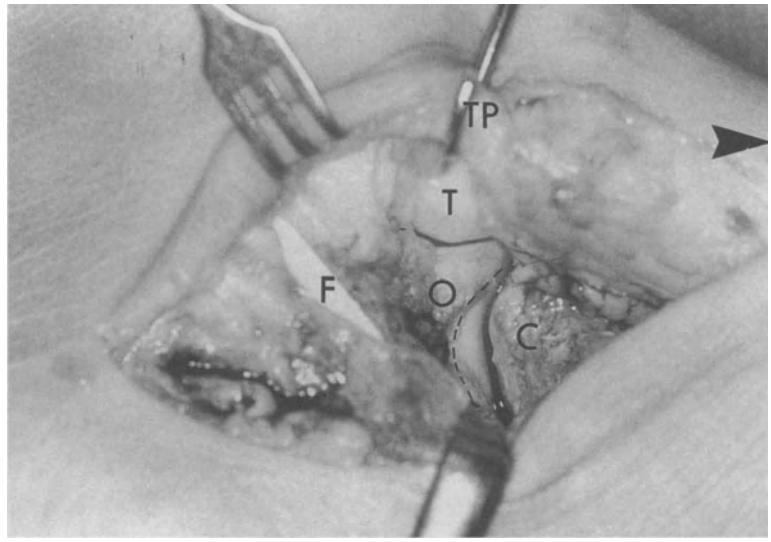


FIGURE 8.13. Demonstrates the technique of calcaneocuboid joint release (left foot). The medial side of a left clubfoot. TP, tibialis posterior inserting into the navicular; T, head of the talus; F, flexor digitorum; O, the front of the calcaneus; C, cuboid. The long and short plantar ligaments have been divided and a complete capsulotomy of the calcaneocuboid joint has been performed. Note that, as the adductus deformity is corrected, cartilage is exposed on the anteromedial surface of the front of the calcaneus (curved line). In all of the figures the black arrow points toward the toes. (Note that the toes in this print are on the reader's right.)

8.13). The medial and plantar aspects of the capsule are divided, which enables the joint to be opened, exposing the rest of the capsule, so that the joint can be freed completely.

Summary

The technique of plantar release and calcaneocuboid joint release in CTEV is described. Through a medial incision the proximal abductor hallucis is reflected off the accessorius fascia. The fascia is opened to identify the lateral plantar artery and nerve. Under direct vision the plantar fascia, flexor digitorum brevis, and abductor digiti minimi are divided by placing one blade of the scissors in the tunnel for the lateral plantar artery and nerve and one blade superficial to the plantar fascia. Through the anterior part of the medial incision the tibialis anterior is identified where it inserts into the base of the 1st metatarsal. This is used as a guide to find the peroneus longus. The peroneus longus sheath is opened and the tendon is protected while the long and short plantar ligaments are divided. The calcaneocuboid joint is identified, the medial and plantar aspect of the capsule is divided and the joint is opened to expose the rest of the capsule so that the joint can be freed completely.

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Calcaneocuboid Joint Deformity in Talipes Equinovarus

J.G. Thometz and George W. Simons

In 1818, Scarpa[14] reported that the position of the talus was relatively normal within the ankle joint in congenital talipes equinovarus (CTEV) and that the primary deformity was secondary to the shifting of the other bones of the tarsus around the talus. Other authors since have reported similar findings: the navicular, the cuboid, and the anterior part of the calcaneus are rotated around the head of the talus.[1,8]

However, less attention has been given to possible deformities involving the calcaneocuboid joint. Tubby[23] alluded to the etiology of the calcaneocuboid joint deformity, and others[8,9,16,24] described pathological changes in the calcaneocuboid joint. Carroll[2] recently recommended partial release and Malan[13] and Thomas[22] advocated complete release of the calcaneocuboid joint for all surgically treated clubfeet.

Based on our previous observations and experience, gross malalignment of the calcaneocuboid joint is present in some, but not all, clubfeet. This deformity appears to be the result of medial angulation of the anterior calcaneus and/or subluxation of the cuboid on the head of the calcaneus.[19] When significant deformity is present, this must be corrected to achieve a satisfactory clinical and radiographic appearance of the foot.

Purposes

This paper assesses the incidence of calcaneocuboid joint deformity in congenital idiopathic clubfeet, presents a grading system for the deformity that is both practical and prognostically significant, and describes the operative procedure required to correct calcaneocuboid joint malalignment.

Materials and Methods

We reviewed radiographs of 100 consecutive idiopathic clubfeet (66 patients) who had surgery at the Children's Hospital of Wisconsin, Milwaukee, between 1985 and 1988.

Radiographic Classification of Calcaneocuboid Joint Deformity

A radiographic measurement system was devised to assess the alignment of the calcaneocuboid joint on the preoperative anteroposterior (AP) weight-bearing or simulated weight-bearing radiographs and intraoperative posteroanterior (PA) radiographs (Figure 8.14).

When normal calcaneocuboid alignment is present, the midpoint of the cuboid ossification center* lies on the longitudinal axis of the calcaneus (i.e., the cuboid is not subluxated). Grade one subluxation is present when the midpoint of the cuboid ossification center lies between the longitudinal axis and the medial tangent (parallel to the longitudinal axis along the medial border of the calcaneus). In grade two subluxation, the central point of the cuboid ossification center lies medial to the medial tangent of the calcaneus. In grade three subluxation, there is proximal migration of the cuboid to the level at which the central point of the cuboid ossification center lies approximately at the distal edge of the ossified head of the calcaneus.†

*The time of the appearance of the ossification centers has been well documented. By 5 months, 100% of girls and by 7 months 100% of boys have ossification within the cuboid.[4,5,10]

†With progressive correction of hindfoot varus in children over 1 year of age, the outline of the sustentaculum tali comes into view and presents an irregularity of the medial border of the calcaneus. This can be compensated for by drawing the medial tangent line parallel with the longitudinal axis and locating its medial position at the point where the rounded anterior end of the calcaneus begins to straighten out or deviates medially, indicating the anterior margin of the sustentaculum tali.

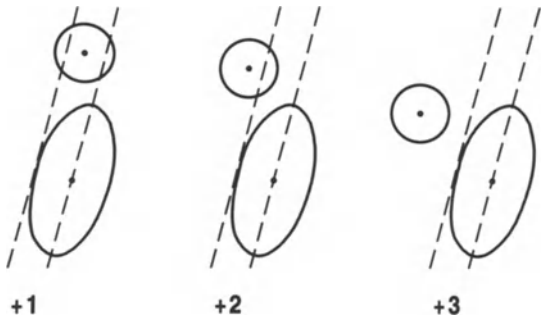


FIGURE 8.14. Grading system for calcaneocuboid deformity on the AP or PA radiograph. Normal: the midpoint of the cuboid ossification center lies on the midlongitudinal (long) axis of the calcaneus. +1: midpoint of the cuboid ossification center lies between the long axis of the calcaneus and a line along the medial border of the calcaneus (medial tangent) parallel to the long axis of the calcaneus. +2: the midpoint of the cuboid ossification center lies medial to the medial tangent. +3: the midpoint of the cuboid ossification center lies proximal to the distal end of the ossification center of the calcaneus. The measurements are essentially the same on the AP view as they are on the PA view.

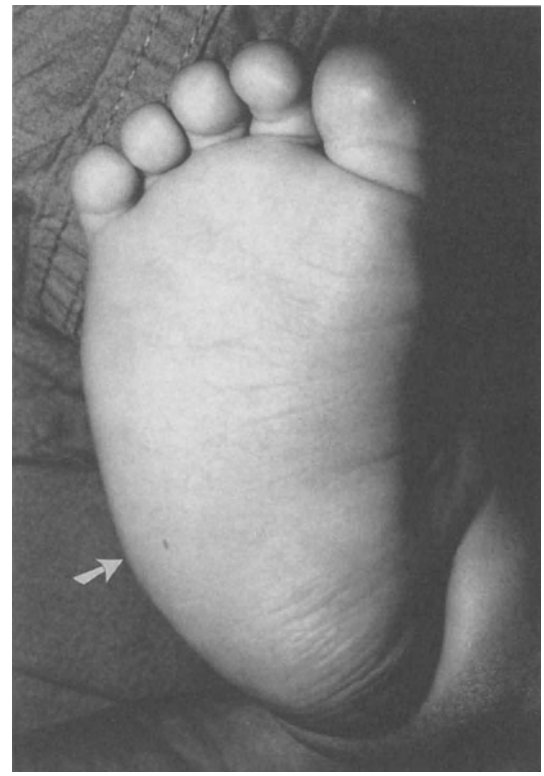


FIGURE 8.15. The clinical appearance of a foot with calcaneocuboid subluxation. The lateral angulation is more prominent than that which occurs with metatarsus adductus. (The arrow indicates the level of the subluxation at the calcaneocuboid joint.)

Surgical Management

We refer to our extensive soft tissue release as the complete subtalar release (CSTR).[18,20] This involves the release of the entire subtalar joint including the interosseous talocalcaneal ligament, the calcaneofibular ligament, the lateral subtalar capsule and ligaments, and the entire talonavicular joint through the Cincinnati incision.[3] The calcaneocuboid joint release is always performed as a part of the CSTR, but CSTR may be performed without the calcaneocuboid release.

Calcaneocuboid Joint Release

Indications

Calcaneocuboid joint release is indicated in cases with a radiographic grade two or three.

Technique

The surgical approach to the calcaneocuboid joint, when necessary, is performed by slightly extending the lateral arm of the Cincinnati incision (1 to 2 cm). The calcaneocuboid joint is identified by locating the summit of the anterior lateral elevation of the calcaneus, which articulates at its distal end with the cuboid. The lateral aspect, the dorsal, the medial, and finally the plantar surfaces of the joint are released. Care must be taken to avoid inadvertent injury to the peroneus longus tendon. Following release, the cuboid must be freely movable in *all* directions.

In order to maintain correct alignment once the calcaneocuboid joint is reduced, a small, threaded Kirschner wire is inserted across the calcaneocuboid joint. The most satisfactory sequence of pin insertions following CSTR is the calcaneocuboid joint, the talonavicular joint, and finally, the talocalcaneal joint.

Results

Of the 100 consecutively treated clubfeet (66 patients) that were studied, 29 feet had no deformity and were not given a deformity grade. Forty-five feet had grade one deformity, which was considered insignificant; 25 feet had grade two deformity; and 1 foot had grade three deformity. Consequently, 26 feet were thought to have significant deformity that required surgical treatment, i.e., grade two and grade three.

The mean age at operation was 10 months (range 5 to 48 months). The mean follow-up was 43 months (24 to 71 months). Twenty-eight patients had bilateral CTEV.

Of the 25 feet in grade two, 15 had a calcaneocuboid release. Of these, 12 feet were normal at follow-up, 2 feet had grade one deformity and 1 foot had grade two deformity.

The remaining 10 feet with grade two deformity did not have a calcaneocuboid release. None of these feet was normal at follow-up; 8 feet had grade one deformity and 2 feet had grade two deformity.

There was 1 foot with grade three deformity. This foot had a calcaneocuboid release and tibiofibular shortening. At follow-up this foot had a mild grade one deformity of the calcaneocuboid joint.

Discussion

The etiology of the deformity of the distal calcaneus is undetermined. Some authors have noted minimal deformity at the calcaneocuboid joint at birth. Irani and Sherman[9] stated that "the calcaneus, although abnormal in all clubfeet, is always much less distorted than the talus. Invariably, the calcaneus is slightly short and slightly wide." They made no mention of the distal articular portion of the calcaneus being angulated. Settle[16] observed that the calcaneus in general had a normal contour, but that if appeared slightly smaller than normal. The cuboid showed only minimal changes from normal.

Others who have noted calcaneocuboid deformity have proposed explanations for its etiology; they include Tubby,[23] LeNoir,[11,12] Hoke,[8] Carroll,[2] Tachdjian,[21] and Goldner.[6,7]

When marked calcaneocuboid malalignment is present, a noticeable angular deformity can be seen on the lateral side of the foot which is more posterior than that which may occur at the metatarsotalar level (Figure 8.15). Only when the calcaneocuboid joint abnormality (as well as adduction of the forefoot) was corrected surgically did the clinical appearance



FIGURE 8.16. Several radiographic configurations that may be seen in feet with calcaneocuboid subluxation. A: The uncorrected clubfoot. t, talus; n, navicular; cu, cuboid; ca, calcaneus. B: The clubfoot, in which a complete subtalar release (CSTR) has resulted in reduction of the talonavicular subluxation but the calcaneocuboid deformity remains uncorrected. Valgus of the calcaneus is present (increased TC angle). C: "Spin out" of the calcaneus. A marked degree of valgus results when CSTR is performed along with a partial calcaneocuboid joint release in a patient with significant calcaneocuboid subluxation. Leaving the lateral capsule intact enables the capsule to act like a hinge. D: Complete release of the calcaneocuboid joint along with CSTR allows the calcaneus to be rotated back to its normal alignment and the calcaneocuboid joint to be anatomically reduced and pinned. All bones have been restored to normal alignment. E: Translation at the subtalar joint, which results following reduction of the calcaneocuboid subluxation and talonavicular subluxation when the calcaneus is not properly positioned with internal fixation across the subtalar joint. This is not unique to calcaneocuboid subluxation but also may occur without it.



A B

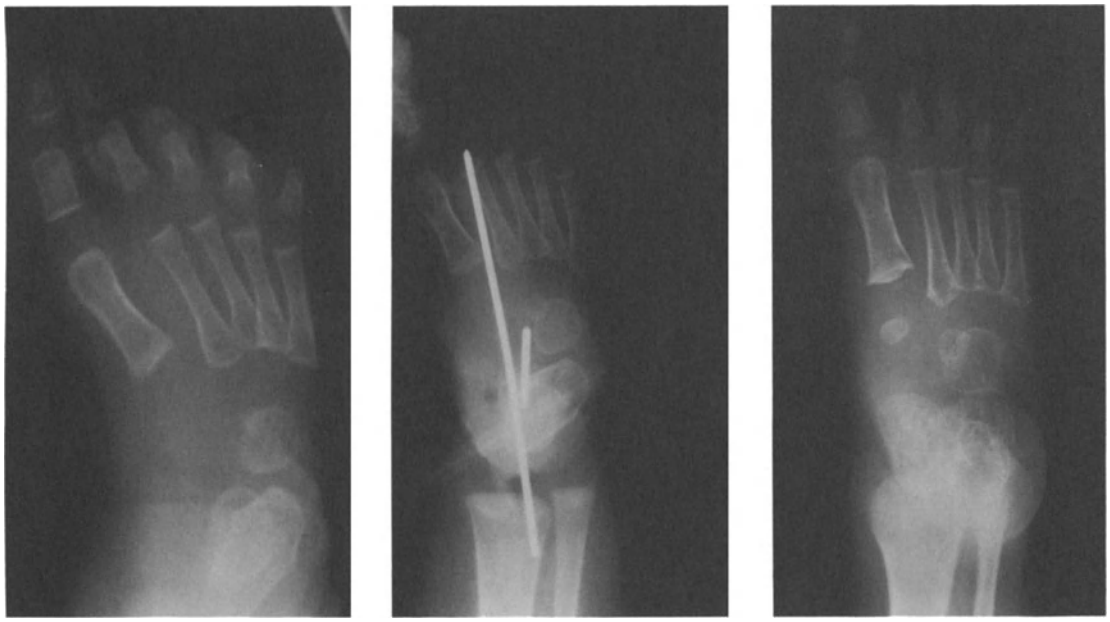
FIGURE 8.17. A case of calcaneocuboid joint deformity treated by CSTR with plantar release but without complete calcaneocuboid release. A: There is a grade two calcaneocuboid subluxation on the preoperative radiograph (not drawn). After complete subtalar release (including talonavicular release) but without calcaneocuboid release, the calcaneocuboid subluxation remains. (Also see Figure 8.16B.) B: Several years later, calcaneocuboid subluxation remains. Only when the calcaneocuboid joint is completely released and reduced can the normal osseous relationships be restored. While the navicular is nicely reduced, rotational valgus of the heel has occurred (see text). This result could have been prevented by completely releasing the calcaneocuboid and talonavicular joints with accurate reduction and pinning, and by verifying the accuracy of the reduction with interoperative radiographic criteria.[18,20]

of the lateral side of the foot appear to be straight.

In surgery, the bones must be aligned precisely, but clinical examination is often deceiving. These patients must have, in addition to preoperative radiographic evaluation, intraoperative radiographic verification of correction.[17–20]

The various calcaneocuboid relationships that may be present in congenital talipes equinovarus are shown in Figure 8.16.

Following soft tissue release (specifically, release of the talonavicular and the subtalar joints), the navicular, cuboid, and calcaneus move as a unit or as one block of bone.[15,16] When these bones are repositioned on the talus, they are repositioned as a unit. If the calcaneocuboid joint is significantly displaced (i.e., grades two and three), the navicular, when reduced, will force the cuboid laterally, which, in turn, forces the calcaneus into excessive valgus. On the AP radiograph this appears as an increased



A B C

FIGURE 8.18. A case of calcaneocuboid joint subluxation treated by complete subtalar release and plantar release but with only partial release of the calcaneocuboid joint. A: Preoperative radiograph shows grade two calcaneocuboid subluxation. B: Interoperative radiograph following partial release of the calcaneocuboid joint with attempted reduction and pinning (also see Figure 8.16C). The calcaneus has "spun out." The anterior portion of the calcaneus has rotated almost 70° in the lateral direction. Note that the cuboid has migrated proximally around the distal end of the calcaneus, probably due to the obliquity of the distal portion of the articular surface of the calcaneus. C: Postoperative radiograph following complete release, reduction, and pinning of the calcaneocuboid joint. This radiograph was taken following removal of internal fixation. [Observe the abnormally large anteroposterior talocalcaneal (APTC) angle and APTC divergence due to overreduction and pinning of the navicular on the head of the talus, thereby producing rotational valgus of the calcaneus. The use of clinical criteria with interoperative radiographic verification has greatly reduced the incidence of this complication.][18,20]

talocalcaneal angle with calcaneocuboid malalignment. This was especially obvious at surgery in the patients with grade two and three deformities. Thus, valgus of the hindfoot will occur if the calcaneocuboid malalignment is not corrected and the talonavicular subluxation is fully reduced (Figure 8.17).

Partial calcaneocuboid release (releasing the medial, dorsal, and plantar ligaments while leaving the lateral ligament intact) resulted in worsening of the original deformity of the calcaneocuboid joint with the calcaneus rotating into severe valgus deformity (Figure 8.18). However, this was easily corrected by completing the calcaneocuboid release, by reduction, and by pinning the cuboid on the calcaneus (Figure 8.18C).

We now believe that all grade two and three subluxations require surgical treatment. They were treated most successfully by complete subtalar release, plantar release, and complete calcaneocuboid release (Figure 8.19). In two cases, further surgery was necessary in addition to the above. One case with marked grade two subluxation required resection of the anterolateral portion of the calcaneus. In the grade three case, tibiofibular shortening osteotomies were required (Figure 8.20).

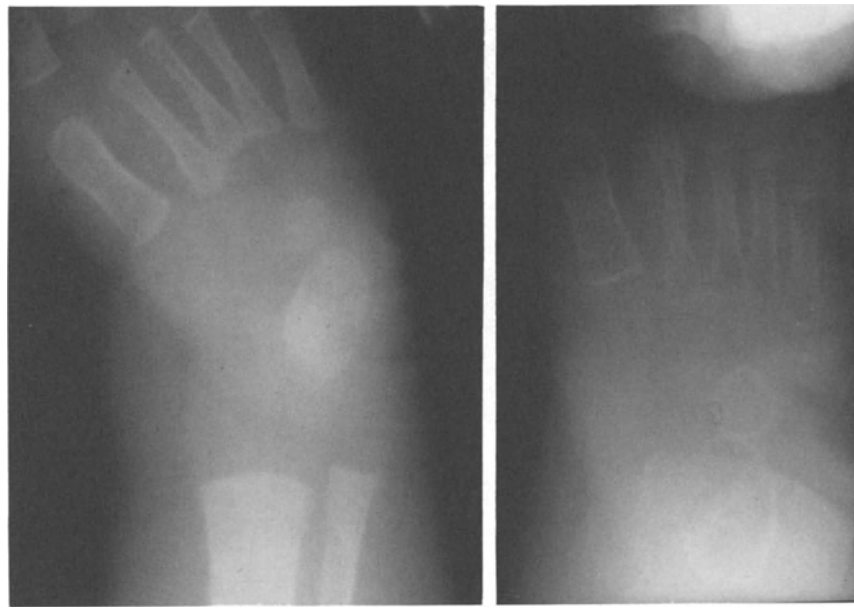
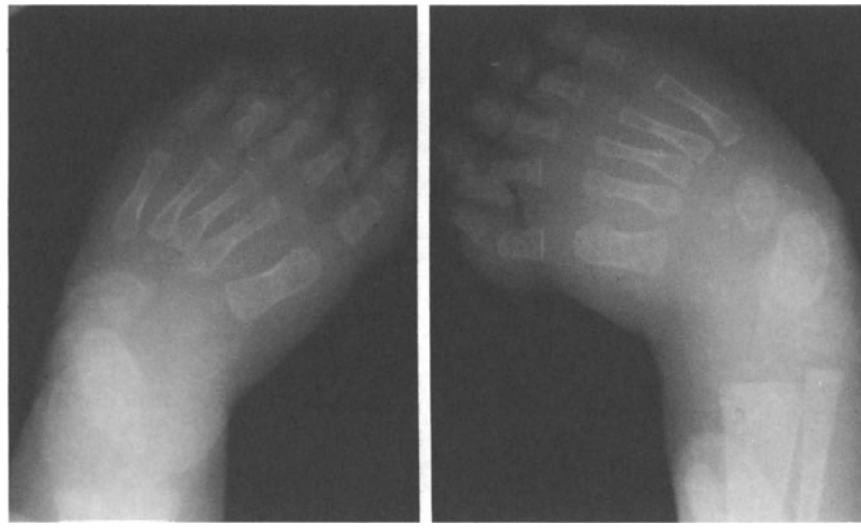
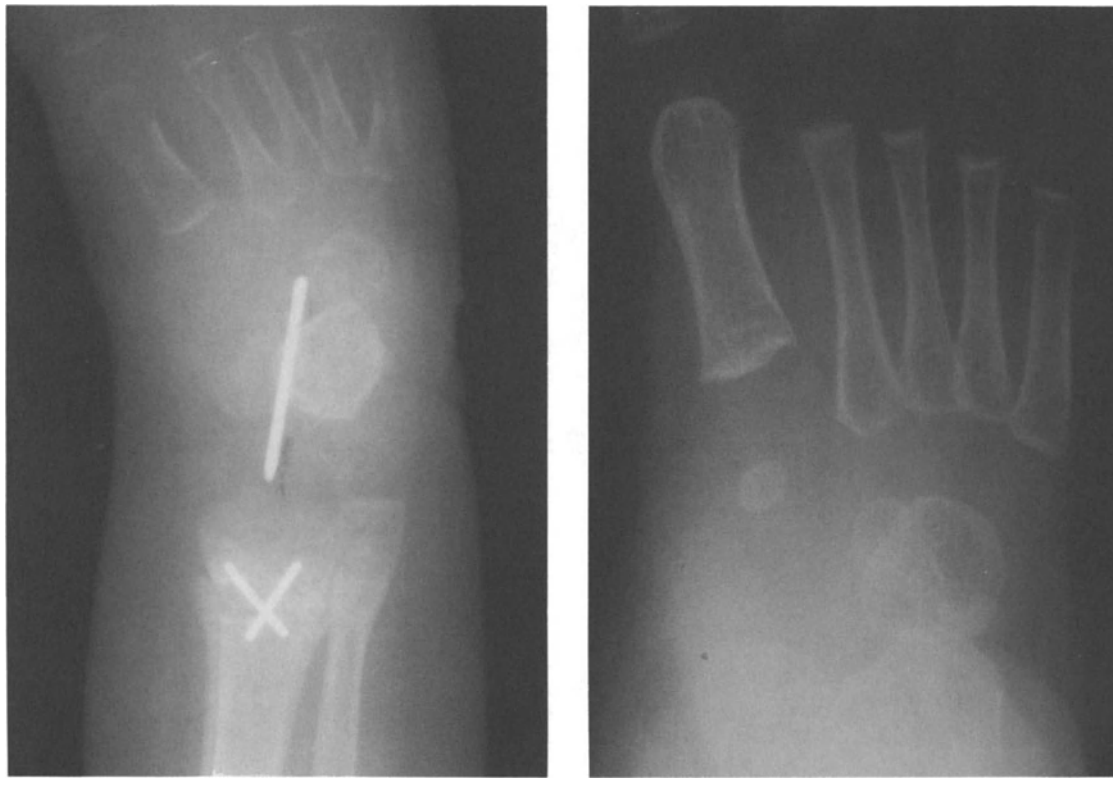


FIGURE 8.19. A case of calcaneocuboid subluxation treated by complete subtalar release, plantar release, and calcaneocuboid release. (Also see Figure 8.16D.) A: Preoperative radiograph shows grade two calcaneocuboid subluxation of the right foot. B: Postoperative radiograph following complete release of the calcaneocuboid joint with reduction and pinning. There is complete correction of calcaneocuboid subluxation. The APTC angle (not drawn) and APTC divergence are within the normal range, denoting no residual lateral subluxation of the talonavicular joint.

FIGURE 8.20. In two of our cases, a complete subtalar release, plantar release, and complete calcaneocuboid joint release failed to achieve reduction of the subluxated calcaneocuboid joint. This was due to marked medial tissue contracture and to a contracted neurovascular bundle. Therefore, one case with grade two calcaneocuboid subluxation required resection of the anterolateral aspect of the calcaneus to achieve reduction. The other case (the only grade three patient) needed tibiofibular shortening before the subluxation could be corrected. A: Preoperative radiographs show grade two calcaneocuboid subluxation in the left foot and grade three in the right foot. B: Postoperative radiograph of the right foot 6 weeks following the tibial and fibular osteotomies with several pins still in place. C: Postoperative radiograph 1 year later. The calcaneocuboid subluxation remains reduced.



A



B C

Summary

In the past, considerable attention has been given to both the talonavicular and the subtalar joints with relatively little consideration being given to the calcaneocuboid joint. Evaluation of 100 cases treated surgically revealed that 26% had a significant degree of displacement of this joint at the time of surgery. Of these 26 cases, some did not receive surgical reduction of the joint, as the importance of this deformity was not recognized at that time. Consequently, 16 feet were operated on by complete release of the calcaneocuboid joint, and 10 feet had no surgery at this level. These two groups of patients were compared, and it was found that once significant deformity was present at the calcaneocuboid joint, the only way to achieve complete correction of the midfoot was to release this joint, reduce it, and pin it.

Failure to include calcaneocuboid release with an extensive soft tissue release (e.g., CSTR) resulted in valgus of the heel. Partial release of the calcaneocuboid joint, leaving only the lateral capsule intact, resulted in "spin out" (severe rotary valgus of the heel). However, this could be easily corrected by releasing the lateral ligament and by reducing and pinning the joint.

Whereas grade one deformity did not require release of the calcaneocuboid joint, grade two deformity required subtalar release as well as release of the calcaneocuboid joint. It would appear that grade three deformities may also require bone surgery.

A relatively simple radiographic classification of deformity at the calcaneocuboid joint has been developed that measures both the medial displacement and the proximal migration of the cuboid.

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Discussion

Coleman (Salt Lake City): Dr. Grant, our plastic surgeons tell us that even in the best of circumstances the average complication rate for tissue expanders across the country is around 30% to 40%. They also state that one can expect skin sloughs, foreign body reactions, and rejections. Would you want to comment on that?

Grant (New York City): Our cases were performed with a plastic surgeon who managed the tissue expanders completely. We were there basically to choose the site for the expander and to do the clubfoot correction at the time of retrieval. By operating with the plastic surgeons and managing the cases very carefully, we have not had the incidence of complications that you have mentioned. I think that these cases certainly have to be carefully managed. This is a selective group of patients in whom one can predict with reasonable certainty that the surgeon will not be able to close the skin. In these cases, tissue expanders have some advantage. The kinds of cases we are talking about are the severe arthrogrypotic foot and some of the teratologic feet.

Carroll (Chicago): Our plastic surgeons are very keen on tissue expansion for nonorthopedic conditions. I obtained their consultation about 5 years ago for the use of tissue expanders in clubfeet. We had a lot of problems and have stopped using the tissue expanders.

Gould (Milwaukee): I was greatly excited about the use of tissue expanders and have used them to try to solve the difficult problems with secondary scars and so on. I have had a 100% failure rate using these, so I do not advocate acute tissue expansion in this field.

Tachdjian (Chicago): In discussing ways of obtaining increased length of skin, I think that stretching casts are very helpful when the deformity is rigid. The cast can be changed repeatedly over several weeks. I also occasionally release the abductor hallucis muscle that frequently seems to be very tight. The third thing is to change the cast to obtain gradual correction following surgery. The skin should be carefully checked for capillary refill at the time of the initial cast application and at subsequent cast applications following surgery. The cast should then be changed at weekly intervals until the foot is fully corrected. In this way, skin healing can be achieved without significant complications.

Thometz (Milwaukee): We have had extensive experience with the Cincinnati incision. If you let the foot fall back into the deformed position at the time of closure and then perform serial manipulations at a 1-week or 10-day interval, the problems with the Cincinnati incision will be very negligible.

The classification that we devised for calcaneocuboid subluxation was an attempt to define those patients who need calcaneocuboid joint release. We feel that the calcaneocuboid joint does not need to be released routinely in all patients. If the preoperative radiographs show that the calcaneocuboid joint is only mildly subluxated, then we perform a complete subtalar release but do not release the calcaneocuboid joint. If the radiographs show that there is significant deformity present at the calcaneocuboid joint, then we add a release at this joint also. This must be part of a complete release, however, not an isolated procedure.

Malan (Vanderbijlpark, South Africa): An important factor in calcaneocuboid subluxation is that complete calcaneocuboid joint release should be coupled with complete release of the subtalar joint, which allows some posterior translation of the calcaneus. This immediately solves the problem of the so-called disparity between the length of the medial and lateral rays. I think that normal eversion of the calcaneus is coupled with some posterior translation; therefore, an adequate subtalar joint release allows posterior movement of the calcaneus, which solves any problem of undercorrection.

McKay (Ville Platte, Louisiana): I want to emphasize that if you release the calcaneocuboid joint completely, as Simons has recommended, it should be pinned; otherwise, it will migrate all over the place.

Malan: Do you release the long plantar ligament and the sheath of the peroneus longus, Dr. Thometz?

Thometz: We circumferentially incise the sheath of the peroneus longus tendon and also the sheath of the peroneus brevis when we expose the tendons through the lateral portion of the Cincinnati incision. When we release the calcaneocuboid joint, we release the entire capsular structure on all sides. This includes the long plantar ligament.

You referred to valgus of the calcaneus. I look upon valgus of the calcaneus as increased external rotation. But, in the past when I failed to recognize and treat the associated calcaneocuboid subluxation, there was a very rapid recurrence of supination of the rest of the foot. Therefore, residual supination is also a sequela of undercorrection of the calcaneocuboid joint. Would you agree with that, Dr. Malan?

Malan: Yes, I agree.

Coleman: So much has been said about calcaneocuboid subluxation that I would like to ask, in children 3 or 4 years of age who have a substantial deformity of the joint, how does a simple release restore this square joint to its normal relationship? Do you use the Lichtblau or the Evans calcaneocuboid resection?

Malan: In children at age 3 or 4, I don't find any problem because remodeling is usually fairly rapid. However, at 7 or 8 years of age, it requires osseous reconstruction.

Ward (Pittsburgh): Dr. Carroll, if you approach the calcaneocuboid joint laterally, one generally doesn't have trouble getting 360° around the joint and one is able to release the medial side completely. When approached medially and plantarwardly, can the lateral side of the joint be easily released? If not, is it not important to do so?

Carroll: Yes, with a 3- or 4-month-old child, it's fairly easy to get right across the joint. For a revision procedure on a 4- or 5-year-old, I wouldn't hesitate to make a second lateral incision to make sure that I get all of the lateral capsule released, because there is going to be a significant curve to the front end of the calcaneus and, in trying to get around that curve, one can damage the joint surface.

Simons (Milwaukee): There were several cases in which we did not do a complete calcaneocuboid release. We were in the learning stages of the procedure at the time. We released the dorsal, volar, and medial surfaces, leaving the lateral capsule intact. In these cases when the navicular was reduced, it pushed the cuboid laterally, which in turn pushed the anterior portion of the calcaneus laterally. But, instead of just being pushed laterally, the calcaneus spun out so that it was in about 90° of valgus. Probably the reason for this is the obliquity of the distal calcaneal joint surface. This was really a serious overcorrection. However, it was easily corrected by completely releasing the lateral ligament of the calcaneocuboid joint, reducing the joint, and pinning it in the correct position.

Two other cases are worth mentioning. One was a grade two and one was a grade three calcaneocuboid subluxation. The grade two calcaneocuboid subluxation required resection of the anterior lateral prominence of the calcaneus in order to achieve reduction of the calcaneocuboid subluxation. In the grade three foot, the subluxation was so severe that the neurovascular bundle was extremely tight when the calcaneocuboid joint reduction was attempted. It was so tense that an excessive amount of shortening would have been required by resecting the anterior end of the calcaneus. Therefore, tibial and fibular shortening

were performed through the posterior portion of the Cincinnati incision about 2.5 cm above the joint surface, taking out 1 cm of both bones and internally fixing them with threaded Kirschner wires; this allowed the complete reduction of the calcaneocuboid joint without excessive tension on the neurovascular bundle.

Goldner (Durham): Dr. Carroll, when the medial release and your lateral reconstruction are finished and the cuboid still appears too large in a 6-month-old, will you take a wedge of bone out of it?

Carroll: No, I have not.

Editor's Comments

I would concur with **Breed** that his technique of leaving the wound open following surgery is followed by the rapid development of granulation tissue and healing over a period of 6 to 8 weeks. If the wound is to be left open following clubfoot surgery, there must be sufficient soft tissues to cover the neurovascular bundle, which lies in the depth of the wound. The only disadvantage of leaving the wound open, in my opinion, is that foot motion cannot be started until the wound has closed. Therefore, it is conceivable that further restriction of motion may result from this technique. However, I have never found it necessary to use a skin graft in CTEV feet, as the process of secondary wound healing is so rapid and effective in the young child.

When **Carroll** originally described his technique of the medial release of the calcaneocuboid joint (a partial release), it was performed with the intention of lengthening the medial column and, thereby, giving more correction to the forefoot; i.e., it was a forefoot corrective procedure. However, with the development of techniques on the lateral side of the foot in the last few years, it has become apparent that partial release of the calcaneocuboid joint (leaving only the lateral capsule intact) can lead to an extreme degree of valgus of the hindfoot. In our experience, the complete release is done much more easily from the lateral side of the foot. I have used it primarily for the correction of calcaneocuboid subluxation, and not for adduction, although adduction is improved by this procedure, especially when it is accompanied by plantar release. Furthermore, we have found that the use of the plantar release should be part of the routine soft tissue procedure when calcaneocuboid subluxation is present, as this allows reduction of the cuboid with less tension.

Malan stresses the fact that the calcaneocuboid release should not be done as the sole operative release. It must be combined with an extensive soft tissue release. Malan also observed that feet with overcorrection into hindfoot valgus had little functional disability. This has also been our experience, provided the extent of the valgus was not greater than 3+ (in our classification scale of 1+ to 4+).[1] He further states that adduction deformity cannot be expected to show full correction with these procedures; i.e., the inherent contracture of the ligaments in the forefoot must be addressed in most cases when this deformity is significant.

Carroll describes his technique of plantar release and calcaneocuboid joint release in clubfeet. He claims that the calcaneocuboid joint release is necessary in all cases as the calcaneocuboid subluxation is present in all cases. This again is in direct contrast to our findings, but agrees with those of Malan.

The discrepancy in the reported frequency of this complication is disturbing. The use of the radiographic classification may help to distinguish those feet that do not require release from those that do. Most of the authors agree that the calcaneocuboid joint must be completely released. Although Carroll previously felt that lateral release was not necessary, it is my understanding that he now believes that this is indicated. Following this release it is imperative that the joint be reduced and pinned in as anatomic a position as possible. This can only be evaluated completely by the use of AP or PA radiographs during surgery.

Although he describes the complete release

of the calcaneocuboid joint from the medial side, it has been our experience that this is technically difficult, and release from the lateral side is much easier.

If the deformity is not corrected at the calcaneocuboid joint and is of a moderate-to-major magnitude, then the foot will be ultimately overcorrected at the subtalar level, if the navicular is fully reduced on the head of the talus. Therefore, to avoid this complication of valgus of the hindfoot, it is imperative that we recognize deformity at the calcaneocuboid level. In the past, this has been simply overlooked, both before and at the time of surgery. The resulting hindfoot valgus was then erroneously attributed to the interosseous talocalcaneal ligament release.

Finally, **Carroll** mentions that talonavicular subluxation is always associated with medial calcaneocuboid subluxation. This has not been our experience. Talonavicular subluxation may occur with or without calcaneocuboid subluxation.

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9
New Procedures: Soft Tissue Procedures Without Distraction

Introduction

In the opening paper by **Malan**, the author states that the anterior tibial tendon has been neglected as a deforming force in congenital talipes equinovarus (CTEV). He claims that it acts as an invertor and abductor of the first ray, as opposed to being mainly a dorsiflexor in the normal foot, and that lengthening of the tendon provides muscle balance, which restores nearly normal motion to the ankle joint.

McKay describes an interesting technique that he has performed in only several patients. In this procedure, he performs fasciectomies of the gastrocnemius and soleus muscles as a means of increasing the abnormally diminished diameter of the calf.

In the final paper of this chapter, **Barnett** describes a new procedure for the treatment of dorsal subluxation of the navicular, a complication of previous clubfoot surgery. In this procedure, he separates the medial column from the lateral column.

Tibialis Anterior Lengthening in Clubfeet

M.M. Malan

Tibialis anterior function has an important role in the maintenance of correction and the development of normal joint movement following clubfoot surgery.

Maintenance of correction of clubfeet is optimal when balanced muscle action is obtained at the time of correction and retained throughout growth. Each of the 10 tendons crossing the ankle joint is involved in foot and ankle balance. Surgical correction of clubfeet reduces the distance between the origin and the insertion of the evertor and the lateral dorsiflexor muscles. This reduces the contractile force these four muscles can exert. Balanced muscle action can only be obtained if the invertors, including the tibialis anterior, and the plantar flexors are weakened to the same extent. This can be achieved by lengthening of the tendons of the invertors and plantar flexors to the same degree of slackness as the evertors

and dorsiflexors in the postoperative state. Pre- and/or postoperative stretching cannot weaken the action of invertors or plantar flexors to the required level.

The role of the tibialis anterior as the most potent muscular deforming force is clearly demonstrable at clubfoot surgery. After correction of the foot and division of the tendon it can also be shown that this muscle-tendon unit is shortened in rigid clubfeet. In a clubfoot, the tibialis anterior is a weak dorsiflexor and a strong invertor, whereas its action as a dorsiflexor of the 1st metatarsal is altered to an adductor of the 1st metatarsal. Measurement and comparison of tendon diameter in 50 consecutive clubfoot operations indicated that the average diameter of the tibialis anterior tendon is 67% of the diameter of the Achilles tendon and 135% that of the tibialis posterior. This relative strength of the tibialis anterior in CTEV warrants careful consideration of its role.

In a normal foot, dorsiflexion of the ankle is a combined effort of the medial and lateral dorsiflexors. In a surgically corrected clubfoot, the lateral dorsiflexors are weakened. If the tibialis anterior retains its normal strength, active dorsiflexion is coupled to inversion. If the tibialis anterior is weakened, e.g., by lengthening, dorsiflexion coupled with eversion can occur. This is essential for the development of normal movement patterns.

Joint motion improves after surgical correction of clubfeet when normal forces act on the joints and when physiological movement without abnormal tethers occurs. In clubfeet all muscles crossing the ankle have reduced excursions. Joint motion can optimally develop if these muscle-tendon units cause no restrictions. This requires sufficient lengthening to make up for the limited excursion. If the tibialis anterior is not lengthened, the limited excursion of this muscle-tendon unit can lead to severe limitation of ankle joint movement. Limitation of movement of this joint following clubfoot management is often reported.

If muscle balance is obtained by lengthening flexors and invertors, it will be retained throughout growth since the effect of growth on movement is similar on all the muscle-tendon units that cross the ankle joint. This balance obviates the need for further corrective splints or shoe wear. When growth takes up the slack in the lengthened invertors and plantar flexors and the stretched evertors and dorsiflexors, normal strength in all muscles is regained. If these muscles act on joints of normal mobility, optimal muscle development can be expected and calf and leg diameter will become normal.

At the Medical University of Southern Africa the tibialis anterior muscle has been lengthened routinely in more than 1,500 surgical corrections of clubfeet since 1980. Following the use of postoperative casts, no splints or restrictive shoe wear were used. An excellent range of ankle motion has been observed in 90% of patients 2 to 6 years following surgery.

Summary

Anterior tibial tendon lengthening has been performed routinely as part of the extensive soft tissue procedure for the correction of CTEV in more than 1,500 feet since 1980. This has resulted in restoration of a normal range of ankle motion and normal calf size.

Plantar Flexor Sheath Resection

Douglas McKay

Twenty-five years ago, I treated a child with a congenital short femur (CSF) with coxa vara. I tried, unsuccessfully, on three occasions to correct the coxa vara. I was unsuccessful in the early phases of surgery as well as in the late recurrence of the coxa vara. I found this very disturbing. I also had two other patients that had come to me for treatment with whom other orthopedists had the same problems.

I reasoned that there must be a congenital

malformation of the collagen of the fascial components of the limbs in patients with congenital defects. Before attempting to correct the coxa vera in the next child with a congenital short femur, I decided to do a fasciectomy of the thigh and hip region. This allowed correction of the deformity and the deformity did not recur.

After this experience, I removed the entire fascia of the thigh including the linea aspera and the iliotibial band in patients with congenital short femurs and patients with proximal focal femoral deficiency (PFFD), as a prelude to performing corrective osteotomies and leg lengthenings.

Much to my surprise, after complete fasciectomies, the limb length discrepancy did not progress, particularly in children with a limb length discrepancy of less than 5 cm. The fasciectomy also improved the cosmetic appearance of the limb, in that the thighs in patients with congenital short femurs became soft, and atrophy of the thighs disappeared. This added to my belief that the fascia in congenital defects of the limb was pathological, that it acted as a tether to the longitudinal growth of the limb, and that asymmetrical fascial tethers caused angular deformities of the limb.

I was fortunate to find a histopathologist at George Washington University Medical School who agreed to examine the excised fascial specimens by biomedical techniques. She agreed to compare the fascia removed from three patients with PFFD or CSF, with the fascia of eight patients who had acquired deformities such as trauma, cerebral palsy, and poliomyelitis. Tissue taken from the investing fascia, linea aspera, and the iliotibial band was used for comparison.

The major changes in patients presenting with congenital defects as opposed to acquired defects were (a) increase in collagen and hexosamine content, (b) the presence of galactosamine, and (c) abundant type III collagen. Posttranslational changes included (a) elevated hydroxylysine, (b) increased total number of reducible cross-links, and (c) the appearance of hydroxylysinohydroxynorleucine.

Following this investigation, I became increasingly more interested in the atrophy of the calf in clubfeet. I asked myself why it was more difficult to correct the deformity of a child with clubfeet than a child with equinus due to cerebral palsy. The inevitable answer seemed to be that the clubfoot was more difficult to correct because of the presence of congenitally abnormal fascia. Thus, I extended my reasoning about abnormal fascia of the thigh in patients with PFFD and CSF to include the calf in patients with clubfoot. Therefore, I removed fascia from patients with clubfeet, and investigations were performed on this fascia that were similar to those of the fascia performed on patients with PFFD and CSF. This included the investing fascia, plantar fascia, and deltoid ligament. The same pathological changes were noted.

Unfortunately, our ability to obtain funding to perform an ongoing study and my inability to persuade the pathology department to obtain normal tissue for comparison resulted in the premature termination of the study. The exact biochemical content of fascia in children is still unknown.

However, I continued with the orthopedic surgical intervention of the fascia of children with clubfeet. I reasoned that, if the fascia was removed from the posterior, the lateral, and the deep compartments of the calf of a child with clubfeet, the atrophy of the calf would disappear. Therefore, I performed this operation on two children with idiopathic clubfeet and on two other children with more extensive congenital defects, such as absence of certain muscle groups and defects in the bone, and on one child with a congenital absence of the fibula.

Results

There is no doubt that the apparent atrophy of the calf improved following fasciectomy. In the two children with clubfeet, the calf of one child 4 years old expanded 4 cm at the time of surgery. The calf of the other child at the time of surgery expanded 6 cm. This, of course, created another problem, i.e., closure of the skin. The incision dehisced in two patients, and in two others the scars spread unsightly. Therefore, I had corrected one cosmetic problem, the atrophy of the calf, and created another, an unsightly scar. The unsightly scar appeared even with cast immobilization and non–weight bearing for 6 weeks. Thus, in the future, if fascial resection of the calf is to be used as a means of treatment for calf atrophy, the child

should have tissue expansion prior to excision of the fascia.

I am also firmly convinced that, if the investing fascia of the posterior and lateral compartments of the calf could be removed in a child with clubfeet *before* treatment, the correction of the foot would be much simpler. I believe that the fascia invests the muscle like a rigid cone, not allowing it to expand or to slide distally with growth.

Summary

This is a preliminary report on the results of calf fasciectomy as a form of treatment for marked calf atrophy in patients with CTEV. In two patients with CTEV and three patients with secondary types of TEV, circumferential fasciectomy of the gastrocsoleus permitted significant expansion of the calf. However, wound closure was a problem. The use of tissue expanders is suggested as a means of overcoming this.

Medical/Lateral Column Separation (Third Street Operation) for Dorsal Talonavicular Subluxation

R.M. Barnett, Sr.

In an earlier paper (in Chapter 7), I described the important anatomical landmarks and my basic surgical technique of soft tissue release for the previously unoperated clubfoot. This paper will deal with extension of that operation for a specific complication following previous surgery, i.e., dorsal talonavicular subluxation.

Following extensive soft tissue release, dorsal talonavicular subluxation may result as either an early or late complication. Repeating the conventional soft tissue procedures has resulted in persistence of the subluxation. Results uniformly have been poor when this surgery has been carried out a second time.

The usual sequence of events following incomplete initial reduction is for the "recurrent" clubfoot to present several years later with a bimalleolar axis of less than 80°,[1–3] an internal foot progression angle, a curved lateral border of the foot, a shallow sinus tarsi, and dorsal

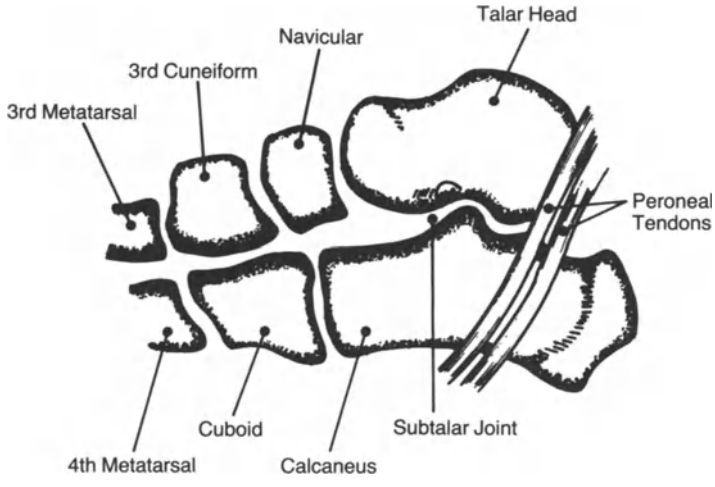


FIGURE 9.1. Capsulotomies between the lateral column (calcaneus, cuboid, 4th metatarsal), and the medial column (talus, navicular, 3rd cuneiform, and 3rd metatarsal base).

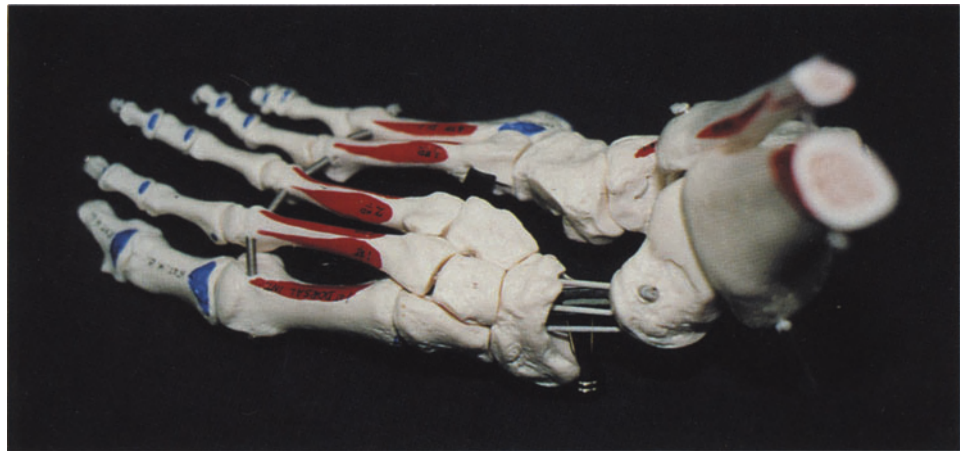


FIGURE 9.2. Skeletal photograph showing separation of the medial and lateral columns, and separation of the talonavicular joint.

rotary subluxation of the navicular on the talar head with accompanying equinus and rotation of the medial column of the forefoot.

Principle

The medial column of the foot consists of the navicular, three cuneiforms, and three metatarsals. The lateral column of the foot consists of the calcaneus, the cuboid, and the two lateral metatarsals.

If the released navicular does not reduce easily on the talar head, with its inferior surface flush with the line of the subtalar joint (i.e., the inferior surface of the head and neck of the talus), additional release is required to free the medial column of the foot from the lateral column. The resistance to reduction lies in the articulation of these two columns, not in tendon attachments such as the anterior tibial tendon.

The talonavicular reduction is critical to the long-term good results of clubfoot surgery. The reduction must be accompanied by a complete absence of the tendency for the navicular to spring back into a dorsally subluxated position. This principle applies not only to the foot undergoing a second procedure or "repeat correction," but also to those feet having the initial surgical correction.

Indication

The indication for the medial/lateral column separation is dorsal subluxation of the navicular following previous ligamentous release of the talonavicular joint.

Technique

Medial/lateral column release is always preceded by the extensive soft tissue release of the midfoot and hindfoot as previously described; it is not performed as an isolated procedure. Through the lateral limb of the Cincinnati incision, dissection is carried from the previously opened subtalar joint distally to accomplish a complete capsulotomy between the cuboid and the navicular, and the cuboid and the third cuneiform on both the dorsal and plantar surfaces. The capsulotomy is then carried distally between the base of the 3rd and the 4th metatarsals. This dissection is complete when the third interspace is entered and the interosseus muscle becomes visible (Figures 9.1 and 9.2, color plate 2). Using this as the end point of dissection, the vessels entering the interspace at this level are not injured.

I have called this medial/lateral column separation the "Third Street" operation, since the dissection proceeds down the third intertarsal interval to enter the third interspace. This separation of the medial and lateral columns extending into the forefoot, combined with the subtalar and talonavicular release, and the complete plantar detachment of the posterior tibial tendon (described in Chapter 7) allows the navicular to be placed in its proper orientation upon the talar head. Once the navicular has been rotated to its proper placement, one will see a corresponding rotation occurring at the cubonavicular and cubocuneiform junctions. At the same time, the calcaneocuboid joint will shift to align the cuboid with the calcaneus.

Suture fixation of the talonavicular joint (as described earlier) is no longer used. I now use a single Kirschner wire to secure the medial column reduction (see Chapter 7, p. 221). No suture or pins are needed to cross the calcaneocuboid joint.

The closure, cast application, and postoperative care are the same as described in Chapter 7.

Results

Having used the "Third Street" operation in conjunction with the complete peritalar (subtalar) release,[4,5] for only 2 years, it is too early to

TABLE 9.1. Third Street release in 27 feet in 17 patients, January 1990 through December 1990.

Age at operation	Number of feet
1st year	13
2nd yr	2
3rd yr	6
4th yr	3
5th yr	2
6th yr	1

report results. During 1990, I performed 27 of these procedures in 17 patients. Table 9.1 indicates the ages of the patients at the time of operation. I have seen no untoward complications, e.g., neurovascular, residual instability, etc. None of these feet has yet required further surgery.

Summary

A new procedure, medial/lateral column separation, or "Third Street" operation, is described for the treatment of the surgical complication of dorsal talonavicular subluxation.

Acknowledgment
I am deeply indebted to the Shriner's Hospital for Crippled Children for providing me with the opportunity and the patients over the past 30 years to develop the concepts and philosophy regarding clubfoot surgery.

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Discussion

Simons (Milwaukee): Dr. McKay, when you performed your fascial release of the calf, did you try to examine the excursion of the muscle before the fascial release and then afterward? If so, what were the ranges of dorsiflexion?

McKay (Ville Platte, Louisiana): At the time of surgery, I tested the range of motion before and after the release. I felt that there was an increase in the range of motion. I did not attempt to measure it, so I cannot really be sure.

Simons: Was anything dramatically different once the fascia was released?

McKay: Yes, the dramatic difference was that suddenly a lot of muscle bulged out of the wound and the wound was very difficult to close.

Goldner (Durham): I would like to discuss the significance of the anterior tibial tendon. The first thing I do when I enter the medial side of the foot is to find the neurovascular bundle. The second thing is to find the anterior tibial tendon, which I release completely from its attachments. When I get through with the operation, I reattach the tendon to the dorsum of the 1st metatarsal. It usually recedes about 4 mm.

Schoenecker (St. Louis): I would like to emphasize that the anterior tibial tendon may well have been overlooked in the past. Eberle[1] and others have been doing dynamic electromyograms (EMGs) in postoperative clubfeet. The only muscle that really functions in the dynamic EMG has been the anterior tibial. He noted that these children have primarily an anterior tibial functioning leg. He has seen one child in whom he could demonstrate gastrocsoleus function but this was about 2 years postoperatively. The anterior tibial tendon may be more of a culprit than we appreciate.

Drennan (Albuquerque): I think I've seen a few patients in whom the tibialis anterior was very definitely overactive. Why is it that we don't

see it more often? Is it simply by changing the position at the time of surgery that we convert the muscle to a pure dorsiflexor?

Malan (Vanderbijlpark, South Africa): From my observation, I think that's true. When the anterior tibialis is put back in the right axis of function it will function mainly as a dorsiflexor of the foot.

Goldner: Dr. Barnett, I have been doing surgery on the lateral side of the foot for what I call the "lateral impingement syndrome." I found exactly what you found on the lateral border of the foot. By removing part of the 3rd cuneiform or the dorsum of the beak of the calcaneus, or taking a wedge out of the cuboid, we accomplish the same thing.

Crawford (Cincinnati): When we get dorsal subluxation of the talonavicular joint, it is usually iatrogenically caused. Retrospectively, we have found subluxation at the talonavicular joint when we looked at the intraoperative and postoperative x-rays. We attempted to project a line through the talus to the base of the 1st metatarsal. When the talar axis passed below the 1st metatarsal, we had actually forced the navicular into that position. However, I have found that along with the dorsal subluxation these often developed a cavus foot subsequently. We now believe in intraoperative x-rays and we make an effort now to depress the forefoot so that the 1st metatarsal is in line with the talus. We've had fewer dorsal subluxations since doing this.

Simons: If there is also a lateral subluxation in addition to the dorsal subluxation of the talonavicular joint, I think that Dr. Barnett's medial/lateral column separation "(Third Street" operation) as well as a complete subtalar release must be used. One or the other is insufficient.

Barnett: The Third Street operation is not an isolated operation. It is always used in conjunction with a complete subtalar (peritalar) release.

Simons: A previous speaker said that with dorsal talonavicular subluxation he thought that just the Third Street operation would be sufficient. I would agree with Dr. Barnett that his Third Street operation is not adequate. If there is also lateral talonavicular subluxation, which frequently occurs with it, one must also perform the subtalar release. For lateral talonavicular subluxation alone, the complete subtalar release is adequate.

Barnett: I have never done the Third Street operation as an isolated procedure. I would like to clarify that I don't do the medial/lateral column separation as part of the initial operation because dorsal talonavicular subluxation occurs as an iatrogenic complication. It is not present before surgical treatment. Its place is in the 2- or 3-year-old child who returns with dorsal subluxation of the navicular following previous surgery.

Griffin (Charleston): Dr. Barnett, I think that one cause for a supinated foot in which the navicular is dorsally subluxated such as the one you showed, is that the surgeon has failed to move the cuboid completely out of its inverted position beneath the talus. Then, in order to push the navicular laterally, it must move dorsally; we push it dorsally and laterally until it is in contact with the talar head, pin it in position, and assume that we have achieved correction. However, the cuboid remains beneath the navicular. Have you noticed at surgery that you are able to see the cuboid under the navicular more medially than it should be?

Barnett: It is under the navicular because the supination has not been corrected. In fact, the entire heel column may be supinated. Which comes first, I'm not sure. However, I think the key to this problem, as in other deformities of the clubfoot, is that the talonavicular joint, when reduced, must be reduced in a completely relaxed position without tension. If you have to push on the navicular, or hold it down, your release has not been adequate. An obstruction to the reduction must be searched for, found, and then released.

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Editor's Comments

In **Malan's** paper, lengthening of the anterior tibial tendon was regularly performed in a very large number of cases. This is an interesting and, for the most part, previously neglected structure in the treatment of clubfeet. I have occasionally incised the anterior capsule of the ankle for postoperative diminished plantar flexion. In addition to the capsulotomy, I have performed associated lengthening of the dorsiflexor tendons. However, I have not performed anterior tibial lengthening as a routine part of the primary soft tissue release. Certainly in the future it will be important for all of us to examine the excursion of the anterior tibial tendon following the completion of the primary soft tissue release and fixation of the bones. If the tendon is truly contracted with restriction of plantar flexion, I believe that lengthening is indicated.

In a previous study at Children's Hospital of Wisconsin,[2] ankle joint motion was measured radiographically pre- and postoperatively; the total range of ankle motion did not change appreciably, but the arc of motion moved upward into dorsiflexion about 10°. Thus, plantar flexion was lost, and dorsiflexion gained, following surgery. Whether joint contractures or tendon contractures come first, I'm not sure, but they are usually both present.

Although **McKay** states that one of the main reasons he obtains a good range of ankle motion is the way he handles the flexor tendons by flexor tendon sheath recession,[1] **Barnett** claims that he obtains a good range of motion in those feet in which the posterior tibial tendon has been released at its insertion and probably fails to reunite following surgery (see **Barnett**, Chapter 7). He also believes that if the tendon reattaches in a lengthened position, a good range of motion will occur, whereas if it reattaches at its normal point of insertion, a restricted range of dorsiflexion occurs. **Malan** attributes his excellent range of motion postoperatively to lengthening of the anterior tibial tendon.

Malan's statement that he obtains an almost-normal range of motion with normal calf and leg development following anterior tibial tendon lengthening is extraordinary, yet **Goldner** verifies this. If **Malan's** observations are verified by others, his contribution will be of considerable significance in the treatment of CTEV.

Thus, five different authors incriminate six or seven structures as possible sources of decreased postoperative range of ankle motion in the clubfoot: the anterior tibial tendon (**Malan** and **Goldner**), the posterior tibial tendon (**Barnett**), the flexor tendons and posterior tibial tendon (**McKay**), and (anteriorly subluxated) peroneal tendons as well as the anterior ankle capsule contracture and flattop talus (**Simons**). Further research in this area is certainly needed.

McKay's observations following fasciectomy of the calf are fascinating. These cases should certainly be corroborated by further investigations on the extent of contracture and the amount of resection of fascial tissue necessary.

Barnett's medial/lateral column operation is both unique and ingenious. He is correct in stating that the repeat CSTR is inadequate for this problem, as this has been our experience as well. Dorsal talonavicular subluxation is usually due to pinning the navicular in a dorsiflexed position in relationship to the talar head. This occurs because (a) the surgeon is unaware of the clinical criteria for anatomical reduction of the talonavicular joint, (b) the surgeon fails to commit the time and the meticulous detail to achieve a precise anatomical reduction, and (c) he does not verify his clinical reduction by intraoperative radiographs. Although the navicular is not ossified and cannot be seen on interoperative radiographs, on the lateral intraoperative radiograph, if the talar axis passes through the base of the 1st metatarsal, the navicular should not be dorsally subluxated. Unfortunately, too few surgeons use this radiographic parameter and instead depend upon their clinical judgment for this very difficult and important part of the procedure. When the joint appears to be dislocated or subluxated in postoperative radiographs, if the surgeon has not taken interoperative radiographs, he will be unable to know

whether the complication developed gradually over a period of time or was the result of his failure to accurately pin and verify a precise reduction at the time of surgery.

Barnett's medial/lateral column separation has the potential for instability and, possibly, other complications not yet apparent. It is solely intended for the correction of dorsal talonavicular subluxation with or without lateral talonavicular subluxation. (It is not intended for lateral talonavicular subluxation alone.) Therefore, it is indicated as only a secondary procedure to correct a complication of a previous surgery. Furthermore, it should always be performed in conjunction with the CSTR or similar soft tissue procedures. Like **McKay's** procedure, **Barnett's** procedure is still in the developmental stage and should be performed with caution until Barnett has fully evaluated it.

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10
New Procedures: Soft Tissue Procedures with Distraction

Introduction

In this chapter, three different external distraction devices are used to realign the congenital talipes equinovarus (CTEV): Wagner's device, Joshi's device, and the Ilizarov apparatus.

Watts introduces the use of a Wagner fixator to straighten the severe forefoot deformity in previously operated or previously infected clubfeet. These feet all had marked medial contractures involving the soft tissues on the medial side of the foot.

Joshi and colleagues present a paper on controlled differential distraction for correction of complex CTEV. This paper describes the use of an external fixator (a homemade miniversion), a device that Professor **Joshi** himself made and that he utilizes for the treatment of young children in India. Unlike other reports in this monograph, in which the Ilizarov and other large external fixators are used for older patients, **Joshi et al.** present the results of 20 patients under 4 years of age, as well as patients over 4 years of age.

This is used to correct all deformities of the clubfoot. They state that this technique can be used (and should be used) in the young patient. They do not say how young, although their youngest patient was 3 months old. They add that further research is now in order.

Grill, **Cantin et al.**, and **Paley** each present papers reporting their early experience with the Ilizarov technique.

Grill reports his experience in relapsed and neglected clubfeet between 7 and 16 years using the Ilizarov device for distraction but without osteotomy.

Cantin and her colleagues also describe the use of the Ilizarov apparatus, in most cases without osteotomy.

In his first paper, **Paley** describes his use of the Ilizarov apparatus with distraction but without osteotomies. In a second paper, presented in Chapter 11, he describes his experience with distraction with the use of osteotomies.

In addition, **Paley** describes his use of the Ilizarov apparatus by a constrained versus an unconstrained technique, and gives his indications for the use of the apparatus without osteotomy. Finally, he describes in detail his technique for application of the Ilizarov apparatus for the various deformities.

Gradual Midfoot Distraction for the Treatment of Severe Adductus Deformity in Children with Clubfeet After Multiple Prior Operations

H. Watts

Occasionally, one is presented with the problem of a child born with clubfeet who has had multiple previous surgeries or prior postoperative infection, who presents with severe residual midfoot adductus with thick scar formation along the medial aspect of the foot (Figures 10.1 and 10.2).

Correcting these deformities by lengthening the medial column of the foot is not realistic because of the severe medial scarring. If the child is old enough, the foot can be straightened by taking a very large lateral-based wedge through the bones of the midfoot, but this results in an unacceptable shortening of the foot.

Gradual distraction of the foot using Ilizarov's apparatus may be successful. However, it can be very demanding to place the hinges at the correct rotation points in the complex deformities of a clubfoot. It is particularly difficult when dealing with very small feet. In addition, the technique is tedious and very time-consuming.

We have adopted a different technique for gradual distraction that we have found useful.

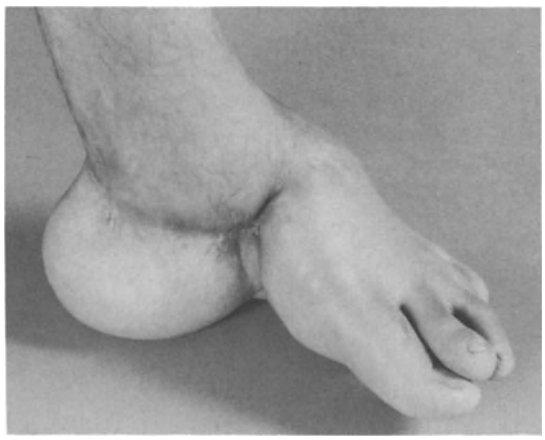


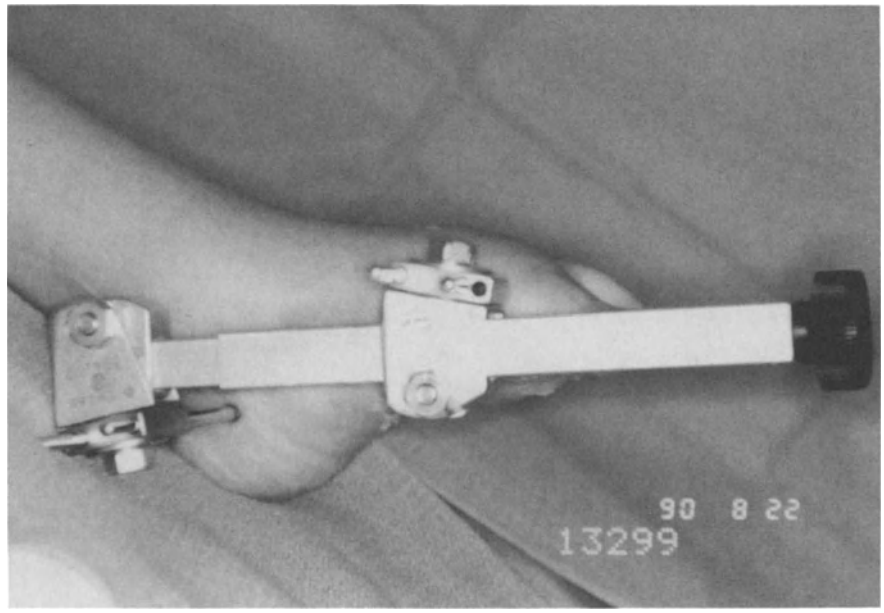
FIGURE 10.1. Severe adductus deformity with scarring medially are evident in this 12-year-old Saudi Arabian boy. He had four prior operations with postoperative infection following two of the surgeries. This boy's problem led to the use of this technique. Unfortunately, postoperative photographs are not available.

Patients and Methods

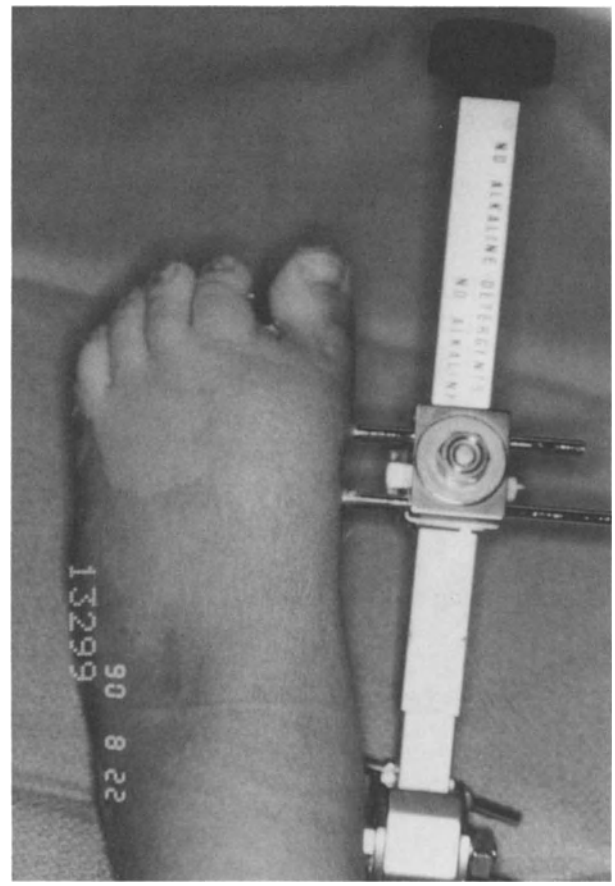
Four children, ages 5 years 3 months, 10 years 2 months, 10 years 4 months, and 12 years, pre-



FIGURE 10.2. A 5-year-old girl with two prior surgeries seen before the gradual lengthening procedure.

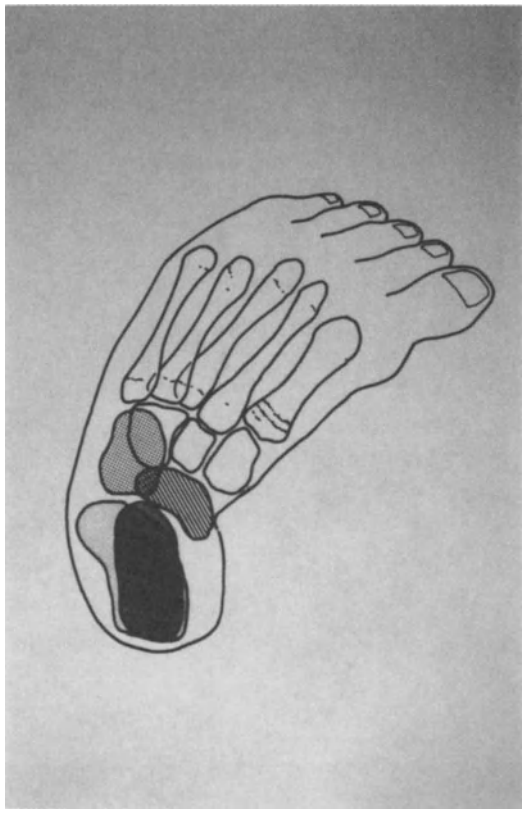


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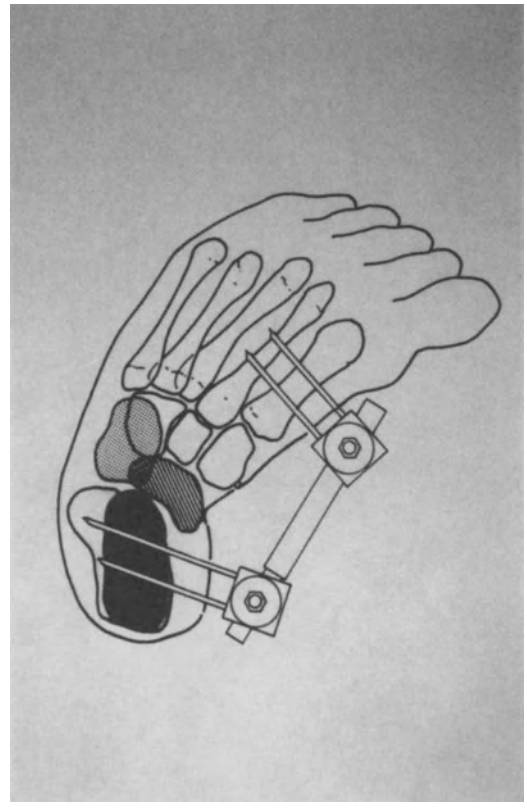


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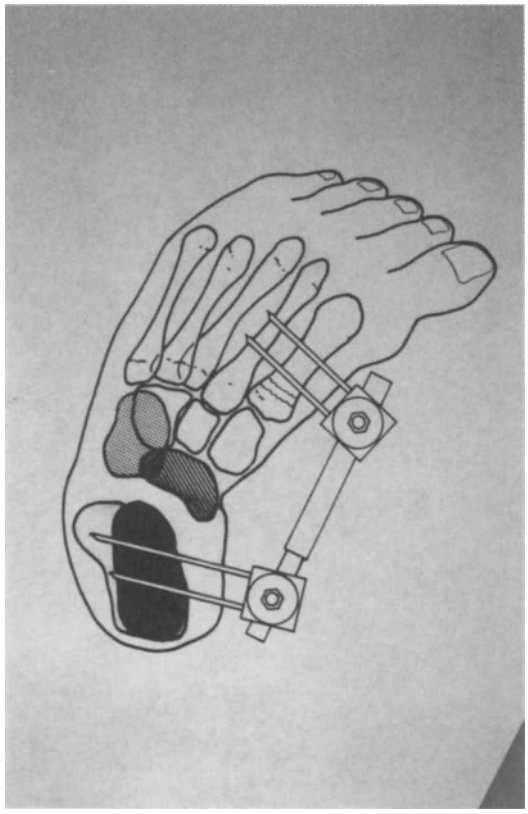
FIGURE 10.3. The same child after application of a small Wagner lengthening apparatus. A: Medial aspect: note that the carrier for the distal pins was inverted to fit the placement of the pins. B: Anterior aspect.



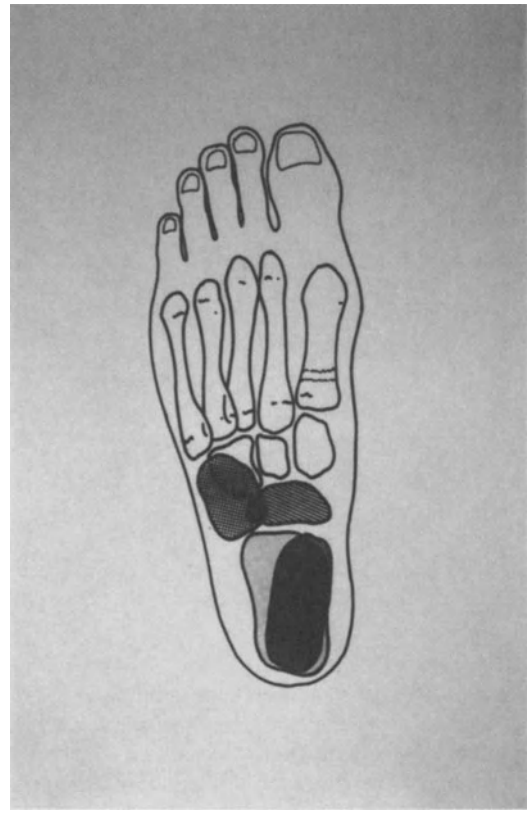
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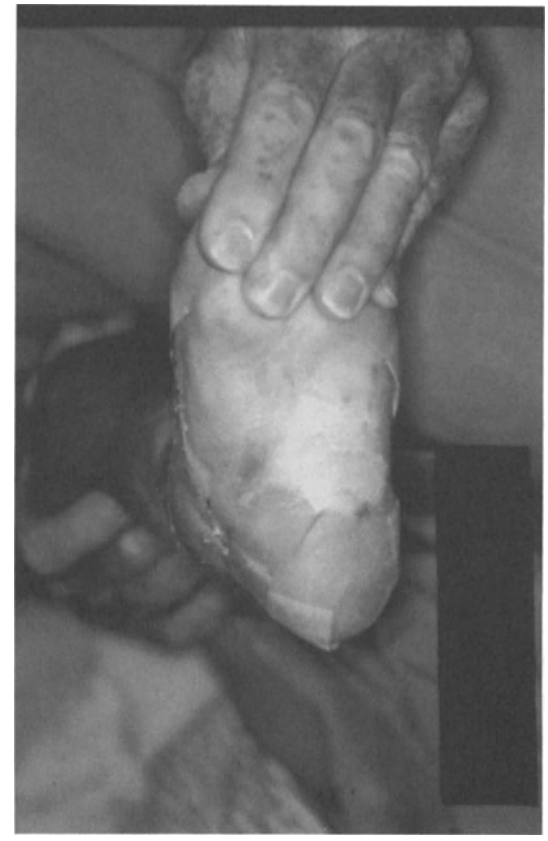
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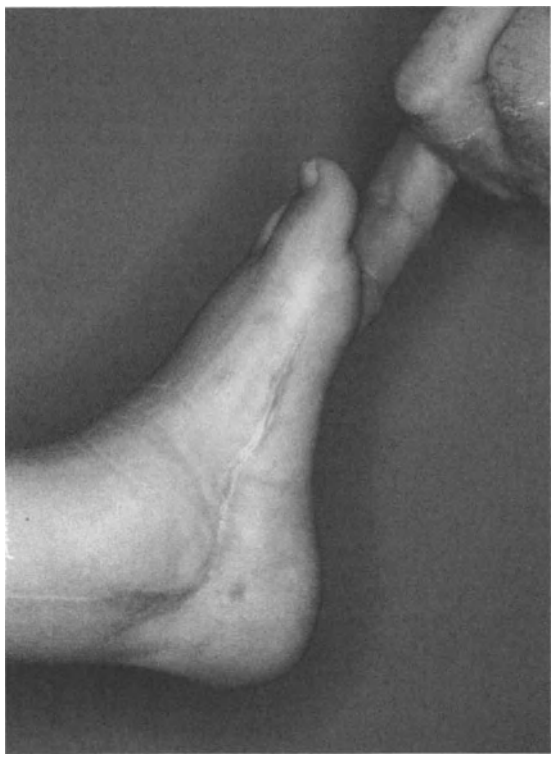
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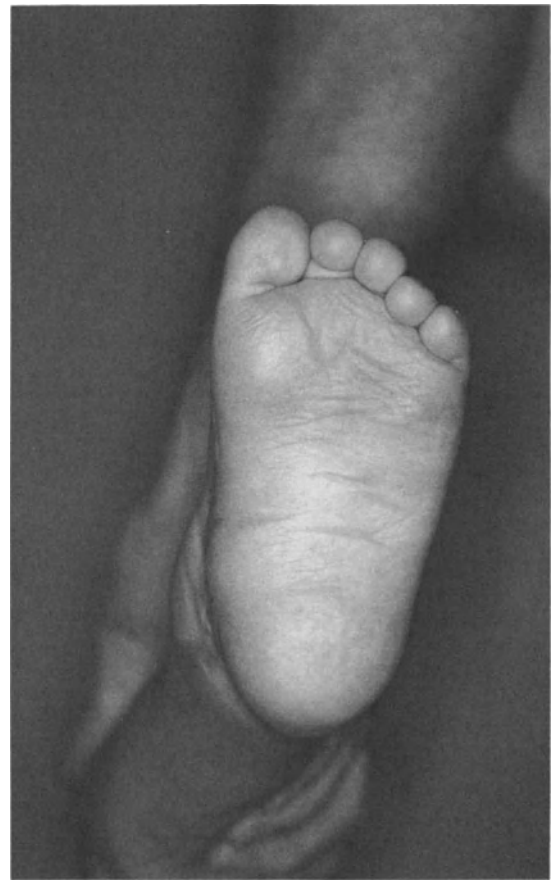
B

FIGURE 10.4. Schematic representation of the foot during the distraction process. A: Prior to surgery. B: At the application of a small Wagner distraction apparatus. C: At the end of the distraction period; note the separation of the navicular and cuboid from the talus and calcaneus. D: After removal of the distractor and after manual manipulation under anesthesia (prior to cast application): note that the distraction gap has closed and the midfoot has slid laterally through the gap.

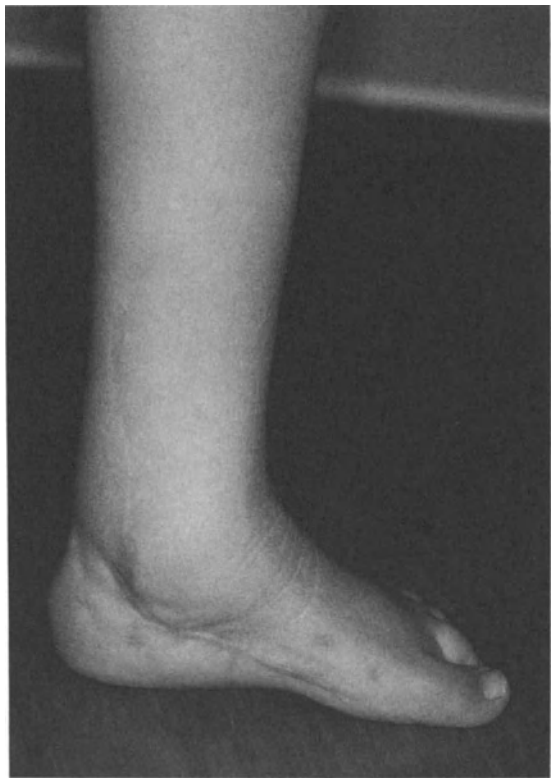
FIGURE 10.5. Postoperative status of the same child at removal of the apparatus and after manual manipulation. A: Medial aspect. B: Plantar aspect.



A



B



C

FIGURE 10.6. The same child 10 months after surgery. A: Medial aspect. B: Plantar aspect. C: Standing view.

sented to our hospital. Each child had previously undergone multiple surgeries for the correction of clubfeet at other institutions and had had a postoperative wound infection or skin slough. When the patients were seen, they each had marked midfoot adductus together with thick scar formation along the medial aspect of the foot.

The patients were taken to surgery where, through a longitudinal incision along the medial aspect of the foot and a second incision at the sinus tarsi, the subcutaneous tissues were dissected free from their adherence to the underlying bone. The capsules of the talonavicular and calcaneocuboid joints were divided circumferentially. In one patient, a prior calcaneocuboid fusion was divided. A small pair of Schanz screws (4 mm in diameter) was placed into the calcaneus and a second pair across the medial two metatarsals, taking care to avoid the proximal physis of the first metatarsal. These were mounted onto a small Wagner distraction apparatus. Occasionally, this required that one of the pin-mounting carriers be inverted (Figure 10.3).

Distraction was started 4 to 5 days after surgery (to allow the child to get comfortable) and was performed at a rate of 0.25 cm four times a day until distracted to 2 to 3 cm. This amount of distraction was entirely arbitrary. The distraction took place along the axis of the rigid bar. No attempt was made to swing the foot out of adductus during the distraction (Figure 10.4A–C). Approximately 1 week after the distraction was complete, the child was taken back to the operating room where the apparatus was removed and the foot easily manipulated out of adductus under anesthesia (Figure 10.4D). The feet were held in a short-leg plaster cast for 12 weeks and thereafter in a molded foot-ankle orthosis for 6 months.

These patients have been followed up for only 10, 15, 17, and 48 months.

Figures 10.2 through 10.6 illustrate an example of this technique.

Results

All four patients showed good correction with maintenance of alignment over the short follow-up time of this study. There were no infections or significant wound problems. No patients have complaints of pain in the feet.

The toes may become fixed in flexion during the distraction period. This has not proved to be a problem. When the apparatus is removed, and the forefoot dropped back into its new abducted position, the toes can be readily brought into their normal position.

Discussion

The advantage of this technique over using Ilizarov's apparatus is its simplicity. The goal of the distraction is not to change position during the distraction but merely to gain skin and soft tissue length medially. The correction of deformity takes place during the manipulation at the time of the second anesthesia.

This sample of patients is small and the follow-up time is short. These can be considered only preliminary data. However, we have been sufficiently pleased with our results that we have now operated on 11 similar feet. With some of these children, we have used, without problems, a pediatric Hoffman external fixator with through-and-through pins when a Wagner apparatus was not available. The Wagner apparatus, however, is simpler. In addition, we have used the same principle on three others with dorsiflexion deformities using a Hoffman apparatus extending from the tibia to the metatarsals.

With cautious optimism, we suggest that this technique may prove useful to others in meeting this challenging problem.

Summary

After repeated operations, children with clubfeet may be left with severe adductus secondary to medial scar formation with contracture (especially if there had been a wound slough or infection). Four patients are presented who were treated by gradual distraction using a small Wagner fixation-distraction device applied medially to the metatarsals and the calcaneus. Correction was achieved and maintained in all four patients without complication. In addition to adduction, this technique has been recently used to correct calcaneus deformity.

Although Ilizarov's techniques can also be used, we believe that our alternative technique is simpler for both the patient and the surgeon.

Controlled Differential Distraction for Correction of Complex Congenital Talipes Equinovarus

B.J. Joshi, N.S. Laud, A. Kaushik, H. Patankar, and S. Warrier

Various methods and approaches have been described for correction of complex CTEV. A method of treatment based on the use of external fixation in combination with controlled distraction for stretching soft tissues for realignment of the skeleton of the foot in CTEV will be presented. The correction is obtained with minimal surgery and trauma to the foot. Correction of adduction deformity of the forefoot is achieved simultaneously with the correction of hindfoot equinus and varus deformities, and yet there is individual control in the correction of each deformed element in sequence.

The tarsal joints are realigned by distraction of the medial border of the foot at the rate of 1 mm per day while the lateral border is distracted at 0.5 mm per day, thus preventing crushing of the cartilage of the lateral border due to a wedging effect. Threaded rods between the tibial and the calcaneal pins allow correction of the hindfoot equinus and varus of the heel. During the correction of equinus, pressure on the ankle is relieved by rods connecting the tibia to the forefoot. At the same time, they allow stretching of the anterior capsule and ligaments.

Total correction is achieved within 3 to 6 weeks. The correction achieved is later maintained in plaster casts for a period of 6 weeks to permit stabilization of the stretched tissues. This method has been successfully used in 16 patients and has shown satisfactory results in difficult situations, as seen in (a) arthrogryposis, (b) congenital constriction band syndrome, (c) relapsed clubfoot, and (d) neglected clubfoot.

Purpose

The primary aim of treatment in clubfeet (CTEV) is to gradually stretch the soft tissues and to correct the adduction of the forefoot, the inversion, and the equinus deformities. The elongation of tissues results in a supple foot that is maintained in the corrected position by orthotic devices, while muscular development and gait training is being performed. The object of treatment is to obtain lasting correction, i.e., a pliable, plantar grade and cosmetically acceptable foot.

Materials and Methods

Though statistics vary widely, it is generally accepted by many investigators that over 50% of cases are correctable[5,6] by noninvasive techniques, i.e., taping, serial plaster casts, orthotic devices, and physical treatment. The remaining 50% require some form of surgery. Correction by gradual stretching of soft tissues with an external fixation device, being a semi-invasive method, was tried on 23 feet in 16 patients in lieu of surgical release.

Our experience is limited to the selected cases referred by our orthopedic colleagues because of our interest in correction of deformities by the distraction-lengthening technique. Older children, as well as those in the preambulatory age range, were subjected to this treatment when conservative procedures had failed to render the foot plantar grade.

These cases were grouped as follows:

1. Failure of conservative treatment (six cases), ages 5, 6, 10, 18, 22 months, and 3 years.
2. Recurrence after surgical release (four cases), ages $2\frac{1}{2}$, 4, $4\frac{1}{2}$, and 9 years.
3. Known resistant cases, e.g., arthrogryposis, cases associated with constriction band syndrome, and severely contracted foot (three cases), ages 3, 5, and 12 months.
4. Late presentation (three cases), ages 15 months, 21 months, and 4 years.
5. Adjunct to surgical treatment for realignment of skeleton, (one case), age 8 years (under treatment not included).

Components of the Device

Since a specific apparatus is not available for pediatric use, an external fixation distraction

assembly was made by using the following readily available components:

10 Kirschner wires (2 to 2.5 mm)
24 link joints
6 distraction units
9 stabilizing rods (two "car handle" shaped, two U shaped)
1 foot plate

Assembly of the Device

The basic assembly requires three pinhole sites in the tibia to be made as follows:

1. Tibial pinhole (Figure 10.7): Two parallel transfixing pins (preferably threaded in the middle) or one transfixing pin and two half-pins are passed into the upper third of the tibia, about $1\frac{1}{2}$ inches apart. The middle parts of the "car handle"-shaped stabilizing rods are attached by link joints to these pins over the medial and lateral aspects. This provides an anterior and posterior vertical pillar to be connected with transverse bars anteriorly and posteriorly, making two rectangular frames. These transverse connections give the assembly extra stability and additional sites for link joints.
2. Calcaneal pinholes (Figure 10.8): Two transfixing pins are passed from the medial to the lateral aspect of the calcaneus parallel to each other. A third pin is passed posteriorly along the axis of the calcaneus. A rectangular-shaped assembly is attached to these pins to provide connections to the tibial pinhole proximally and to the metatarsal pins distally.
3. Metatarsal pinholes (Figure 10.9): One transfixing pin is passed through all five metatarsals at the level of the neck or distal shaft. Two separate pins, one from the medial aspect and one from the lateral aspect, are inserted parallel to the transfixing pin to engage three metatarsals on each side.

Rod Connections and Adjustment

Six threaded rods (Figure 10.10) connect the above pin assembly. The length of these rods is

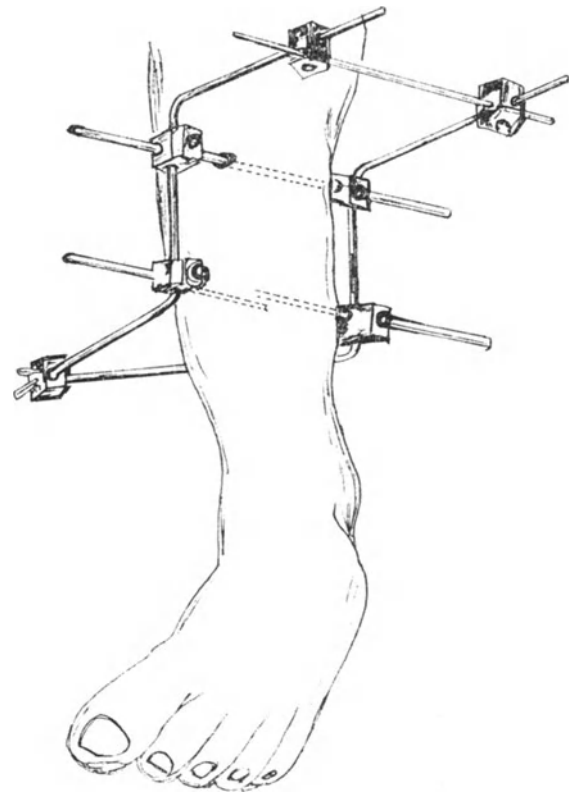


FIGURE 10.7. Tibial pinholes: one transfixing and two half-pins are inserted in the upper third of the tibia. The half-pins prevent rocking of the assembly. Two "car handle"–shaped bars are attached to these pins. The vertical pillars of the bars are joined together to provide stability and extra sites for link joints.

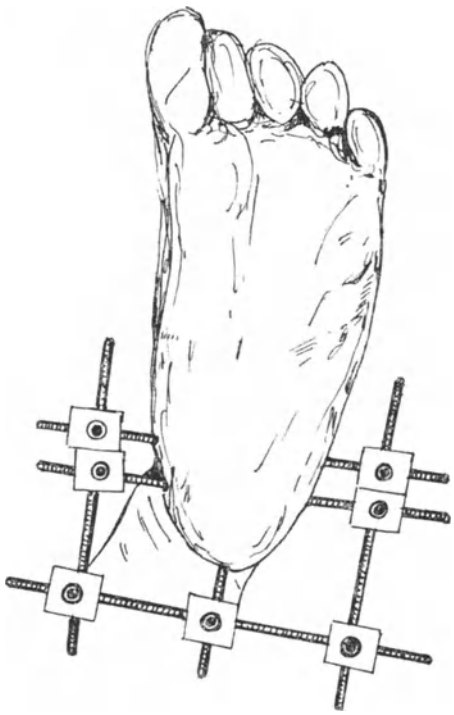


FIGURE 10.8. Calcaneal pinholes: two transfixing pins parallel to each other are passed through the calcaneus from the medial to the lateral side. Another pin is passed along the axis of the calcaneus posteriorly. A rectangular-shaped assembly is formed as shown for connection to the tibial and metatarsal pins.

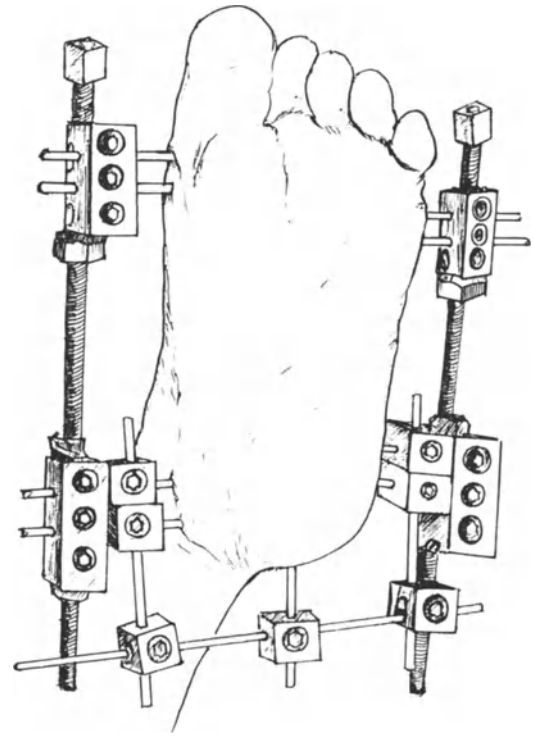


FIGURE 10.9. Metatarsal pinholes: one transfixing pin and two half-pins are passed into the distal metatarsals. The half-pins engage only three metatarsals. Two distracting rods (on either side) connect the calcaneal assembly and the metatarsal pins.

adjusted as needed by tightening or loosening nuts.

A pair of threaded rods connects the calcaneal and metatarsal pins on either side of the foot. Unequal distraction by these rods leads to correction of the forefoot adduction, with stretching of the tight midtarsal, the tarsometatarsal ligaments, and the plantar fascia. This facilitates reduction of the talonavicular joint. The medial rod is distracted at the rate of 1 mm (or a fraction of a millimeter) per day, whereas the lateral rod is distracted at half that rate. The distraction on the lateral side relieves any pressure on articular cartilage over the lateral aspect of the foot and also helps to unlock the calcaneocuboid articulation.

Another pair of threaded rods, which connects the posterior limbs of the tibial frame, is connected to the rectangular calcaneal assembly. These threaded rods are initially attached near the transfixing pins on the lateral and medial aspects of the calcaneus. Unequal distraction in this plane corrects hindfoot varus and inversion. The medial rod is distracted at twice the rate of the lateral rod to correct the varus alignment and to stretch the subtalar ligaments more on the medial side and to a lesser degree on the lateral side. This not only corrects varus of the calcaneus but also facilitates its derotation under the talus.

After correction of the varus and rotational deformities, the frame is adjusted to align the foot with the ankle and knee. At this point, equinus of the hindfoot is corrected by shifting the connecting rods posteriorly to provide better leverage of the calcaneus. Distraction in this plane provides "thrust force" that stretches the posterior structures of the ankle and subtalar joints, including the calcaneofibular, tibiocalcaneal, and talocalcaneal ligaments. It

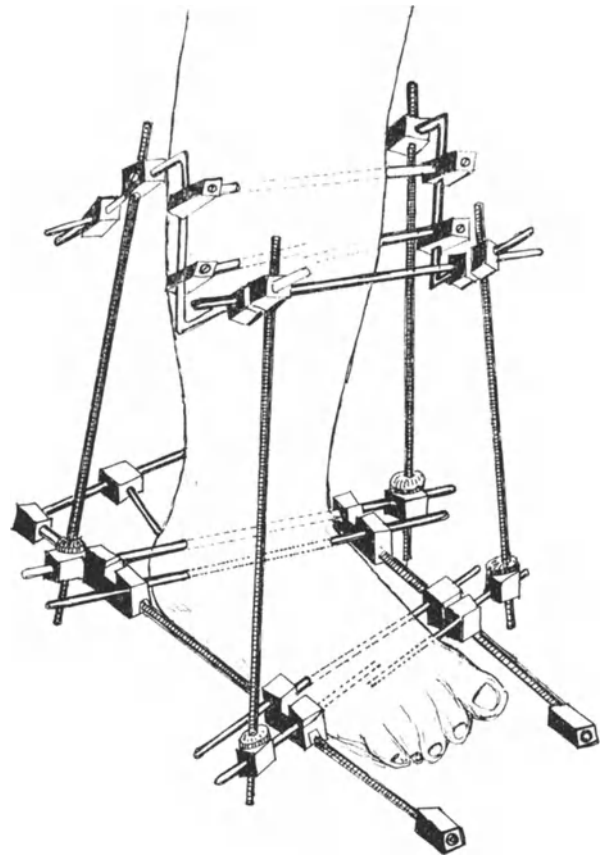


FIGURE 10.10. The assembly showing six adjustable threaded rods for distraction in three planes for correction of adduction of the forefoot, varus, and equinus of the hindfoot.

makes room at the ankle mortise for the talus to glide into the mortise. The tight tibiofibular ligament may limit the fibular movement associated with dorsiflexion of the ankle.[3] In such cases, an additional separate distractor may be needed to widen the syndesmosis between the tibia and fibula at the level of the ankle. This had not been necessary in our series.

Another pair of threaded rods connects the anterior limbs of the tibial bars to the metatarsal bars laterally and medially. Shortening the lateral rod pulls the foot into eversion. Initially, both of these rods are kept in a static mode to provide a "tension force" while the equinus of the hindfoot is being corrected by a "thrust force." This helps to stretch the anterior structures. During this period of controlled stretching, these rods must be adjusted frequently. Once the hindfoot equinus is corrected and the tarsocalcaneal angles are restored, the longitudinal arches of the foot are protected by bending the calcaneometatarsal threaded rods with convexity dorsally and medially to maintain 5° of abduction of the forefoot (Figure 10.11). The medial rod is bent more than the lateral rod to conform to the foot's normal shape. The foot is now ready to be pulled into dorsiflexion as a unit by gradual shortening of the tibiometatarsal rods and simultaneous tibiocalcaneal distraction until the desired dorsiflexion of the foot is achieved. This arrangement prevents rocker-bottom deformity from occurring by guarding against collapse of the longitudinal arches.

Attaching the Foot Plate

Two shallow U-shaped attachments connect the metatarsal and calcaneal pins on the plantar aspect of the foot (Figure 10.12). These interconnections provide not only a slot for the foot plate but also added stability for the metatarsal and calcaneal pinholes. A transparent acrylic plate is slotted between the sole and the extended assembly. The plate prevents flexion

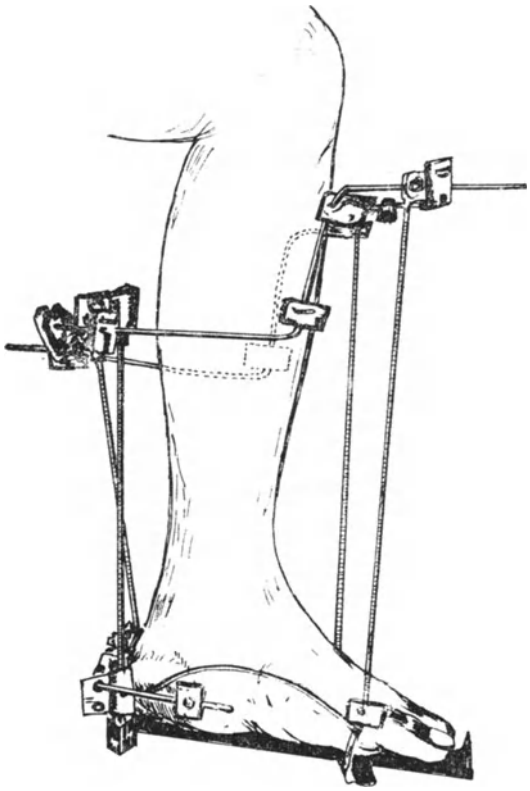


FIGURE 10.11. The tibiocalcaneal distractors are moved more posteriorly toward the calcaneal axial pin for final correction. Distraction in this direction improves "thrust force" for correction of equinus deformity. Simultaneous tibiocalcaneal distraction and shortening of the tibiometatarsal rods allow dorsiflexion of the foot. The calcaneometatarsal rods are bent dorsally and medially to prevent collapse of the foot arches.

deformity of the toes and forefoot drop, which may develop secondary to the tightness of the flexors following correction of the equinus deformity. The foot plate should be transparent to allow inspection of the sole for blanching of the skin and thus prevent skin necrosis.

Clinical and Radiographic Assessment

Clinical and radiographic assessment is needed to regulate the distraction of the soft tissues and avoid over- or understretching. The proper amount of stretching will create sockets for

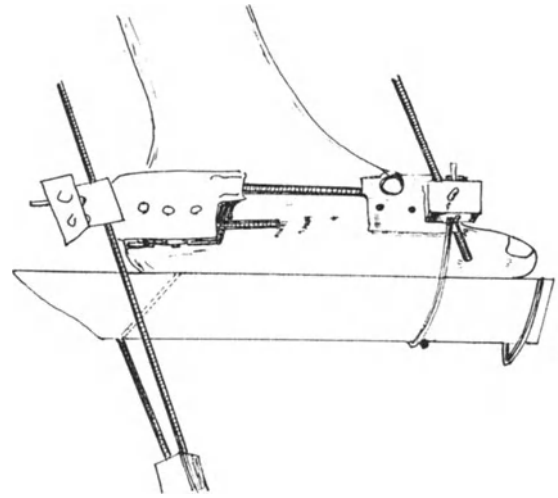


FIGURE 10.12. Foot plate attachment.

realignment of the joints. Standard anteroposterior (AP) and stressed dorsiflexion lateral views are taken preoperatively followed by intraoperative views after fixation of the assembly. Postoperative roentgenograms are taken on the 10th and 2lst days, and later if necessary, to assess and direct the distraction forces in the proper axis. The object is to restore angles to criteria established by many authors[4] for satisfactory alignment of the foot.

Aftercare Protocol

The pins are cleaned daily. Distraction is performed at the rate of 0.25 mm at 6-hour intervals, or longer at reduced speed. The entire assembly is covered by a cardboard splint to prevent injury by the pin ends. Once the deformities are corrected, the position is held with distractors in a static mode for 3 weeks to allow the tissues to adjust to their elongated position. At this stage the foot is quite pliable and readily molds into correct skeletal alignment.

After removal of the fixator under general anesthesia, a well molded below knee cast is applied with x-rays taken to confirm the position. Any remaining deformity is corrected by Kite's wedging technique.[2] The plaster cast is retained for 6 weeks with the child being allowed to walk with full weight-bearing. After this cast is removed, a plaster boot, which allows mobilization of the ankle while holding

the foot in corrected position, is applied for another 3 to 6 weeks.

Appropriate orthotic devices, which will be needed long-term to prevent recurrence, are fitted to maintain the corrected position until the tarsal bones are remolded with resulting stable articular surfaces. At this stage the patient is referred for physical therapy to develop and strengthen the weaker muscles that are needed for balancing the foot and for gait training.

Results

In every case a plantar grade foot was achieved. One case developed a rocker-bottom foot due to overstretching and another (arthrogrypotic) foot had recurrence of the deformity due to understretching. These cases required restretching on the assembly and the desired correction was obtained.

Minor complications such as pin tract discharge, edema, and occasional blisters on the dorsal and medial aspects of the foot were seen, especially in our early cases. Pin tract problems were solved by using two pins rather than the single pin that was used initially. Edema and blister formation were due to tissue stretching following rapid distraction and were largely avoidable.

Discussion

The introduction of Ilizarov's apparatus has created interest among surgeons for the correction of complex deformities of the limb. In clubfoot its use has been described by Grill and Franke,[1] but they used it for older children and adolescents with neglected or resistant deformities and relapsed deformities.

Our apparatus has been developed primarily for the pediatric age group, though its larger version can be used in adolescents. It provides precisely controlled distraction and direction at the site of the deformity with six adjustable axes in three planes for gradual elongation of the soft tissues under radiological control. At the end of the distraction the foot is supple and pliable, like a bag of bones and cartilage in an envelope of soft tissue, and is amenable to precise molding in casts or external fixation.

Our experience in treating these 16 patients has led us to believe that this method should be tried prior to any surgical correction, even in early childhood, as it may obviate the need for extensive surgery.

Further correction was needed in two cases. In one case, (arthrogryposis) understretching led to a recurrence and in the other stretching in an uncontrolled direction caused a rocker-bottom foot. The procedure was repeated and correction achieved after 3 months with no problem. Only long-term follow-up studies will show whether instrumental soft tissue stretching at a young age will affect the skeletal development and growth, whether insertion of interosseous pins at a young age would have any ill effects, and to what extent it will minimize the need for additional surgical procedures.

Conclusion

This distraction-lengthening technique and the external fixator assembly made with readily available components described in this paper has proved quite suitable for pediatric practice. We are currently performing further biomechanical studies of the fixator assembly to produce an improved version. The method seems to have a future and will be an addition to our armamentarium in the management of clubfoot deformity even at a preambulatory age, but careful and longer studies will be needed to answer certain questions before its universal application is recommended.

Summary

This is a preliminary report on the treatment of clubfoot in children by a distraction-lengthening technique that uses an external fixation device composed of readily available materials. The report discusses how to assemble this device.

Treatment proceeds by gradually stretching and elongating tight tissues in sequence. The feet are rendered supple, pliable and easily moldable to the normal shape in plaster. The direction and rate of distraction are controlled by regular clinical and radiographic monitoring to prevent the complications of overstretching and understretching.

Acknowledgments
My thanks to Drs. K.V. Chaubal, Bhandare, Chawra, Vaishnav, and Shahane and to others who displayed confidence in me and my team for permitting us to treat their cases. My special thanks to Dr. Vaishnav for making the slides and to Dr. N.S. Laud, who allowed free treatment for many of the cases at his clinic.

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Correction of Clubfoot Deformity Without Osteotomy by the Use of the Ilizarov Method

F. Grill

Correction of clubfoot deformity using the Ilizarov technique can be performed with and without the use of osteotomies.[1] The nonosteotomy method involves slow progressive correction through the joints and soft tissues of the foot. Even very severe complex deformities, such as relapsed and neglected clubfeet, can be corrected.[7,8] The modular apparatus allows the surgeon to build a frame around the foot. Its circular nature and its versatile small parts allow correction of flexion, extension, adduction, varus, supination, and equinus at the same time.[1,7,12,14] Simultaneous correction of the clubfoot and lower leg shortening is also possible. Posttraumatic clubfeet caused by partial growth arrest is a special indication for the use of the Ilizarov distractor. With the distractor, a disruption of a physical bar by gradual distraction is possible.

In adults, however, the nonosteotomy method has a higher risk of recurrence because of definite bone deformations. This method is contraindicated in cases with distinct shortening of the foot. According to Ilizarov, foot elongation should be performed only after osteotomy, which is followed by guided corrective distraction of callus formation.

The Ilizarov method thus is a viable alterative to a major operation such as wedge osteotomy, V osteotomy, or triple arthrodesis, which usually result in further shortening of the foot.[2–6,9–11,13,15] The Ilizarov method, however, should be reserved for complicated cases and should not replace approved surgical procedures, especially in children between birth and 6 years of age.[2–6,9–11,15]

Materials and Method

Basically, it is necessary to differentiate between a uniplane correction, a triplane correction, a correction with or without osteotomy, and a correction combined with a lengthening procedure.

Twenty feet in 18 patients were treated between 1980 and 1990. There were 11 boys and 7 girls, ranging in age from 7 to 16 years. All had severe deformity and were strongly motivated to undergo treatment. Thirteen children had neglected or relapsed CTEV; three had posttraumatic deformity; one was a case of bilateral arthrogryposis; and one case had an equinocavovarus deformity secondary to peripheral

neuropathy (Charcot-Marie-Tooth disease). A leg length discrepancy was diagnosed in five patients and corrected simultaneously. Fifteen of the 18 patients had an average of two operations; the mean follow-up was 5.4 years.

Technique

The nonosteotomy technique described in this paper consists of inserting a pair of crossed wires through the 1st and 5th metatarsals distally and another pair of crossed olive wires through the calcaneus. Crossed olive wires are better than nonolive wires because they prevent medial migration of the foot from its central position in the apparatus during lengthening. When only the 1st and 5th metatarsals are fixed by Kirschner wires, this may eventually lead to distraction of only the first and fifth rays. For this reason, in severe cases an additional olive wire should be inserted laterally through the proximal metatarsals. At this level it is possible to fix all five metatarsals with one wire, thereby creating a very stable fixation of the forefoot. A wire fixation through the talus is necessary only when an osteotomy is performed. The two pairs of wires are inserted into the tibia at different levels to achieve stability for the foot construct. The metatarsal wires are fixed to a half-ring, the calcaneus wires to a $\frac{5}{8}$-ring; the tibial wires are fixed to two connected half-rings at each level and connected by three rods.

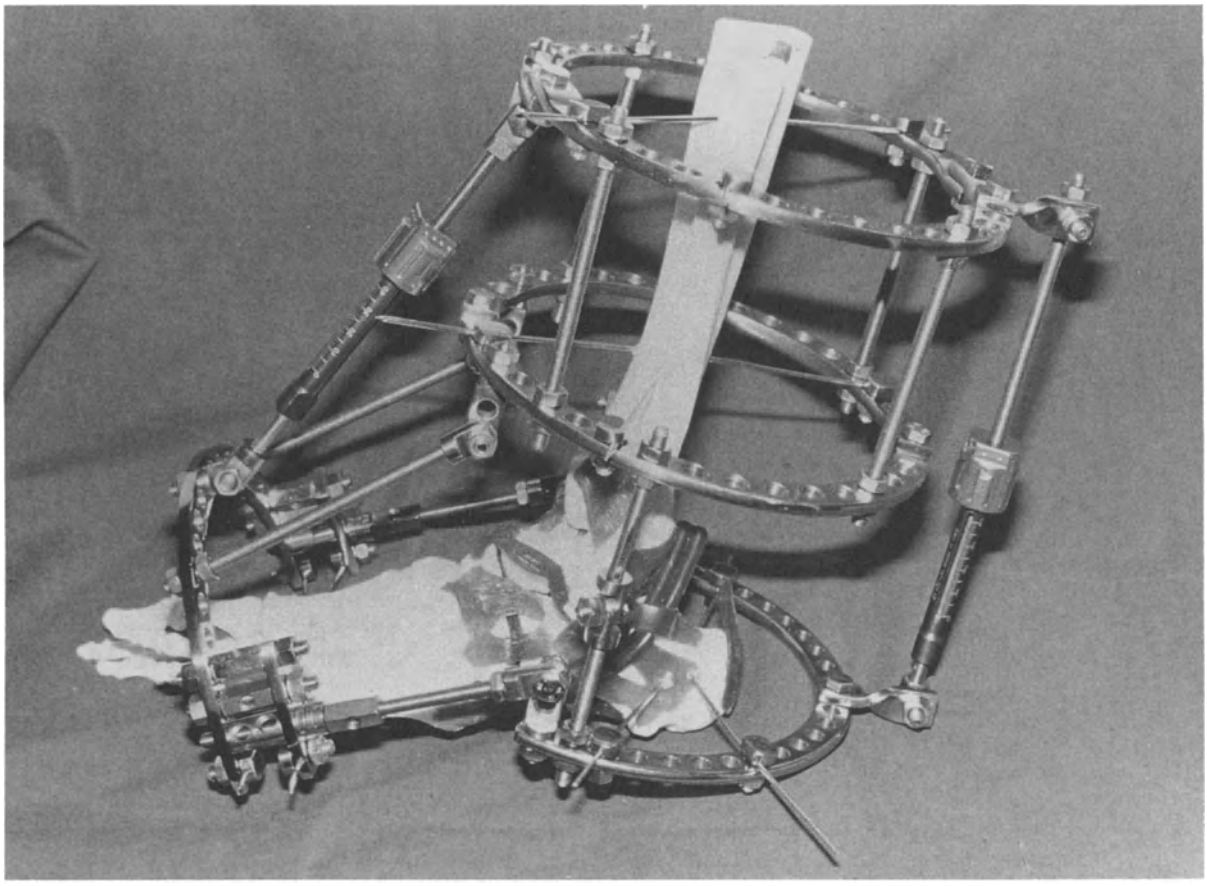


FIGURE 10.13. A frame has been placed around the foot and the Ilizarov device has been attached to the foot. Wire fixation has been inserted through the calcaneus and metatarsals with hinges at the level of the ankle joint for equinus correction, and hinges at the level of Chopart's joint for distraction of the forefoot. Thus, three-dimensional correction is possible.

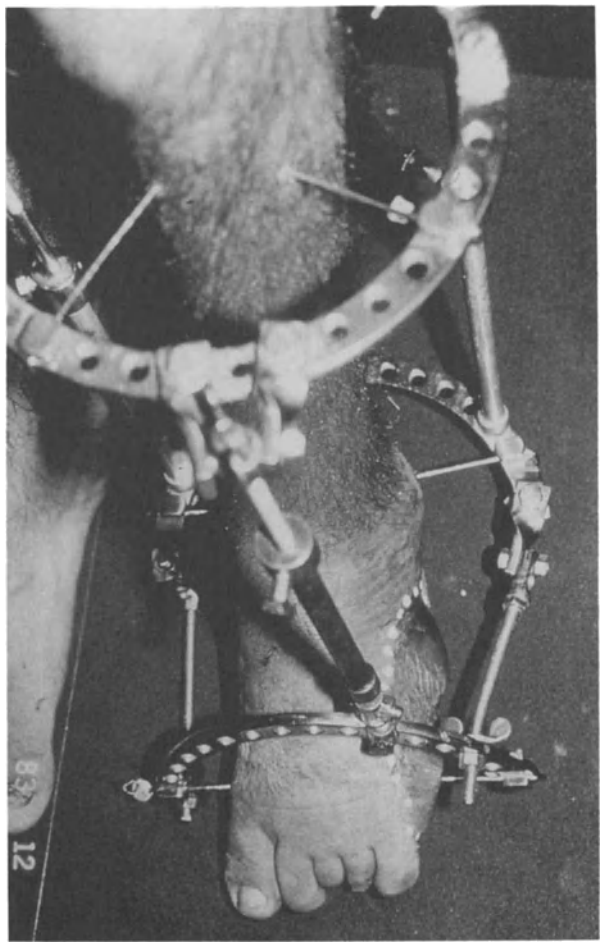


FIGURE 10.14. Severe relapsed clubfoot in a 15-year-old boy is shown in the apparatus after correction has been achieved. This early construct was less sophisticated and very simple, but effective. Note the eccentric position of the anterior bar, which is used to correct equinus and varus.

The calcaneal $\frac{5}{8}$-ring is connected with the distal tibial ring by two rods with hinges medially at the level of the ankle joint and with a distraction rod posteriorly. The connection with the metatarsal half-ring is performed by two threaded rods, which are fixed on triplane hinges to allow correction of adduction and supination.

From the anterior aspect of the tibial ring, a hinged bar is connected to the metatarsal ring in an eccentric lateral position to correct forefoot varus (Figures 10.13 and 10.14).

A more stable construct consists of four threaded rods connecting the midfoot and the metatarsal ring. Two of these rods are connected with the calcaneal ring and two with the lower tibial ring (Figure 10.13). Nevertheless, sometimes it is impossible to mount the fixator unless preliminary soft tissue surgery, e.g., a Steindler plantar fasciotomy, is performed.

Flexion contractures of the small toes and flexion, extension, or varus deformity of the large toe should be treated either during correction by open tendon lengthening or following the osteotomy.

Distraction begins 2 to 3 days after application of the device. Forefoot adduction is corrected by simultaneous distraction of 1 mm per day on the medial side and 0.5 mm per day on the lateral side. Thus, the foot is stretched both medially and laterally. The equinus position is corrected by distraction between the tibial and calcaneal rings and shortening of the anterior bar between the tibial and metatarsal rings until the foot is in 10° of dorsiflexion. This anterior bar is located lateral to the center of the

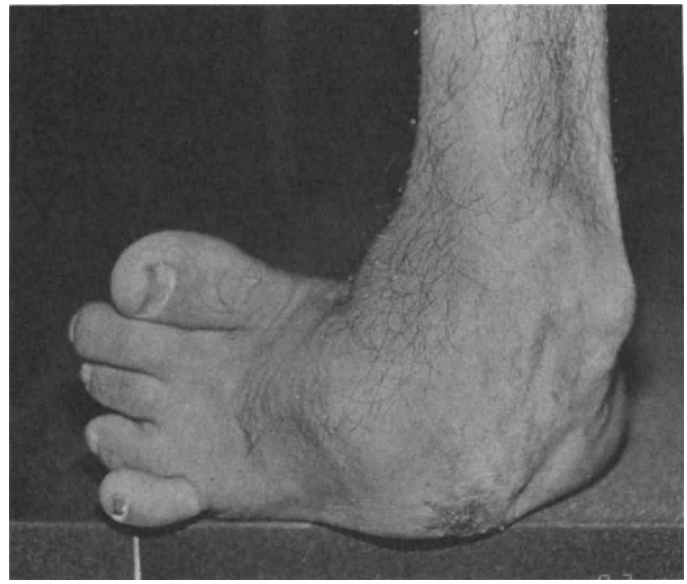
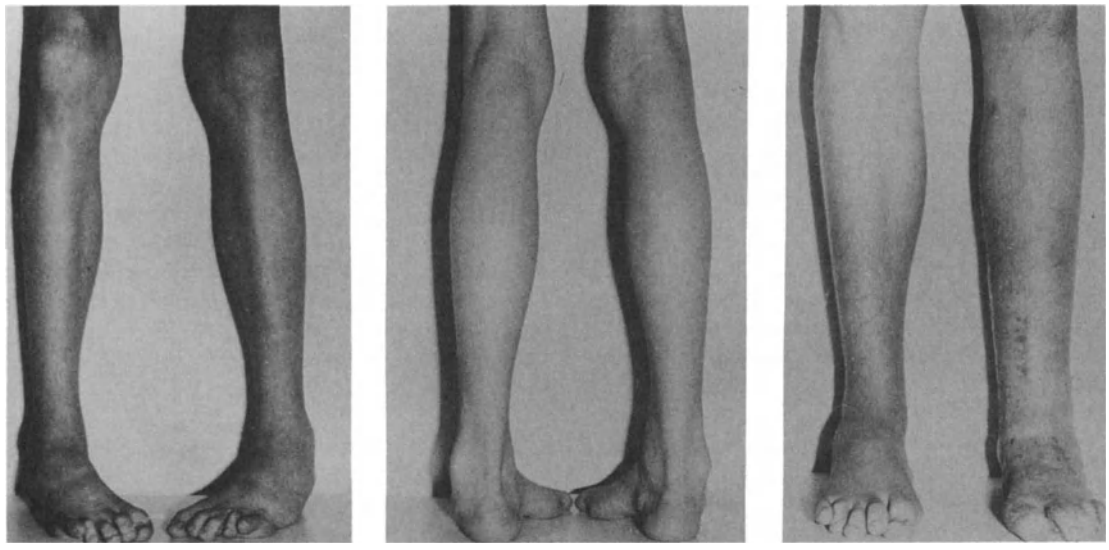


FIGURE 10.15. The same foot as in Figure 10.14 before placement in apparatus.

metatarsal ring so that it can also be used to correct forefoot supination (Figure 10.14).

The duration of correction depends on the deformities and varies from 4 to 10 weeks. During correction, the apparatus must not hinder full contact of the foot with the ground; thus, it is important to allow the patient to walk with specially fitted sandals. Weight-bearing is allowed and, when correction is complete, the device is retained in a fixed position for another 8 to 10 weeks. After removal of the Ilizarov device, the limb is immobilized in a



A B C

FIGURE 10.16. Patient with Charcot-Marie-Tooth disease. Before and after correction with an Ilizarov device and soft tissue surgery by tibialis posterior transfer through the interosseous membrane. A and B: Precorrection. C: Postcorrection.

full-leg plaster cast for 3 months to prevent relapse (Figure 10.16). Daily active and passive exercises of the toes are recommended during the distraction period to avoid contractures.

Very often a simultaneous foot and leg length correction must be performed. This involves the additional rings and wires at the distal tibial level.

Results and Complications

Treatment had to be discontinued in two patients because of pain and very severe lymphedema in the forefoot. There were no cases of skin necrosis, or sensory or motor disturbances of the foot. A plantar grade foot with a satisfactory radiographic appearance was thus achieved in all but two of the 18 patients. All feet showed stiffness of the subtalar and tarsal joints, and the average range of motion at the ankle was 20°. However, previous surgical intervention and osseous adaptation to long-standing deformities are major contributing factors to the limitation of motion. It is important to emphasize that mobility of the ankle, subtalar, and midtarsal joints cannot be improved by this method.

Ten patients required additional soft tissue surgeries, such as tendon lengthening and tendon transfer; four required osseous surgery, such as supramalleolar rotation osteotomy, supramalleolar wedge osteotomy, and triple arthrodesis. All but two patients were satisfied with the result and, for the first time, were able to wear ready-made shoes.

Discussion

The Ilizarov method is a new approach in treatment of clubfeet. It permits simultaneous correction of all components of the deformity. Furthermore, it is unnecessary to wait for the completion of skeletal growth. The nonosteotomy technique does not damage bone; it works by gradual stretching of soft tissues, especially ligaments and joint capsules. Due to this gradual distraction, the shape and form of severe deformities can be corrected and even the tarsal bones can partially adapt to the new position. This method offers a new horizon in the correction of very difficult deformities of the foot. It is no longer experimental. Several recent publications have also reported good results with this technique.[7,8,12,14] Thus, we should consider this technique for use in the treatment of severely deformed, relapsed clubfeet.

Summary

Current methods of treating relapsed and neglected clubfeet between the ages of 6 and 13 years are unsatisfactory. Correction by triple arthrodesis is not possible before the end of skeletal maturation. Because of this, we have used the Ilizarov external fixator to correct all components of clubfoot simultaneously by continuously guided distraction without osteotomies. Twenty feet in 18 patients were treated by this technique. A plantar grade foot was achieved in all but two cases. Complications included two cases of severe lymphedema and two relapses, which were successfully treated by a second procedure.

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The Ilizarov External Fixator in Severe Foot Deformities: Preliminary Results

M.A. Cantin, F. Fassier, B. Morin, K. Brown, and M. Rosman

Hippocrates was the first to advocate orthopedic treatment of the idiopathic clubfoot by gentle manipulation and bandaging. According to Turco,[28] manipulative treatment leads to a 35% success rate, whereas surgery is the method of treatment in about 65% of idiopathic talipes equinovarus feet (CTEV).[12,17–19]

Regardless of early and adequate surgery, the failure rate in the best series remains as high as 20%.[5,7,12,14,20,25,26] When facing complex congenital foot deformities, this rate of failure is even higher.

In the relapsed clubfoot and complex foot deformities, the recommended treatment will include repeated soft tissue procedures, osteotomies, bony resection, or arthrodesis. Although a satisfactory and permanent correction can be achieved, these salvage procedures correct only one deformity at a time. They are preferably performed at skeletal maturity and often produce a short stiff foot. By progressive soft tissue stretching, the Ilizarov external fixator seems to avoid the above problems, allowing a simultaneous three-dimensional correction at an earlier stage without the need for bony resection or fusion.

The few guidelines available in the present literature suggest that the technique must be reserved for children older than 3 years of age with severe residual deformities.[8] It should never replace the standard procedures.[8,10]

To evaluate the ability of this technique in giving adequate and permanent correction and to identify the indications, limits, and complications of the procedure, we reviewed all cases of foot deformities treated by the Ilizarov external fixator in our institutions.

Materials and Methods

Between March 1988 and March 1990, 13 children (14 feet) were treated by the above technique at both STE-Justine Hospital and Shriner's Hospital for Crippled Children in Montreal for severe foot deformities by the above technique.

There were 10 boys and 3 girls. The mean age at surgery was $9\frac{1}{2}$ years, varying from between $2\frac{1}{2}$ and $16\frac{1}{2}$ years of age. All patients had several previous surgeries (mean 3). The patients were divided into two groups according to their pathology. The first group included eight idiopathic clubfeet (CTEV) (Table 10.1) and the second group six feet (in 5 cases) with

TABLE 10.1. Group 1: idiopathic clubfoot.

Case no.	Sex	Age	Side	No. of previous operations	Clinical features
1	F	$11\frac{1}{2}$	L	5	Equinovarus/cavus
2	M	7	L	8	Equinovarus/adductus
3	M	10	R	2	Equinovarus/adductus
4	M	$6\frac{1}{2}$	R	3	Equinus/adductus/cavus
5	M	$11\frac{1}{2}$	L	7	Equinus/cavus
6	M	7	L	2	Equinovarus/adductus
7	M	$9\frac{1}{2}$	L	4	Equinovarus/adductus
8	M	$14\frac{1}{2}$	R	6	Equinus/rocker-bottom

TABLE 10.2. Group 2: complex congenital foot deformities.

Case no.	Sex	Age	Side	Etiology	No. of previous operations	Clinical features
1	M	8	R&L	Diastrophic dwarfism	1	Equinovarus
2	F	9	L	Spinal dysraphism and congenital high arch foot	2	Equinus/cavus Adductus/supinatus
3	F	$6\frac{1}{2}$	L	Arthrogryposis	2	Equinus/cavus Adductus/supinatus
4	M	$2\frac{1}{2}$	R	Incomplete para-axial tibial hemimelia (type 4)	1	Equinovarus Supinatus
5	M	$16\frac{1}{2}$	R	Vertical talus	0	Rocker-bottom

complex congenital foot deformities (CCFD) (Table 10.2).

The preoperative assessment included clinical and radiographic evaluation. In most patients the frame of the fixator was preconstructed for the patient's foot the day before surgery. In some cases, a plastic molding of the involved foot was made,[23] from which the Ilizarov frame was built.

Under general anesthesia the tibial frame is fixed to the leg with two wires under tension on each ring. Following this, the "horseshoe" hindfoot frame is secured to the calcaneus by two oblique wires and then connected to the tibial frame by two hinges centered on the ankle joint. The forefoot frame, consisting of either a half or a full ring, is fixed to the distal metatarsals by two wires under tension. Finally, the hindfoot frame is connected to the forefoot frame by either plates or rods. Progressive correction is obtained by a distracting device mounted on the posterior aspect of the frame between the tibial and the hindfoot frame, while a compression system links the forefoot and tibial frame from the front (Figures 10.17 and 10.18).

The surgical procedure varies according to the deformity, stiffness of the foot, and age of the patient. In 11 cases, the Ilizarov frame was used alone, and the fixator was associated with soft tissue release in one case, tibial lengthening in one case, and calcaneal osteotomy in another case.

Partial weight-bearing was allowed, although patients frequently refused.

The duration of correction varied between 5 days and 5 months with a mean of 7 weeks. The number of adjustments required varied between 1 and 14 (mean 3). After removal of this frame, a walking cast was applied for a period varying from 2 to 8 weeks, later replaced by an ankle-foot orthosis.

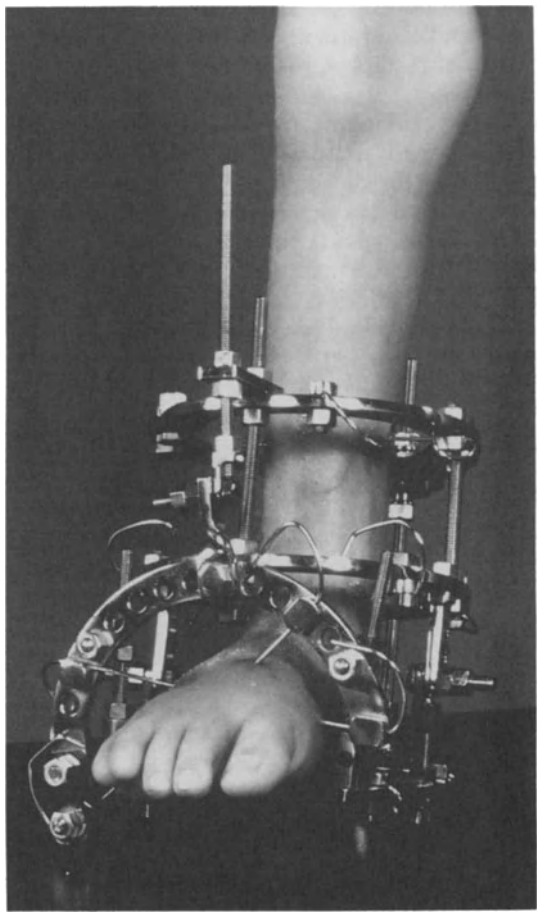


FIGURE 10.17. Front view of Ilizarov apparatus.

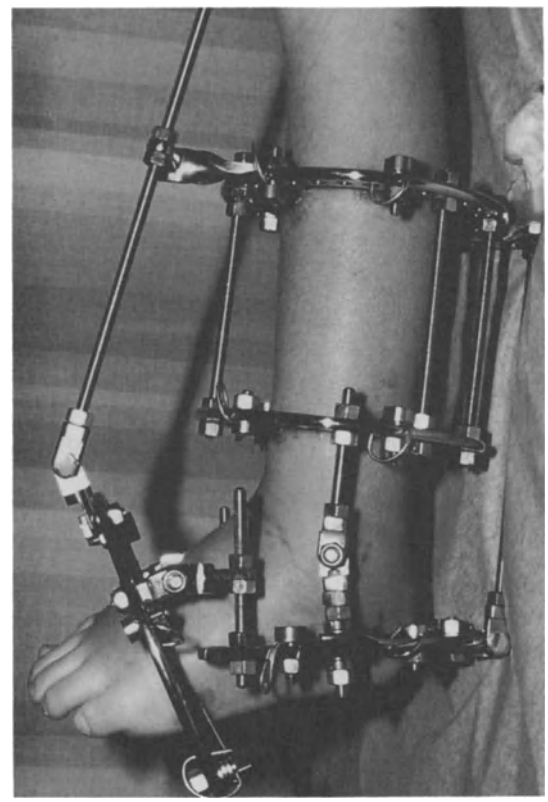


FIGURE 10.18. Lateral view of Ilizarov apparatus.

Results

All patients were reexamined by an independent observer after removal of the frame and cast. The follow-up period varied between 6 and 26 months (mean $10\frac{1}{2}$ months).

The postoperative evaluation was based on the clinical appearance as described by Garceau.[6] At the end of the correction, all feet were plantar grade in both groups. At follow-up, all eight CTEV showed a good or excellent appearance, whereas in the CCFD group results varied: one was good, one was fair, and four were considered as failures, due to a moderate or marked loss of correction.

The most common surgical complications included pin tract infection, dysesthesia, pain, and skin stretching ischemia. There were no major complications such as osteomyelitis, paralysis, or vascular problems. Four feet required additional operations including one posteromedial release, one tendon transfer, and two metatarsophalangeal arthrodeses of the first ray.

Discussion

Dealing with the treatment of relapsed idiopathic clubfeet and complex congenital deformities, the orthopedic surgeon faces major problems resulting from previous surgeries: these include abundant scar tissue, a risk of neurovascular and skin compromise, and residual bone and joint deformation—all factors limiting the extent of the final correction. Moreover, in many patients, bone resection or fusion will be needed to improve the clinical appearance of the foot, leading to a stiff and shortened foot.

The basic advantages of the Ilizarov method is the progressive stretching of soft tissues and

neurovascular structures, allowing significant correction with fewer risks of neurovascular or skin compromise. In younger patients, after foot correction, bone and cartilage remodeling can be expected, which helps to maintain a lasting correction.

Reports in the literature of the Ilizarov method when used for multiple deformities in CTEV[10,11,21] have demonstrated variable results. Grill,[10] reporting on 24 feet treated with a comparable technique, achieved a complete and persistent correction in 21 out of 24 feet (87.5%). Paley,[21] reporting on 20 patients, mentioned that "goals were achieved in all cases with universal satisfaction." In our series, a plantar grade foot was achieved in all patients, but maintained in only 9 out of 14 feet (64.3%). Comparing our results with previous reports,[10,11] our higher rate of failure was related to two factors. First, we found a significant difference in the etiology of the deformity treated by the Ilizarov method, our series including more complex congenital foot deformities. The second factor was the time of immobilization after the end of correction, being half the time reported in the previous studies.[10,11] Although overcorrection of the foot seems desirable, we were not able to correlate any failure to a lack of overcorrection.

Conclusion

Our preliminary results indicate that the Ilizarov technique represents an attractive alternative to invasive surgery for the relapsed idiopathic clubfoot, although its application to the complex congenital foot deformity remains questionable.

The Ilizarov technique has some advantages over the conventional methods. It achieves a three-dimensional correction in the skeletally immature foot. Moreover, if a residual deformity persists, it can allow a later arthrodesis in a better position without extensive bony resection. A plantar grade foot can be obtained but only a long-term follow-up study will help to determine the optimal age for surgery, as well as the long-term functional results.

Summary

The Ilizarov external fixator was used as a distraction device, but generally without the use of osteotomies, for the correction of severe, neglected, and recurrent clubfeet. Although excellent results were achieved in the congenital talipes equinovarus, much less satisfactory results were achieved in the second group of patients with complex congenital foot abnormalities. The device offers an alternative to conventional surgery and has several significant advantages. Although the technique has been successful in the older child with clubfoot, its use in the young child under 3 years of age is not recommended at this time.

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Complex Foot Deformity Correction Using the Ilizarov Circular External Fixator with Distraction but Without Osteotomy

D. Paley

The Ilizarov device is an effective method for correcting clubfoot deformities because the technique permits simultaneous correction in all three dimensions.[6] The Ilizarov method can be used to correct clubfeet in two ways: as a means to distract the soft tissues alone or in conjunction with osteotomies. When the Ilizarov is used to distract soft tissues, correction occurs through the elimination of contractures and by establishing new positions of the joints that result in a plantar grade position.[2,3,5,8] Soft tissue release of this type is based on the view that cartilaginous bones can be remodeled. Distraction methods reshape bones by activating the circumferential physis of the affected bones.[7] The addition of osteotomies permits the growth of new bone, which accomplishes wedge-type corrections.[4,5,7,8] The joints remain undisturbed with the osteotomy distraction technique. Indications for the tech-

nique include (a) the age of the patient, (b) the presence of fixed bony deformities, and (c) stiffness of the foot.

Indications and Contraindications for Nonosteotomy Ilizarov Treatment

The primary criterion for selecting the nonosteotomy Ilizarov approach to clubfoot correction is the age of the patient. If the patient is under the age of 8 years, most deformities can be treated without osteotomy. Above the age of 8, patients are more likely to present with fixed bony abnormalities that require osteotomies. Occasionally, however, the surgeon may see a younger patient whose joints are so stiff that the nonosteotomy approach may result in physeal disruption rather than joint distraction. In such cases, it is advisable to chose an osteotomy approach. The other indications and contraindications are similar to those for any conventional approach to clubfoot surgery.[1]

Nonosteotomy Correction

The Ilizarov method can be used without osteotomies in two ways: with and without constraint. To implement the constrained approach it is necessary to identify the instant center of rotation of the joint contracture. Correction is focused on this single center of rotation. The unconstrained approach, by contrast, permits the contracture to correct itself through adjustments in soft tissue hinges and centers of rotation of the various joints.

The advantage of the constrained approach is that it is possible to disconnect the apparatus for active and passive exercises to maintain the range of motion. When the procedure focuses on a single "hinge" in the foot, the primary distraction rod can be connected and disconnected with ease, because it is relatively simple to reattach and calibrate. Hence, the constrained method is highly appropriate for treating the ankle. When the unconstrained approach is used, however, the whole system of fixation becomes unstable when the distraction rods are removed, and it is correspondingly much more difficult to reestablish the same positions and forces. In practice, this means that the entire apparatus must remain in position at all times, sacrificing the opportunity for joint mobilization and exercises to maintain the range of motion. The unconstrained approach, on the other hand, is simpler to apply and allows for some error in application because it does not focus on a single hinge in the foot. The constrained approach must be focused very carefully and within a quite narrow range of tolerance to avoid jamming a joint. The unconstrained approach is necessary when the treatment focuses on several joints and when the joints in question do not have clear focal centers of rotation.

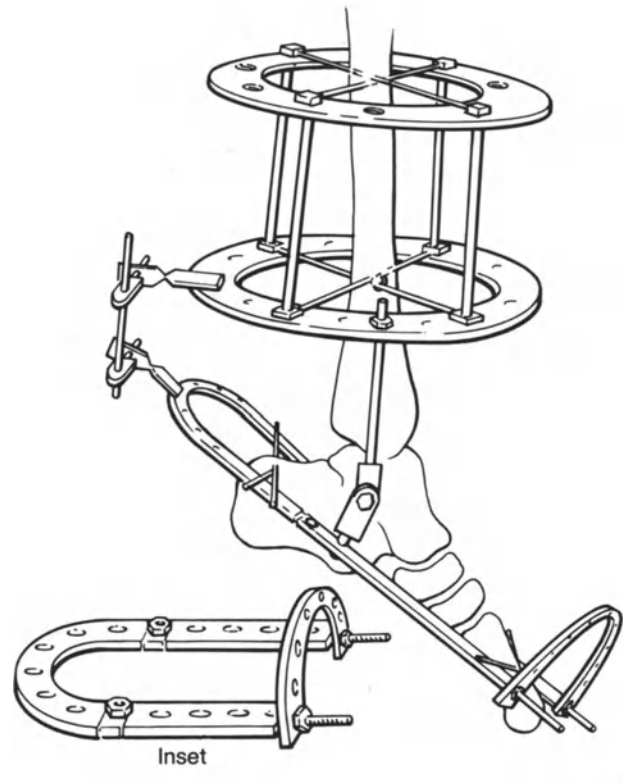
Equinus

The ankle joint can be treated by either the constrained or unconstrained method. The ankle's center of rotation is located at the level of the lateral process, with the axis of rotation extending laterally through the tip of the lateral malleolus and medially below the tip of the medial malleolus. It helps to recall that the joint surface of the ankle is a frustrum, a section of a cone, and that the center of rotation of a cone is not parallel to its outside surface. It follows that the ankle's center of rotation is not parallel to the tibial plafond, but rather the center is higher on the medial than on the lateral side.

Constrained Method (Figures 10.19 and 10.20)

An image intensifier is used to locate the ankle's center of rotation. Mose's circles are applied to a true lateral radiograph of the ankle to find the level of the center of rotation, which is usually within the lateral process. The procedure is as follows: Using the image intensifier, center the lateral malleolus over the midlateral tibia and then point to the center of rotation with a wire. Where the wire overlaps the region of the lateral process, mark a point on the skin. Repeat this procedure on the medial side, making sure that the image intensifier is perpendicular to the tibia. Application of the Ilizarov device proceeds in three steps:

1. Apply a preconstructed two-level frame to the tibia, using four wires, or two wires and one half-pin, to fix the tibial frame to the leg.
2. Suspend hinges from threaded rods



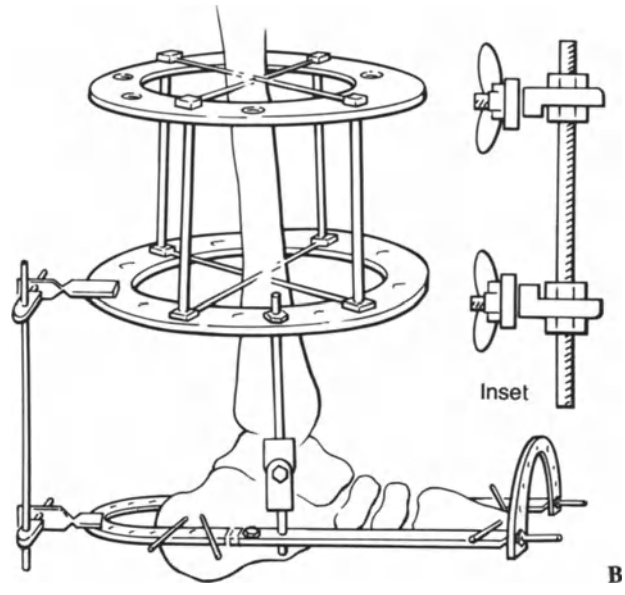
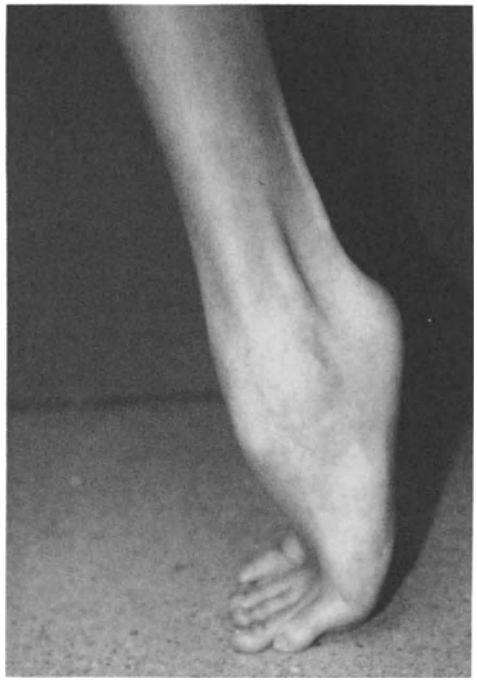


FIGURE 10.19. Ankle equinus deformity correction—using the constrained method. A: The apparatus is shown applied to the tibia and foot. The apparatus consists of a two-ring frame on the tibia and a foot ring on the foot. The two are articulated using a threaded rod and hinges. The hinges are applied medially and laterally so that they overlie the center of rotation of the ankle. The ankle joint can be distracted apart by the threaded rod end of the hinge so as to avoid crushing the joint cartilage. The foot ring consists of a half-ring and two plates with threaded rod extensions connected by an anterior half-ring perpendicular to the rest (inset). The distraction apparatus posteriorly consists of two twisted plates with a threaded rod distracting between two posts connected by a post or hinge, which is fixed to the twisted plate using wing nuts. This allows removal and reapplication with ease. Two wires are fixed on each of the tibial rings with an important olive wire placed anteriorly. Two wires are fixed to the calcaneus and two to the metatarsals. B: The distraction is performed at between 1 and 2 mm per day to the patient's tolerance level. Overcorrection of the equinus is achieved. The patient maintains range of motion during the distraction by removing the wingnuts of the posterior distraction rod (inset).

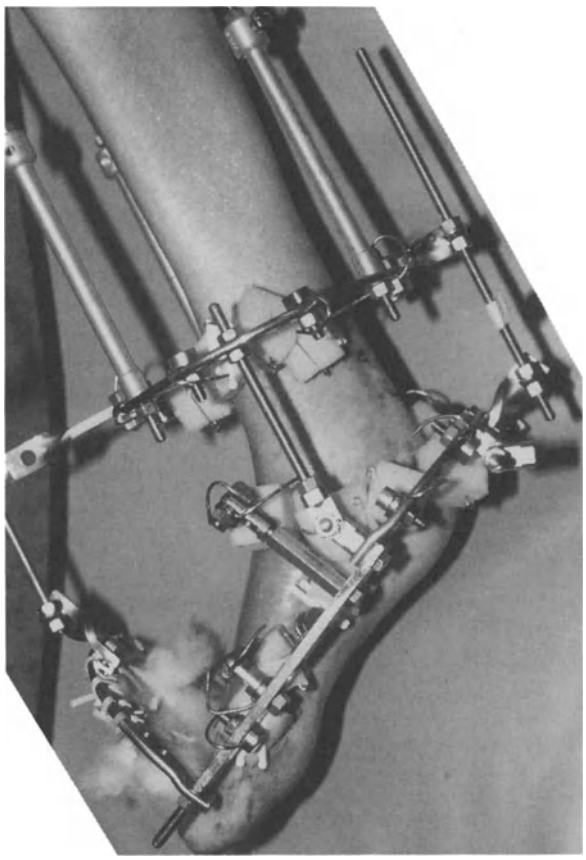


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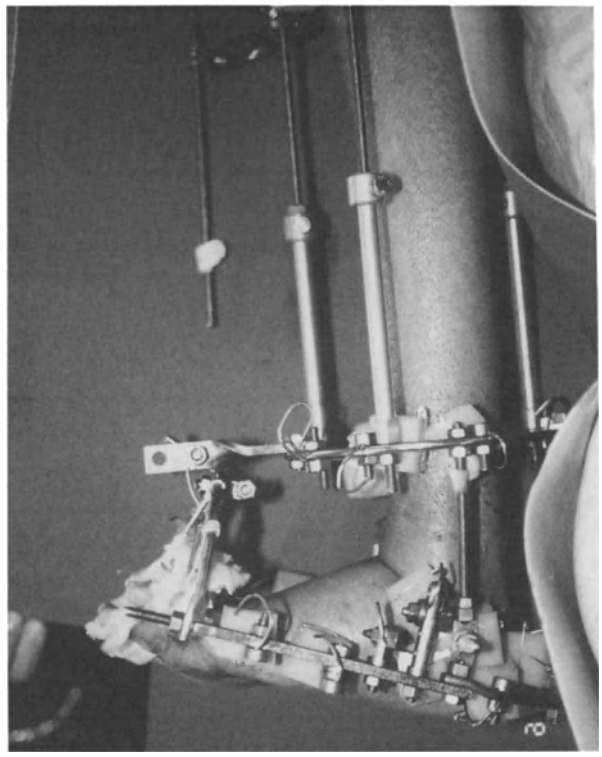


B

FIGURE 10.20. A and B: Lateral photograph (A) and radiograph (B) of the ankle without the apparatus in place, and (C) with the apparatus in place. Note that in this example a wire was inserted across the center of rotation of the ankle joint and connected to the hinges. This is another modification of the constrained technique. C: The apparatus is shown from the lateral view during correction. D: On the lateral radiograph at the end of overcorrection. E: After correction.



C

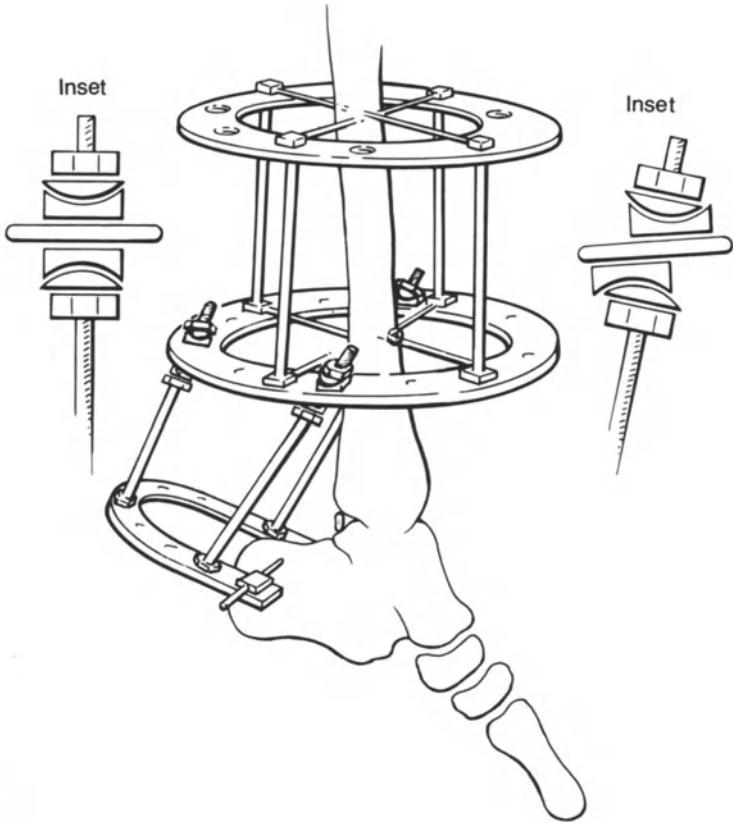


D



E

FIGURE 10.20 (cont.)



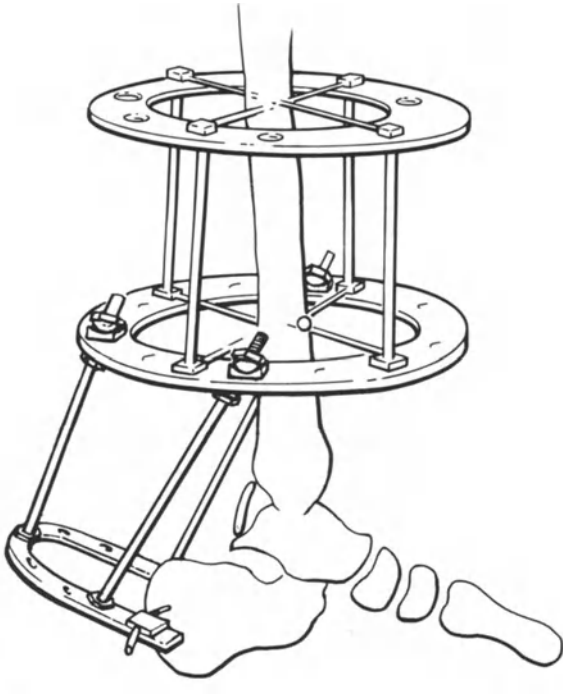
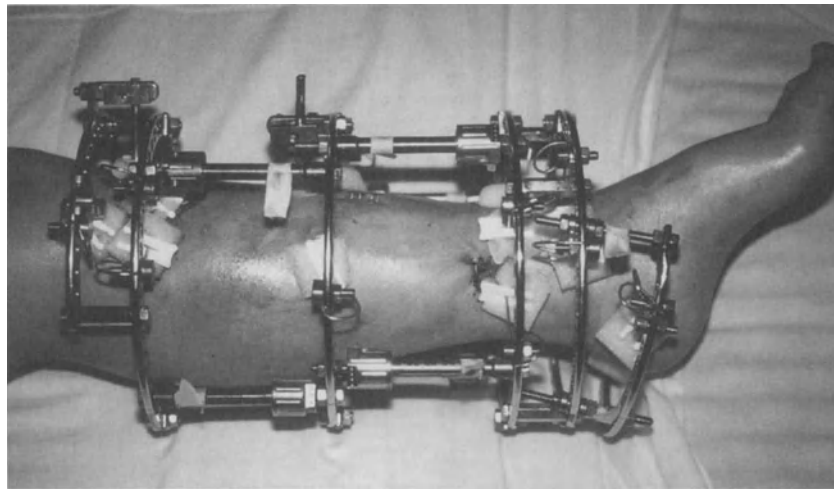
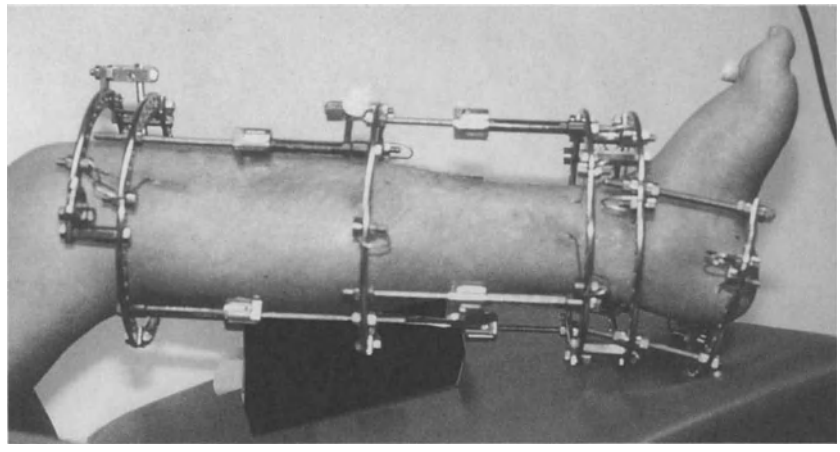


FIGURE 10.21. Ankle equinus deformity correction using the unconstrained technique. A: The unconstrained apparatus consists of two rings on the tibia and a half-ring in the heel. One- or two-wire fixation is used in the heel, whereas two wires are used on each of the tibial rings with an olive anteriorly on the distal ring. Three threaded rods are used to suspend the half-ring. These are fixed with nuts directly to the half-ring but are fixed with interposing conical washers on the distal tibial ring. This allows the half-ring to be tilted posteriorly by approximately 7° (inset). B: At the end of the correction, the foot has been distracted downward and posteriorly at a 7° tilt. This keeps the ankle in the mortise. Notice that the ankle capsule in the uncorrected position runs vertically from the posterior lip of the tibia to the back of the talus. In the corrected position, the ankle capsule is oriented with a posterior slope to it. This slope parallels the 7° direction of distraction. Note also that the ankle and subtalar joints are overdistracted. This method does not allow removal of the rods for exercise of the joints and, therefore, the overdistraction is important in maintaining a loose joint.



A

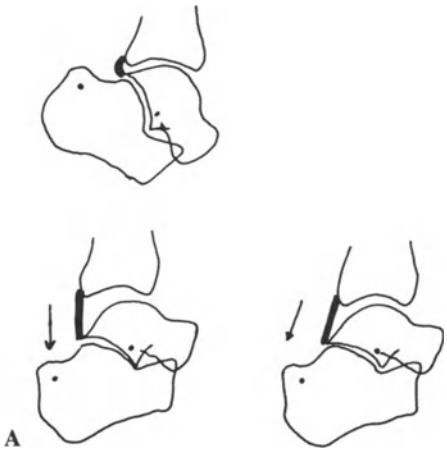


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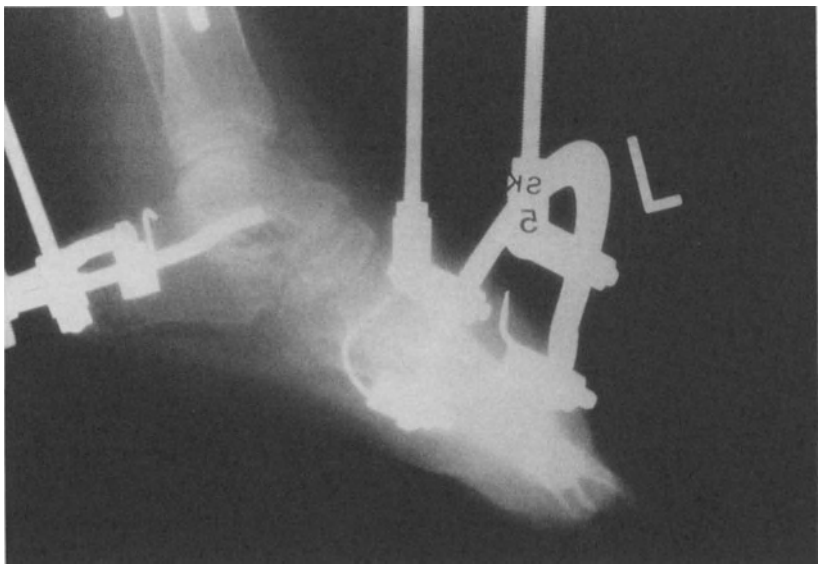
FIGURE 10.22. A clinical example is shown at the beginning of unconstrained equinus deformity correction combined with a two-level tibial lengthening (A). Note that the posterior heel rods are parallel to the tibia. Toward the end of correction note the position of the heel ring (B).

attached to the distal tibial ring. The hinges should overlap the ankle joint's center of rotation.

3. Attach the foot frame consisting of a heel half-ring with lateral plate extensions with an anterior half-ring to close the ovoid ring. The foot frame should be adjusted so that it is parallel to the plantar surface of the foot. It helps to place a board on the plantar surface and then make sure that the foot frame is parallel to the board. Next connect a distraction rod off two pivot points (such as a twisted plate) posterior to the central hole between the two hinges. Wing nuts are used



A



B

FIGURE 10.23. A: If distraction is performed in a pure axial direction perpendicular to the distal tibial ring and parallel to the tibia, then the ankle will tend to sublux forward. B: A clinical example of this phenomenon is shown at the beginning of distraction. C: Note the posterior heel rods are parallel to the tibia during distraction, causing anterior subluxation. D: After correction of subluxation.

on the posts to permit rapid removal and reapplication. A patient can combine distraction with removal of the distraction rod during exercise and rehabilitation.

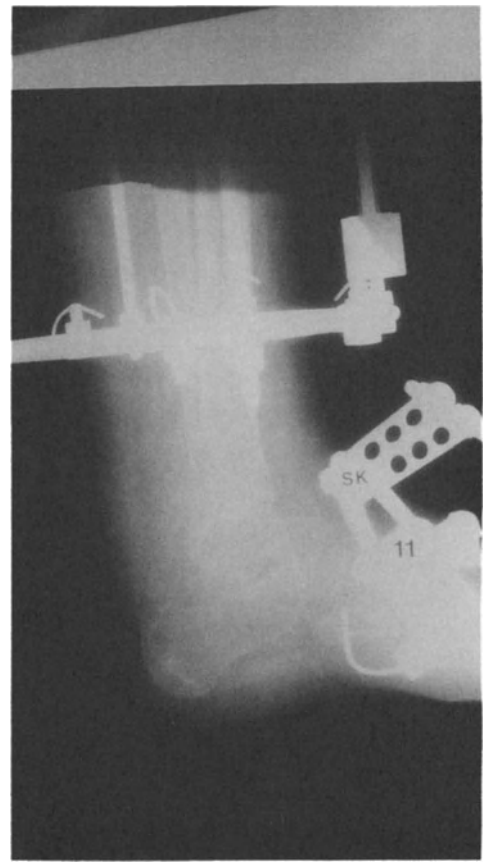
Unconstrained Method (Figures 10.21–10.23)

The unconstrained approach to ankle joint correction begins with the same tibial base of fixation as the constrained approach, but the foot frame is much simpler. The foot frame consists of a half-ring suspended from three threaded rods that are locked perpendicularly to the heel ring by nuts at their distal ends, using conical washers at their proximal ends to allow a posterior tilt of 7°. The half-ring is positioned in place at that angle. Two smooth wires are inserted through the heel and fixed and tensioned to the ring. Correction proceeds by distraction forces applied on all three rods, pulling the heel distally.

The rods are tilted posteriorly because the ankle capsule in equinus runs straight from the back of the talus to the posterior lip of the tibia, whereas in a plantar grade position the capsule is sloped posteriorly. Tilting the rods posteriorly pulls the capsule in the right direction and keeps the talus in the mortise. If the rods, by contrast, were parallel to the tibia, distraction would pull the ankle capsule distally and force the talus anteriorly out of the



C



D

FIGURE 10.23 (cont.)

mortise, since the back of the mortise is not allowed to go posteriorly.

Varus (Figures 10.24 and 10.25)

Heel varus is corrected by the same kind of device used for unconstrained correction of equinus, with the exception that an olive wire is used on the medial side. The threaded rods are connected through intermediary hinges. The posterior threaded rods are connected to a three- or four-hole hinge with the point of the hinge proximal to the level of the heel wire. By this means, as the medial side is distracted, it will pivot around the hinge, translate laterally, and pull the heel out of varus. The medial and lateral rods are connected either to a distal hinge distally with conical washers or to twisted plates that have pivot points at both ends, or some mixture of hinges and twisted plates. The choice of connector is determined by the degree of deformity. Since conical washers can only accommodate a 7.5° tilt in either direction, hinges are sometimes preferable. Correction is produced by asymmetric distraction of all three rods. The medial rod is typically lengthened in five $\frac{1}{4}$-mm increments per day, the middle rod in three $\frac{1}{4}$-mm increments, and the lateral rod in one $\frac{1}{4}$-mm increment per day. This gradual approach protects the joint surfaces from crushing pressures.

Equinovarus

Equinovarus deformity is corrected in the unconstrained technique by combining the strategies used to correct equinus and varus. Greater stress is placed on the olive wires in the tibial construct, since they must resist both the equinus and varus distractions. To cope

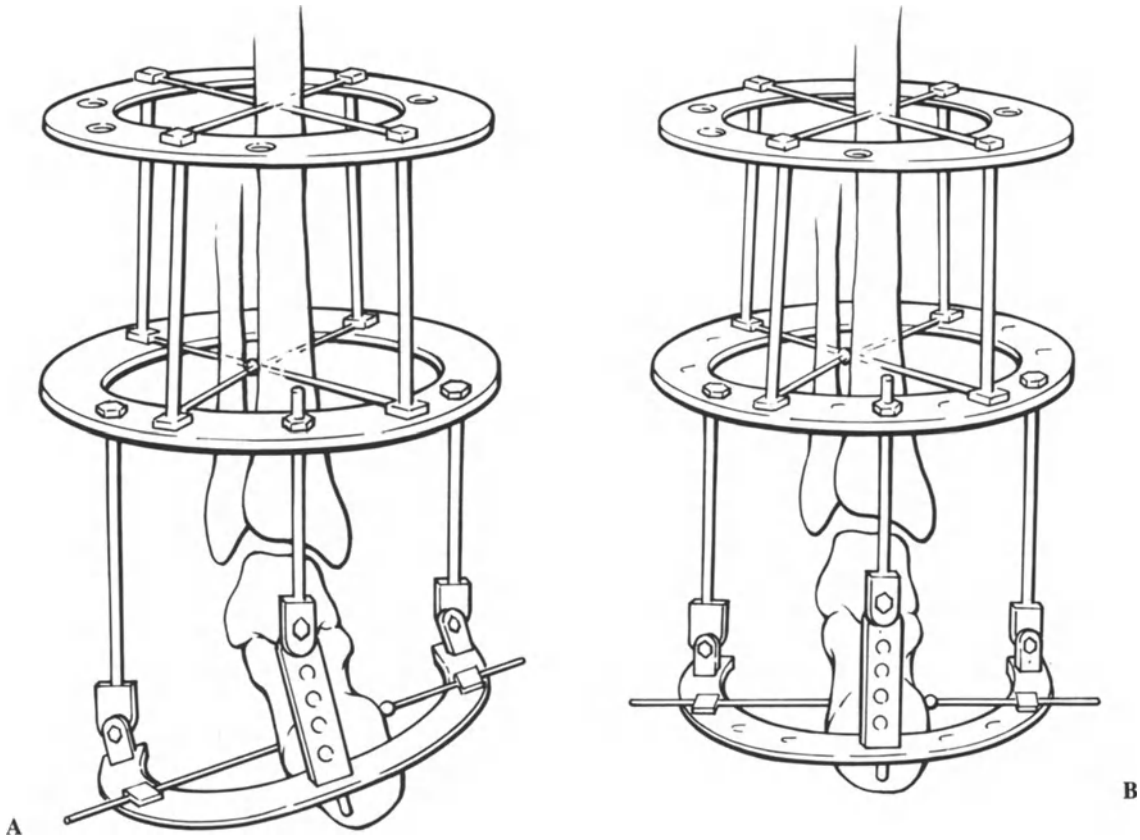


FIGURE 10.24. A: The construct for correction of varus deformity is shown from the posterior view. This utilizes the standard two-ring fixation on the tibia with two wires at each level and one with an olive placed laterally. One hinge is used medially and one laterally on the half-ring. The main hinge is posterior and utilizes a three- or four-hole post to raise it above the level of the other two, so that it is closer to the center of rotation of the subtalar joint. The level of this hinge also serves to force the olive on this half-ring against the body of the calcaneus in order to correct the varus deformity. B: At the end of correction the rings are parallel and the contracture of the subtalar joint is reduced.

with these stresses, an anterolateral olive wire is used distally as a medial face wire and a posteromedial olive is placed proximally as a medial face wire. An olive wire in the heel pulls the foot out of varus. The heel ring is tilted 7° in equinus to resist anterior translation and tilted the number of degrees of varus that appear necessary. The varus tilt is managed by the distal portion of the half-ring, whereas the equinus tilt is managed by the conical washers on the tibial ring. Typically, the daily distraction rates are five $\frac{1}{4}$-mm increments on the medial rod, four $\frac{1}{4}$-mm increments on the posterior rod, and three $\frac{1}{4}$-mm increments on the lateral rod.

A constrained approach may also be chosen. The constraint described for treating equinus is used, but varus complicates the location of the hinges. It is possible to accommodate for limited varus by placing conical washers proximally. Large amounts of varus require a biplanar hinge, which is made of two half-hinges set at 90° to one another. Universal hinges are preferable if they are available and should be oriented to provide maximum accommodation for the correction of varus. A distraction rod is placed posteriorly with a biplanar hinge distally and uniplanar pivot hinge proximally.

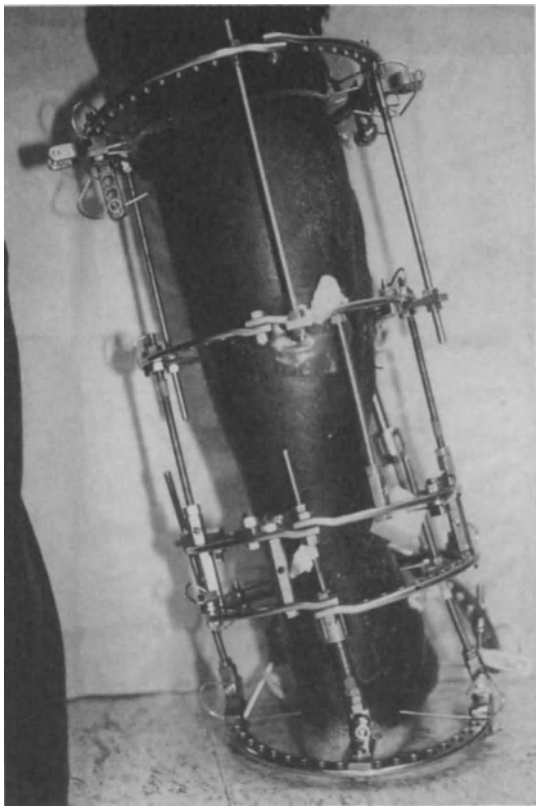
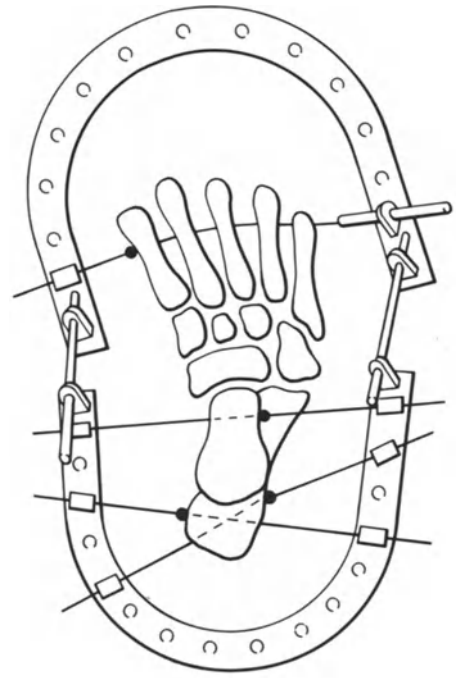
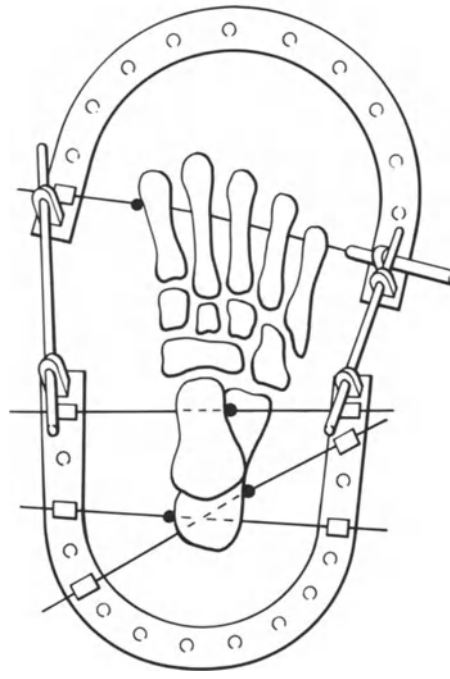


FIGURE 10.25. The posterior view of the construct that was discussed in FIGURE 10.24.

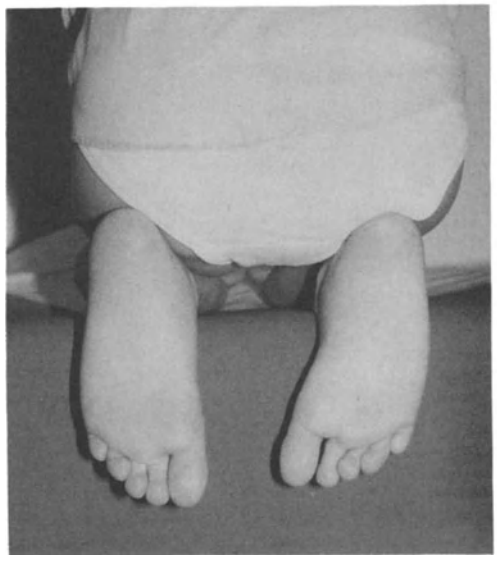


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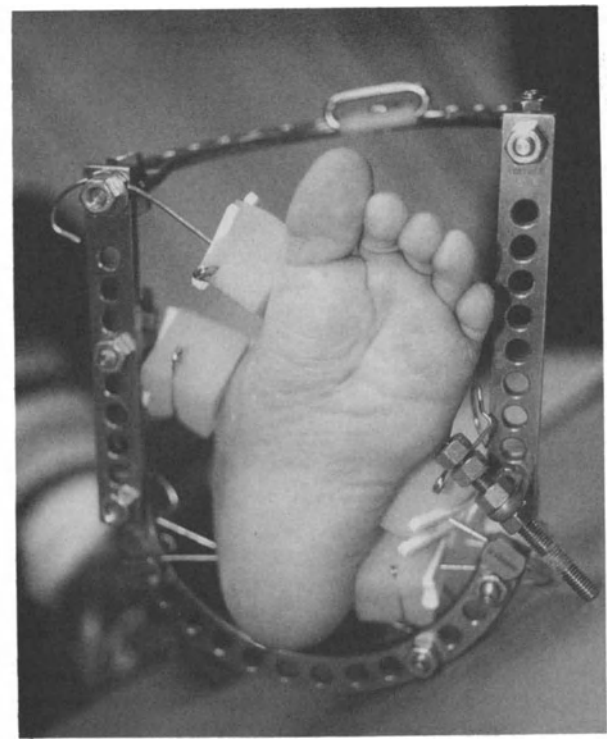


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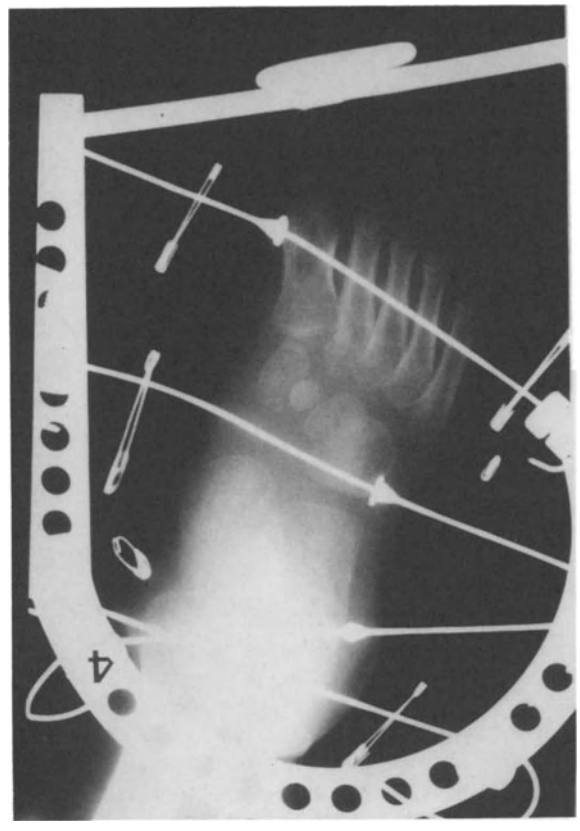
FIGURE 10.26. A: Adductus deformity correction is performed using a half-ring for the forefoot and one for the hindfoot, articulated by threaded rods suspended off of posts. Two olive wires are fixed into the calcaneus with olives on either side; one olive wire into the talus with an olive on the lateral side and one olive into the metatarsals with an olive on the medial side. This forms a three-point bending mechanism in which the midfoot and forefoot are distracted away from the fixed hindfoot. The distraction is produced by the threaded rods connecting the two half-rings and by a translation mechanism in the form of a slotted threaded rod that is connected to the distal wire. Notice that the medial edge of the distal wire is fixed using a buckle onto the half-ring to allow it to slide as the translation of the metatarsals is carried out. B: At the end of the correction, the metatarsals are realigned and even overcorrected into abductus. The 5th metatarsal lies closer to the ring. The distal wire passes through the 1st and 5th metatarsals only, going under the 2nd, 3rd, and 4th metatarsals.



A



B



C



D



E

FIGURE 10.27. A: A clinical example of a 9-year-old boy with a persistent metatarsus adductus and a skew foot despite previous casting. B: The foot is shown in the apparatus during treatment. C: The radiograph at the end of treatment showing overcorrection. D: The clinical appearance of the foot at 1-year follow up. E: The standing radiograph of the foot at the end of treatment (right), compared to pretreatment (left).

Adductus (Figures 10.26 and 10.27)

Adductus can be corrected by means of a single elliptical frame connecting the hindfoot and the forefoot. This ellipse is formed by two half-rings connected by threaded rods. The calcaneus is locked by two olive wires, one lateral wire that extends across the neck of the talus (or the navicular and cuboid) and another medial wire that extends from the medial aspect of the first metatarsal through and into the 5th metatarsal. This metatarsal wire actually goes under the 2nd, 3rd, and 4th metatarsals. A slotted threaded rod connected to the distalmost wire slowly pulls the forefoot into a more lateral position. At the same time, the medial column is distracted at a faster rate than the lateral column: fully 1 mm per day medially and $\frac{1}{4}$ mm per day laterally.

Cavus (Figures 10.28–10.30)

The Ilizarov device can be used in many ways to correct cavus. Cavus should be corrected either after or simultaneously with the correction of equinus. The simplest device is a single half-ring placed anteriorly and another posteriorly with distraction between them. One wire in the heel and one in the forefoot provide sufficient fixation. If there is a need to overcorrect cavus, a wire should be placed at the apex of the deformity, either in the neck of the talus or at the naviculocuboid row. Alternatively, the tibia can be used as a base of fixation, with the device pulling up the forefoot with respect to the hindfoot. With the latter construct, the midfoot wire is essential to prevent pressure on the ankle joint.

Clubfoot (Figures 10.31 and 10.32)

Correction of the clubfoot, of course, commonly requires correction of all the deformities discussed above. To use the Ilizarov technique, a strong base of fixation on the tibia is essential. The heel ring is placed as in the treatment for equinus, and the distraction of the hindfoot follows the instructions for treating equinovarus. The forefoot is fixed by two wires: one wire through the 1st and 5th metatarsals and a second wire through the 1st and 2nd metatarsals. A medial threaded rod connects the forefoot and hindfoot rings. A universal joint should be connected between the hindfoot and forefoot rings, and the forefoot ring should also be attached to a vertical threaded rod that connects to the tibial frame by means of a twisted plate and post. This threaded rod controls the elevation of the forefoot as well as supination and pronation. Finally, the vertical threaded rod is attached to a horizontal push rod that is connected to a post on the tibial ring. The push rod acts on the vertical forefoot rod to push it and the forefoot ring laterally, which helps to correct adductus. The pivot point for this motion is the base of the twisted plate on the tibial ring.

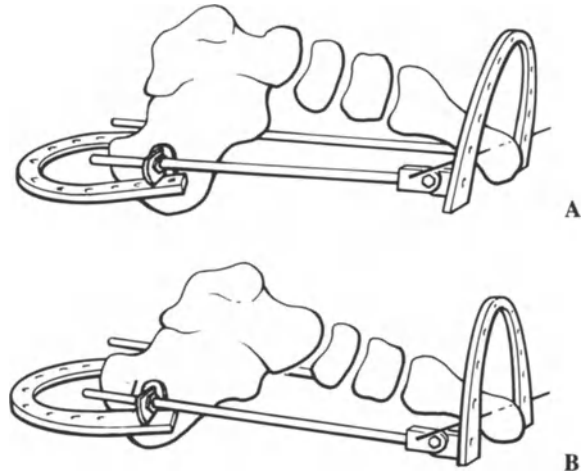


FIGURE 10.28. A: The apparatus for the correction of cavus deformity. This apparatus may be very simple and include only a half-ring posteriorly and anteriorly with one- to two-wire fixations of the forefoot and hindfoot. Distraction of half-rings using threaded rods is utilized. B: The appearance at the end of the distraction.

It is important to pay attention to the order of correction and to move gradually to avoid the creation of pressures that may crush joint surfaces. The lateral ankle radiograph should be monitored to assess the likelihood of damage, which is particularly likely if one pulls up too quickly anteriorly. At the beginning, there should be posterior correction of 1 mm per day, done in an asymmetric fashion, as described for equinovarus. At the same time, the forefoot should be pulled up at 1 mm per day. As the forefoot ring is farther from the ankle than the hindfoot ring, an opening wedge of the ankle joint will gradually develop, stretching the posterior capsule. The medial and lat-

eral rods, which manage correction of the adductus and cavus, are lengthened 1 mm per day on the medial side and $\frac{1}{2}$ mm per day on the lateral side. When there is no cavus present, the lengthening proceeds at 1 mm per day on the medial side and $\frac{1}{4}$ mm per day on the lateral side. Cavus alone would require about half the rate of distraction of the plantar aspect of the foot, as in pulling up on the foot.

When the adductus, varus, and equinus have been corrected, the frame is changed to correct supination. Supination and pronation are corrected by the use of a pair of anterior rods, one of which pulls up more on the lateral side than on the medial side (if cavus correction is still being performed). When no cavus correction is necessary, it is possible to use the device to push down on the medial side and pull up on the lateral side at rates of $\frac{1}{2}$ to 1 mm per day. The adductus push rod is lengthened at 1 to 2 mm per day.

Criteria for Satisfactory Correction

When the Ilizarov device is used, every deformity should be overcorrected well beyond the neutral level. This allows for some expected recurrence of deformity. With younger patients, there is more potential foot growth and, therefore, more opportunity for recurrence of deformities. By overcorrecting 20% to 30%, one reduces the chance of recurrence. The Ilizarov device should be left in place after the deformity is corrected to maintain the correction. For children, this period between correction and removal should be at least 6 weeks; adults need to stay in the device for 3 months after correction to prevent recurrence.

Pain should be treated by limiting the amount of distraction. Since there is no likelihood of bone consolidation with this method, the pace of treatment may be as slow as tolerated.

When the device is removed, the foot should be splinted using an ankle foot orthosis (AFO) or a total contact orthosis. The splint should be maintained full-time for 6 months after the active treatment by the Ilizarov device; after that a splint should be used at night until the patient has reached skeletal maturity.

Recurrence can also be prevented by secondary surgical procedures such as tendon transfers or selective arthrodeses. In Charcot-Marie-Tooth, the Ilizarov distraction will produce a flexible foot and a tendon transfer will help to maintain the correction. Alternatively, a limited arthrodesis (subtalar versus triple) can be performed either by the Ilizarov method or by conventional surgery. The advantage of performing an arthrodesis after correction by the Ilizarov technique is that a simpler procedure can be used, rather than an arthrodesis of sufficient scope to correct the entire deformity by itself.

Results

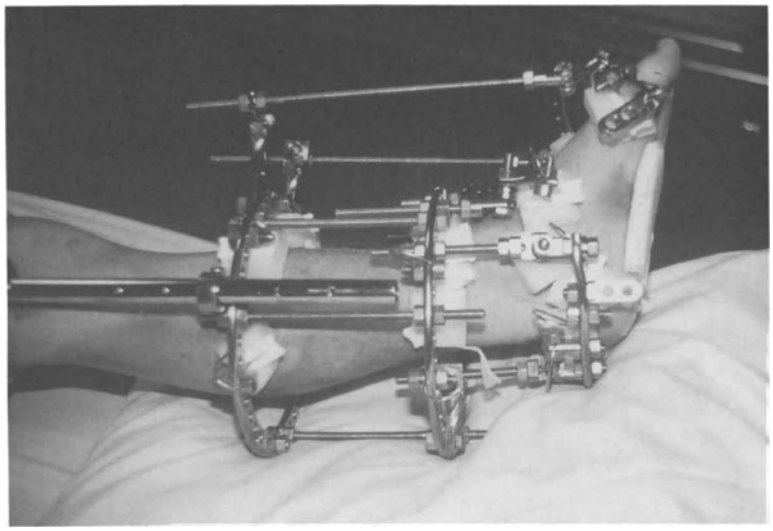
Grill and Franke[2] reported on 10 clubfoot deformities in patients ranging in age from 8 to 15 years who were treated by the Ilizarov non-osteotomy distraction technique. The etiologies included neglected or relapsed congenital clubfoot, posttraumatic equinovarus deformity, arthrogryposis, spastic diplegia, and Charcot-Marie-Tooth disease. All of the feet were stiff preoperatively, and all of the feet had subtalar stiffness postoperatively. The average range of movement at the ankle was 20°. A plantar grade foot was achieved in all patients with satisfactory radiographic and clinical results. The complications were mostly minor, such as pin track infections. One patient required a tendon lengthening for a claw toe. Another patient with an arthrogrypotic foot relapsed because of the lack of postoperative immobilization. The treatment was repeated and a good result was achieved. All patients were satisfied with their result and were for the first time able to wear normal shoes. The period of distraction ranged from 4 to 10 weeks. The device was maintained in place for an additional 8 to 10 weeks. Patients were then put into a below-knee plaster cast for 3 to 4 months. The mean follow-up in their study was 32.3 months (range 6 months to 6 years).

Summary

The principles of correcting deformity in the foot by the use of the Ilizarov apparatus for distraction (without the use of osteotomies) is described. Two techniques of applying distraction—constrained and unconstrained—are presented along with their indications and contraindications. The use of these techniques for the correction of individual deformities and



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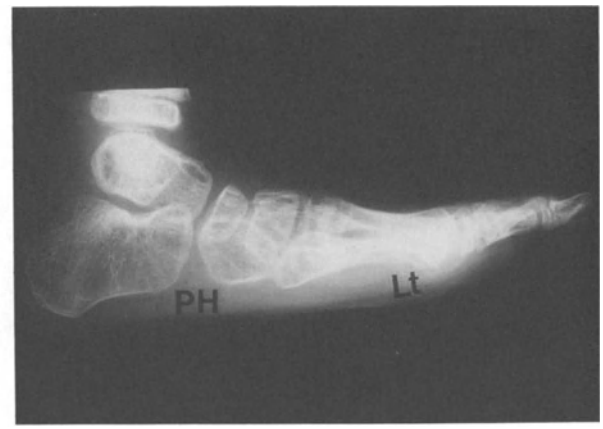
B

FIGURE 10.29. A: A boy with bilateral equinocavus feet of congenital origin. B: The apparatus was applied for the correction of the hindfoot equinus followed by the forefoot cavus. C: A lateral standing radiograph of the foot before the correction. D: A radiograph of both feet at the end of the correction. Notice the overcorrection achieved in the flattening of the arch on the right. One wire was placed in each navicular to act as a fulcrum for the correction. E: The final clinical appearance shows a flatfoot.

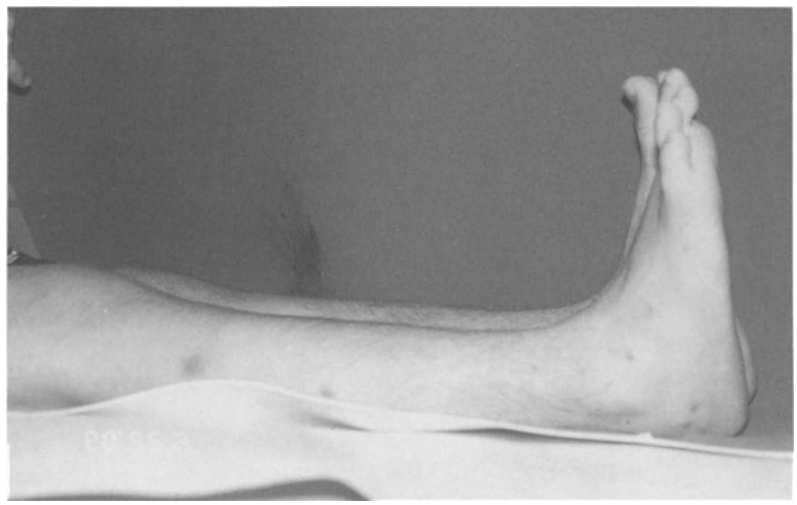


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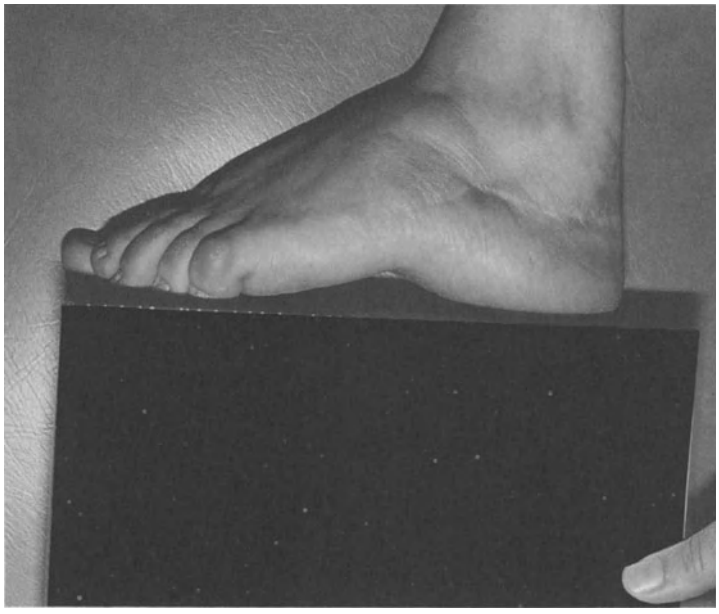
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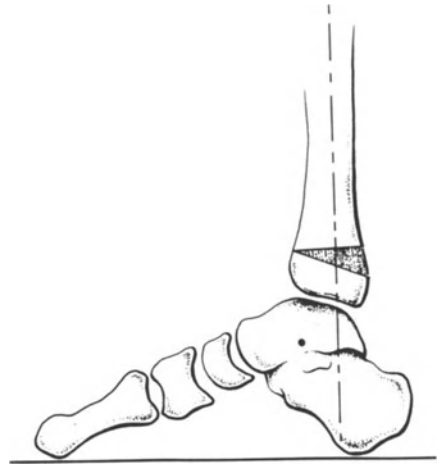


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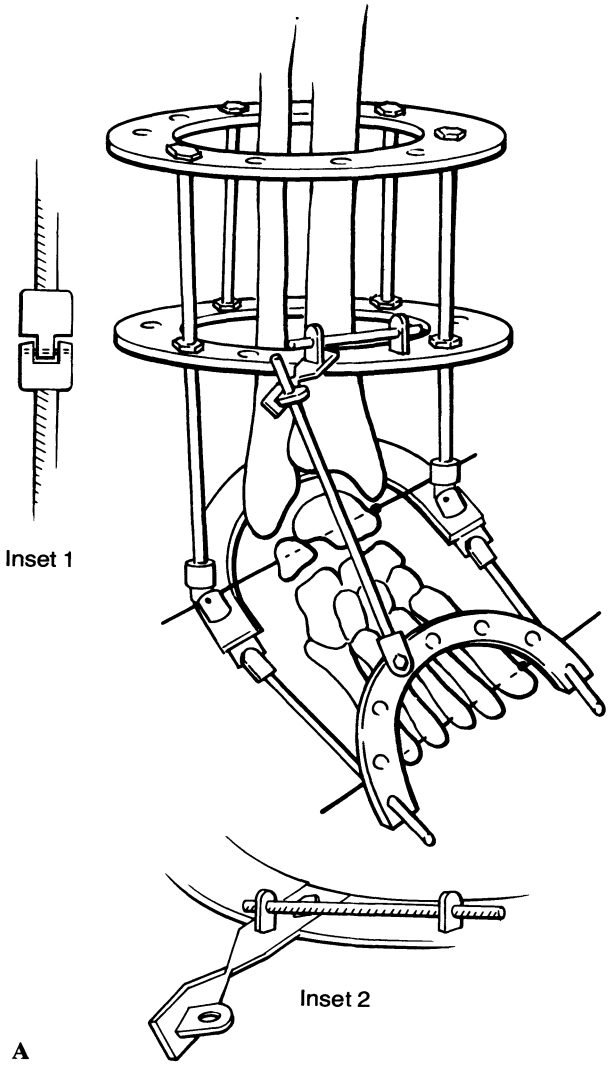
FIGURE 10.30. A: Combined forefoot and hindfoot cavus due to polio as seen on the preoperative radiograph. B: The clinical picture of the same foot is shown. C: Correction was performed using a posterior calcaneal osteotomy to decrease the calcaneal pitch and simultaneous distraction of the forefoot from the hindfoot as well as elevation of the forefoot upward by pulling from the tibial ring. It should be noted that the rate of distraction of the forefoot upward should be approximately two times the rate of distraction of the forefoot away from the hindfoot. This is based on a mathematical calculation. D: The final radiograph demonstrating the correction of the hindfoot and the forefoot equinus.



C



D



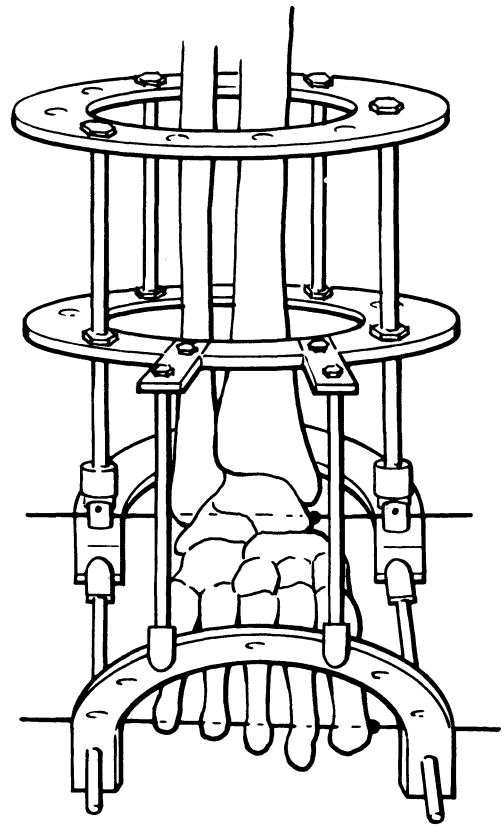
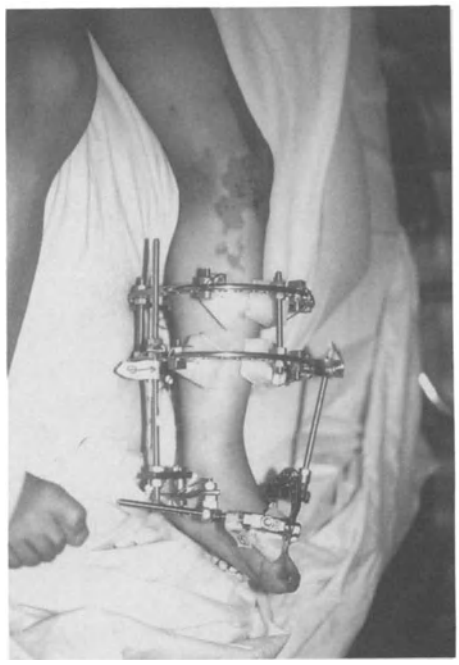


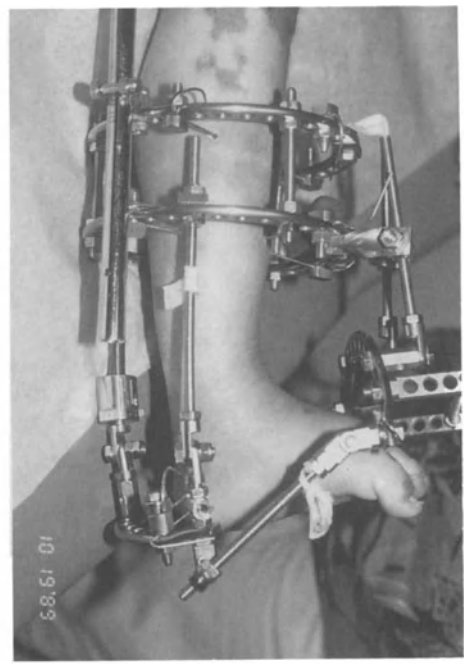
FIGURE 10.31. Clubfoot correction. A: The apparatus used is demonstrated. It consists of two rings on the tibia, a half-ring on the heel, and a half-ring on the forefoot. The forefoot and hindfoot half-rings are connected using threaded rods. Since the deformity is so complex, it requires specialized hinges (insets 1 and 2). One could either construct three hinges together or, preferably, use a universal joint between the hindfoot and forefoot as well as between the hindfoot and tibia. The connection between the forefoot ring and the tibia anteriorly is by a single threaded rod initially, suspended from a twisted plate and hinge (inset 2). This twisted plate and hinge assembly is also pushed laterally using a medially placed olive. The push force comes from a threaded rod assembly that attaches to the twisted plate on the medial aspect of the tibial ring (inset 2). B: At the end of correction, the foot is overcorrected. Two threaded rods are attached anteriorly in order to correct the supination deformity.

FIGURE 10.32. A: This 6-year-old boy had an untreated clubfoot deformity. His foot went untreated because of the extensive hemangiomatous involvement of his lower leg and foot. Notice that he is standing on the lateral border of his foot. B: The apparatus is applied to mimic equinovarus, cavus, adductus, and supination deformities (left). The appearance is shown at the end of correction (right). C: The appearance of the foot from the side and from the back at the end of correction. This photograph was taken 3 months after removal and there is still persistent edema. He has remained splinted using an AFO without any evidence of recurrent deformity.

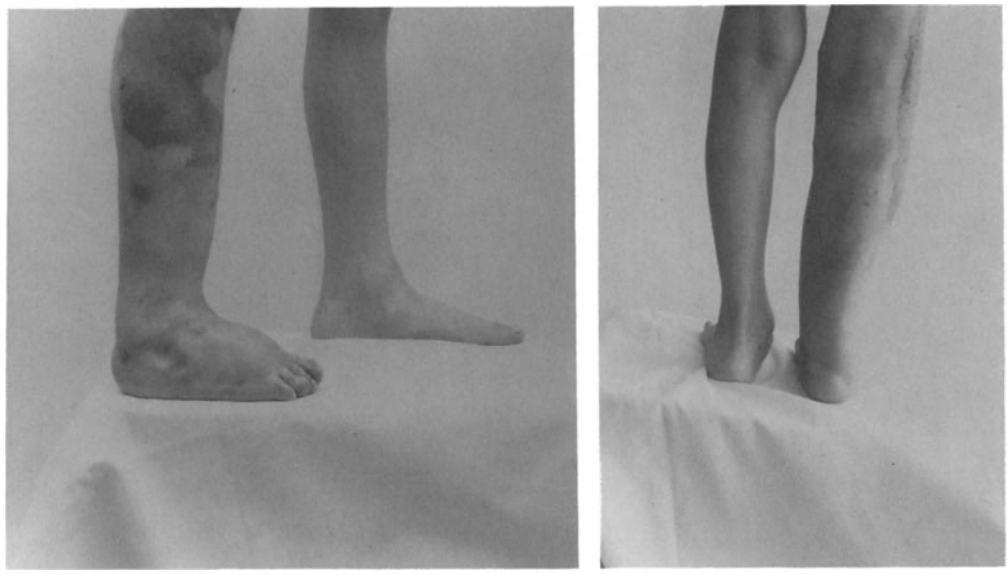


A





B



C

FIGURE 10.32 (cont.)

then the combined deformities of the clubfoot is presented. The techniques of assembling the constructs are described. The published results of this technique are given.

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Discussion

Paley (Baltimore): I think a key point about the Ilizarov technique is that one must have the right indications for using the soft tissue techniques, for using the osteotomy, and for combining the two. I've tried to set up guidelines for the Ilizarov distractor with and without osteotomies. Patients under 8 years of age who have fixed or nonfixed bony deformities are

candidates for use of the soft tissue technique. Patients who are over 8 years of age with fixed bony deformities need a permanent lasting correction, and one should probably use the osteotomy technique, or unwind the foot with the soft tissue technique and then do limited fusions with or without osteotomies.

People are confusing two types of techniques; the constrained and unconstrained. In one technique, one grabs the foot at both ends and then twists it through, perhaps, 12 different joints. In the other technique, a focal hinge is placed adjacent to the foot and the foot is rotated around one point as, for example, an ankle equinus contracture. But when you're trying to move the whole foot, you try to use the natural hinges that the foot has built in. I think that's one of the big advantages.

Carroll (Chicago): Dr. Grill, are you using the hinge at the level of the ankle and the hinge at the level of the midtarsal joints for forefoot equinus? Also, do you distract the ankle joint to improve motion?

Grill (Vienna): I use the hinges at the ankle joint for equinus and hinges at the midfoot for cavus and to distract the lateral side of the foot. By using hinges and avoiding distraction at the ankle joint, I believe that we can maintain better mobility of the foot.

Peterson (Rochester, Minnesota): Carrying the consideration of lateral control one level further, to the metatarsals, all three of the authors appear to have used different techniques of controlling the metatarsals. Dr. Joshi used what appeared to be half-pins; Dr. Grill appeared to use full pins going all the way across the foot, and Dr. Cantin had pins that come forward at an angle. Do you get enough control with half-pins?

Joshi (Bombay): One pin is always a full pin and other two are half-pins. The half-pins hold both cortexes and won't allow the assembly to shift on the pins. We also use a foot plate, which gives additional support to the pins.

Peterson: Dr. Grill, your pin appeared to go across all five metatarsals but normally the five metatarsals don't line up in one plane. Do you push them down to make them line up in one plane before inserting your pin?

Grill: The idea is to pass the pin through all five metatarsals, if possible. It may be necessary to push the 2nd, 3rd, and 4th down a little bit but the pins should certainly go through the 1st and the 5th. One should also use crossed wires to hinder migration so that the foot stays in the center of the frame.

Cantin (Montreal): I think we use the same system for forefoot fixation. We use crossed pins and try to fix at least the 1st and 2nd metatarsal. We have also started to use some olive wires because of migration of the foot on the pins.

Paley: As far as the forefoot fixation, we just use the 1st and 5th metatarsal pins because you're really trying to pull the foot up and rotate it, i.e., supinate or pronate it. If you've got the medial and lateral columns, you've got complete control.

These feet are actually much more flexible at the end of the treatment and you do need to overcorrect by about 20% to 30%. One should create almost a reverse deformity and then maintain it for a period of time. The time depends upon the age of the patient. There is no formula but I wait 6 weeks in young patients. In older patients, I may wait 6 months and then will use a postoperative splint after removing the cast.

Grill: I keep the foot in the apparatus for at least 2 months, then apply a cast and then a splint after that. So, the patient is always protected for at least 6 months after we have achieved correction.

Griffin (Charleston): As a resident, I was taught to correct multiple limb deformities with an external fixator that looks very similar to the Ilizarov apparatus. It had flexible smooth wires and steel horseshoe bars on the outside connected by threaded rods, and we corrected the feet in about 2 months. We got excellent correction of the feet but there was residual pain and stiffness in these feet. The pain would eventually go away, but in the long-term follow-up of 7 to 10 years the pain had recurred in so many of these patients that we stopped doing the procedure. I wonder why Ilizarov's procedure does not give similar results.

Grill: I think a 7-year follow-up is not very long. You're absolutely right that those feet are stiff, they have no movement in Chopart's joint and they have only limited movement in

the ankle joint. The ankle joint movement is often better than before, however, but it is only about 10° to 20°. These feet have been pain-free until now, but I don't know how long they will remain pain-free.

Watts (Los Angeles): The distraction that takes place in these feet will occur at the least resistant part and we have pulled off one distal tibial physis, although the apparatus that we used at that time was not the Ilizarov apparatus. It was the apparatus that Dr. Griffin just mentioned. Three of the x-rays that were presented showed marked widening at the ankle joint and the subtalar joint, and it depends then on which direction you're distracting. I have pulled the talus quite anteriorly in the ankle joint in younger children. If we're going to do this sort of distraction, we probably need to pin each segment in the chain if we're going to get adequate control.

Goldner (Durham): In regard to the insertion of the pin passing through all five metatarsals, I have seen patients who ended up with reversed forefoot metatarsal arch when all five metatarsals were involved. One and two are relatively stable, while three, four and five are flexible. Secondly, I wonder if Dr. Cantin's relapses were due to the fact that she was really not stretching soft tissue. Do the ligaments stretch or is one compressing cartilage in getting the correction and then it springs back?

Cantin: I think that we mainly achieve distraction of the soft tissues because we distract at about 1 mm a day. Depending on what we want to achieve, we usually distract both sides of the foot. If we want to correct the adduction deformity, we distract on the medial side but we also distract the lateral side, although slower than on the medial. It is difficult to assess these feet by x-ray while they're in the frames, but what we saw in some patients was a real distraction of the joint and in one case this was obvious at the talonavicular joint, so I think we do achieve soft tissue stretching.

Editor's Comments

Watts describes the use of a small Wagner leg-lengthening apparatus to correct the severe residual deformities of previously operated clubfeet in which there is marked medial deviation of the forefoot and contracture of the soft tissues. Repeated procedures on these areas for extensive soft tissue release may be dangerous and, in severe cases, may even be contraindicated because of the severity of the deformity. Furthermore, in conjunction with his lengthening, **Watts** performs a capsulotomy of the talonavicular and calcaneocuboid joints. During the lengthening procedure these joints are distracted. Once a distraction of 2 to 3 cm has been achieved, the apparatus is removed on the operating table. Correction of the medial deviation is then performed by a manipulative technique. This may be an important contribution to the treatment of these severe deformities. It appears to have the advantage of simplicity over the Ilizarov apparatus, which, however, may achieve equally good results.

Joshi and his colleagues describe the use of a homemade apparatus to control the differential distraction, which is necessary during the correction of complex clubfeet in very early childhood. This is the first paper describing the use of an external fixator in small children. The other papers reported in this monograph have dealt with the older patient with severe deformities. The authors reported correction of 14 of 16 cases, with only two cases requiring repeat application of the device. Three cases were under 1 year of age. They conclude by recommending it as a trial method prior to surgical correction, even in early childhood.

If, when fully evaluated, this procedure can be shown not to produce residual stiffness or allow the pins to be pulled through the immature cartilage during distraction, it may have great promise as an alternative to surgery.

Grill states that his technique with the Ilizarov apparatus without osteotomy has been very successful in treating very severely deformed

feet that would otherwise have had a very high risk for surgery. He indicates that this procedure is not to be used in children under 6 years of age nor to replace standard, conventional procedures. He emphasizes that stiffness is not improved by this technique. Finally, he indicates that his period of retention of the apparatus after full correction is 8 to 10 weeks.

Cantin and her colleagues state that the Ilizarov procedure without osteotomy, in their experience, may be used in patients as young as 3 years of age. However, they also state that it should not be considered a replacement for standard procedures. Eight of their 14 feet had typical clubfoot deformities, and others had associated congenital deformities. The eight patients with CTEV had excellent or good results; feet that had other congenital abnormalities fared rather poorly. Failures, in their opinion, were due to two causes: (a) too short a period of immobilization following correction in the Ilizarov device, and (b) the nature of the underlying deformities being associated with other congenital anomalies. They cited the duration of maintenance of immobilization following correction as one half that of **Grill's** and **Paley's**.

11
New Procedures: Osteotomies

Introduction

In this second part of an excellent two-part paper, (see Chapter 10 for the first part), **Paley** discusses the indications for osteotomy and classifies them by the level at which the osteotomy is performed. Paley describes in great detail his technique of osteotomy used with distraction for the treatment of CTEV. He describes the deformities that one can expect to correct with each osteotomy and, finally, he describes the prerequisites, advantages, and disadvantages, as well as limitations, of the various procedures.

Ozeki and his colleagues report the long-term follow-up of their patients with talar neck osteotomy used to correct persisting primary deformity, i.e., medial deviation with shortening of the talar neck. The authors used Fuji computerized tomograms in the postoperative evaluation for its advanced graphic image manipulation capabilities. Consequently, they narrow the indications for this procedure and suggest a preliminary procedure to reduce or minimize increased loading in the medial column. Although an earlier report showed favorable results, the longer follow-up revealed unexpected complications, but talar avascular necrosis was not one of them.

Peterson has demonstrated that surgical lengthening of the 1st metatarsal is feasible following physeal growth injury and either partial or complete arrest of the 1st metatarsal physis. The procedure has many advantages over others that shorten the metatarsals and remove or fuse joints.

Complex Foot Deformity Correction Using the Ilizarov Circular External Fixator with Osteotomies

D. Paley

The Ilizarov technique combined with osteotomies is well suited to the correction of foot deformities because (a) the distraction occurs through osteotomy sites, (b) the joints remain undisturbed with osteotomy distraction techniques, and (c) the three-dimensional Ilizarov apparatus is ideal for the three-dimensional nature of clubfoot deformities. As noted in the

previous chapter, the Ilizarov apparatus can be used to create soft tissue distraction or used in conjunction with osteotomies. The choice of approach depends on the age of the patient, the presence of fixed bony deformity, and the stiffness of the foot.

Indications

Osteotomy treatment is preferable when the patient is over 8 years of age with fixed bony deformity, a time when the joints cannot be expected to remodel without osteotomy. The osteotomy approach is also the treatment of choice in the presence of neuromuscular imbalance that is unlikely to be treated by soft tissue correction, especially where it is unlikely that soft tissue correction alone would lead to a lasting result.

Osteotomy Treatment

Distraction osteotomies are classified here according to the level of the osteotomy: supramalleolar, hindfoot, forefoot, and combined hindfoot and forefoot (Table 11.1).

Supramalleolar Osteotomy (Figures 11.1–11.3)

The indications for supramalleolar osteotomy are angular deformities of the metaphyseal or juxta-articular region of the distal tibia, deformity following ankle arthrodesis, or deformities of the talus or subtalar joint with ankle ankylosis. Among the advantages of this approach are the ability to lengthen and to derotate the tibia. This is also a relatively simple procedure that is typically followed by rapid and reliable bone consolidation. The primary limitation of the supramalleolar osteotomy is the inability to address deformities between the hindfoot and forefoot.

The most common undesirable outcome of supramalleolar osteotomy is translational malalignment, which occurs when an angular deformity at one level is "corrected" by adjustments at another level. For example, if a distal tibial deformity is at the level of the plafond rather than in the metaphysis, a metaphyseal osteotomy will lead to a translational deformity. In such a case, it would be necessary to translate the metaphyseal osteotomy in addition to the angular correction.

Supramalleolar osteotomies should be used

TABLE 11.1. Classification of foot and ankle osteotomies.

Type	Deformity level	Deformity correction	Prerequisite
Supramalleolar osteotomy*†	Metaphyseal; juxta-articular region of distal tibia	Leg length inequality; tibial torsion; equinus; calcaneus; varus; valgus; calcaneal rotation	
U osteotomy†	Talus	Flattop talus; equinus; calcaneus; varus; valgus; decrease in foot height	Stiff subtalar joint
V osteotomy	Deformity between midfoot and hindfoot	Essentially all deformities: hindfoot equinus; forefoot equinus; calcaneus; rocker-bottom; cavus; abductus; adductus; foot length; foot height	Stiff subtalar joint
Posterior calcaneal osteotomy	Hindfoot deformity only	Equinus; cavus; varus; valgus; deficiency of calcaneus; bone defects	
Talocalcaneal neck osteotomy	Forefoot deformity only	Cavus; rocker-bottom; pronation; supination; abduction; adduction	Stiff subtalar joint
Midfoot osteotomies	Forefoot deformity	Same as for talocalcaneal neck osteotomy if subtalar joint is mobile	
Metatarsal osteotomies	Metatarsal	Short metatarsal (s); deformed metatarsal (s)	

*Advantages: Simultaneous tibial lengthening, tibial rotation; simplicity; rapid bone consolidation; safer procedure for previously operated foot.
†Limitations: Correction of deformities between hindfoot and forefoot.

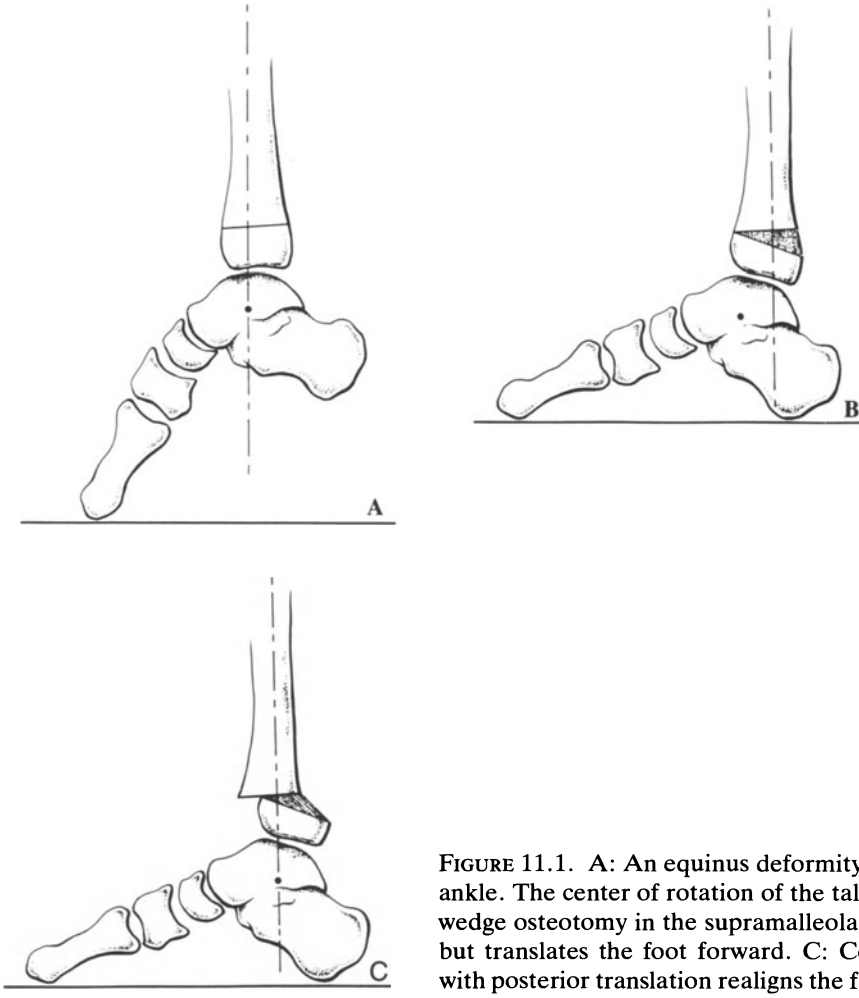


FIGURE 11.1. A: An equinus deformity with a flat-top talus and stiff ankle. The center of rotation of the talus is marked. B: An opening wedge osteotomy in the supramalleolar region corrects the equinus but translates the foot forward. C: Combining an opening wedge with posterior translation realigns the foot.

primarily for correcting malalignment of the distal tibial articular surface. Deformities at the level of the talus when the ankle joint is very stiff can, in some instances, be addressed with this osteotomy.

U Osteotomy[5] (Figures 11.4–11.6)

The U osteotomy is intended primarily for the correction of equinus, although accompanying varus or valgus can be simultaneously addressed. Deformities between the hindfoot and forefoot are not addressed by this osteotomy.

The U osteotomy is especially indicated for talar deformity, such as flattop talus, where there is a limited range of painless ankle motion worthy of preservation. The U osteotomy passes under the subtalar joint and through the superior part of the calcaneus posteriorly and across the sinus tarsi and neck of the talus anteriorly. Since the joint is not spherical, and therefore not congruous in any other position, it is not amenable to soft tissue distraction or release. Treatment alternatives are only osteotomy or arthrodesis. With the U osteotomy, the foot can be repositioned into a plantar grade position while the ankle mortise is left undisturbed, preserving the available range of motion. Since the U osteotomy crosses the sinus tarsi and necessarily reduces the subtalar range of motion, it should be performed only on feet that are already stiff. Most cases of flattop talus have considerable stiffness.

The U osteotomy correction may be performed either acutely or gradually. Before an acute correction, a percutaneous Achilles ten-

don lengthening is done. For the gradual correction, the bone ends are first distracted to disimpact them and to avoid a premature consolidation, with subsequent failure of separation. Once the osteotomy has separated, the deformity then can be corrected by means of a hinge. If lengthening is also indicated, the hinge should be centered anteriorly and, to avoid the possibility of anterior translation of the foot, the hinge should be placed on or distal to the ankle joint's center of rotation.

V Osteotomy[5] (Figures 11.7–11.9)

The V osteotomy is actually a double osteotomy: one across the body of the calcaneus posterior to the subtalar joint and another across the neck of the talus and anterior calcaneus through the sinus tarsi. The two osteotomies converge on the plantar aspect of the calcaneus, leaving a triangular wedge of calcaneus and subtalar joint connected by the posterior facet of the body of the talus. The V osteotomy is useful when there are deformities between the hindfoot and forefoot and when there is a preexisting stiffness of the subtalar joint. The list of deformities that can be addressed in this way includes most of those common to the clubfoot: hindfoot equinus or calcaneus, rocker-bottom foot, cavus, abductus and adductus, shortness of the forefoot and hindfoot, and bony deficiencies.

Posterior Calcaneal Osteotomy[4,5] (Figures 11.10–11.12)

The posterior calcaneal osteotomy is the posterior limb of the V osteotomy. It is useful for treating deformities of the hindfoot in the absence of forefoot deformity and can also be used to correct bony abnormalities of the hindfoot while soft tissue corrections are being carried out on the forefoot deformity. Equinus, valgus, varus, and calcaneus can be treated in this way, as can bone defects and deficiencies of the calcaneus.

Talocalcaneal Neck or Midfoot Osteotomies[4,5,7,13] (Figures 11.13–11.16)

The talocalcaneal neck osteotomy is defined as the anterior limb of the V osteotomy. It is suitable for the correction of forefoot deformities, including abductus, adductus, cavus, rocker-bottom foot, supination, pronation, and shortening of the forefoot. The talocalcaneal neck osteotomy is used when the subtalar joint is stiff. If there is a flexible subtalar joint, the midfoot osteotomy across the cuboid and navicular—or across the cuboid and cuneiforms—is preferable. The cuboid and navicular form a fixed unit with minimal mobility between them. Their wide cross section provides large bony surfaces for bone regeneration.

Metatarsal Osteotomies[4] (Figure 11.17)

Metatarsal osteotomies are generally employed when any of the metatarsals are shortened or deformed. Multiple metatarsal osteotomies, however, are not advisable for lengthening the foot because of the narrow cross-sectional area of the bones and because the interossei would have to be lengthened. This is also a region at higher risk of injury to the neurovascular structures from the corticotomies. Stability and the rate of healing are major issues with surgery to these bones, for there is a risk of metatarsalgia if disruption of the arch occurs. Multiple metatarsal lengthening or correction is indicated only when lengthening of the tarsals is contraindicated or when there is a significant absence or deficiency of the tarsals.

Surgical Methods

Supramalleolar Osteotomy Technique

For supramalleolar osteotomy, a preconstructed Ilizarov apparatus consists of two levels of fixation using two rings: one ring proximal and one ring distal to the osteotomy site. The distal fixations may be augmented by a calcaneal half-ring when there is a stiff or fused ankle. The rings on opposite sides of the osteotomy are connected with a hinge placed at the level of the apex of the deformity. In true metaphyseal level deformities the hinge is located proximal to the distal ring, whereas in juxta-articular deformities the hinge should be placed at the level of the ankle joint, below the ring, where it acts as a translation hinge. The osteotomy is preferably performed at either

the level of the apex of the deformity for metaphyseal deformities or as distal as possible in the supramalleolar region in juxta-articular–level deformities. A distraction rod is connected to two twisted plates on the concave side; the twisted connections permit a pivot point on either end of the distraction and allow for self-adjustment of the alignment. Lengthening is done by distracting the two hinge rods and the distraction rod.

The osteotomy should be performed through two separate incisions. A posterolateral incision is used to cut the fibula, exposing it superiosteally through a 1- to 2-cm incision. The tibia is cut in the standard corticotomy method through a 5-mm anterior tibial crest incision. As stated earlier, the osteotomy must be complete, and this can be determined by distracting it 5 mm to see if it separates fully. A common problem is for a posterior hinge of bone to remain intact.

U Osteotomy (Figure 11.2)

The U osteotomy should be performed before applying the apparatus to the leg. Under tourniquet control, an image intensifier is used to mark the line of the osteotomy on the skin. The anterior half of this line is used as a guide for the incision. The sural nerve should be identified and protected. Retract the peroneal tendons or, in the case of a rigid foot that has no subtalar function and a stiff forefoot, cut the peroneal tendons. A special curved osteotome or a 1-inch gouge is used for the anterior half of the osteotomy after elevating the surrounding soft tissues subperiosteally. Alternate radiographic checks with intermittent hammering on the osteotome; the surgeon should listen and feel carefully as the osteotome penetrates the bone, using the image intensifier as necessary to confirm that the osteotome exits on the medial side. An alternative, and frequently preferable, approach is to first make an incision on the medial side to decompress the tarsal tunnel and use this exposure to both protect the neurovascular bundle and palpate the osteotome as it exits on the medial side. The posterior portion of the osteotomy is performed using a standard curved osteotome. The osteotomy is completed by twisting the osteotome 90° to spread the osteotomy apart. The surgeon should be able to shift the foot from side to side, demonstrating that the



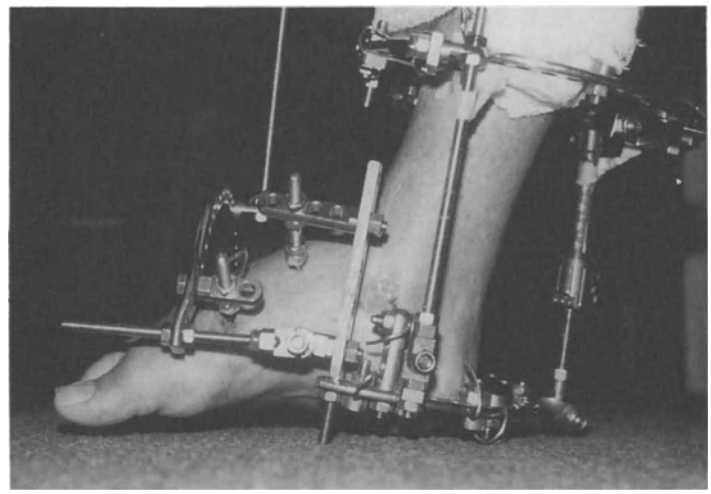
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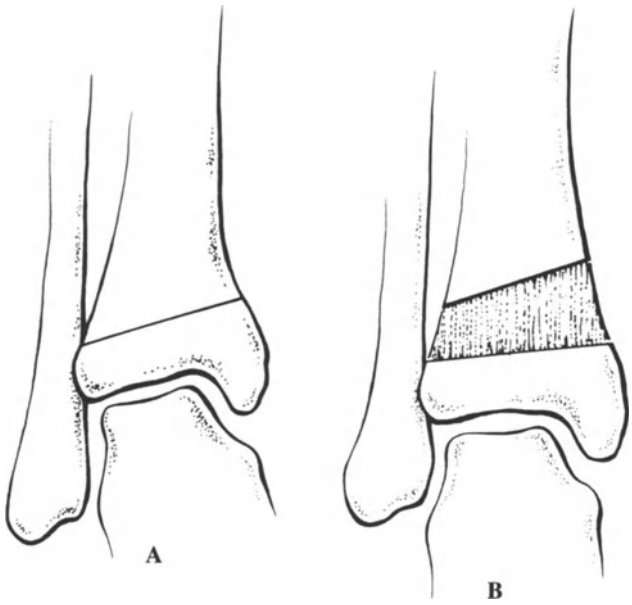


D



E

FIGURE 11.2. A: A 16-year-old girl with fixed equinus deformity of the hindfoot and forefoot cavus and adductus due to clubfoot deformity. B: After correction of the hindfoot by a supramalleolar osteotomy and nonosteotomy distraction of the forefoot. C: Preoperative lateral radiograph of the foot demonstrating 65° of equinus. There has been a previous talectomy and tibiocalcaneal fusion. Note the forefoot cavus and the short heel. D: The medial view of the apparatus is shown. The hinge lies below the level of the osteotomy to create a translation effect. E: After correction, the heel is more prominent, since the foot was translated posteriorly; $2\frac{1}{2}$ cm of lengthening were performed through the distal tibia. Using a translational hinge, the regenerated bone was translated posteriorly. Note that forefoot equinus was eliminated by distraction through the joint and soft tissues. The leg was also simultaneously widened for cosmesis.





D

FIGURE 11.3. A: Varus deformity of the distal tibia, with shortening relative to the fibula. B: Supramalleolar osteotomy with distraction and correction of the varus deformity and differential lengthening of the tibia relative to the fibula. C: A posttraumatic varus deformity of the distal tibia with shortening of the tibia relative to the fibula, as in the diagram above. D: A supramalleolar osteotomy was performed. E: The final radiographic appearance after correction of the varus deformity and lengthening of the tibia relative to the fibula by $1\frac{1}{2}$ cm.



C



E

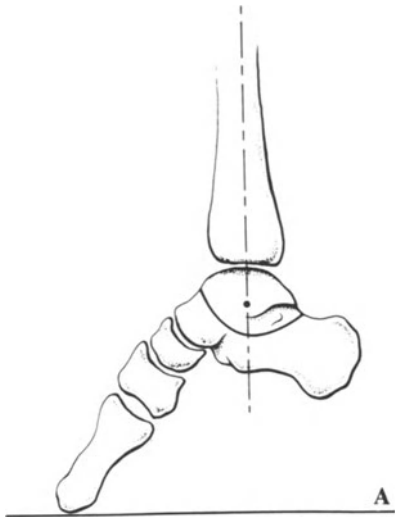
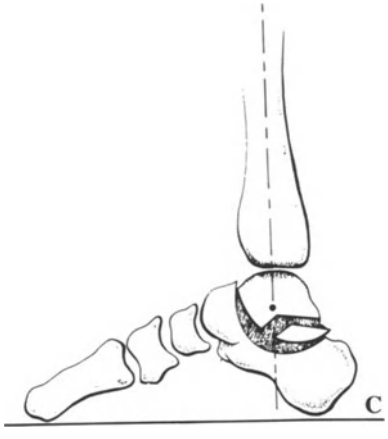
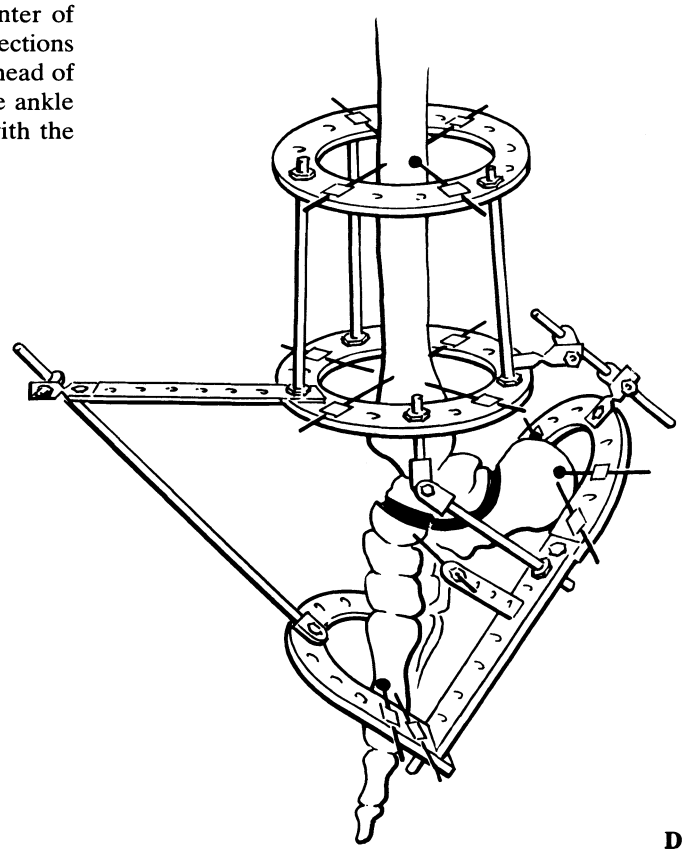




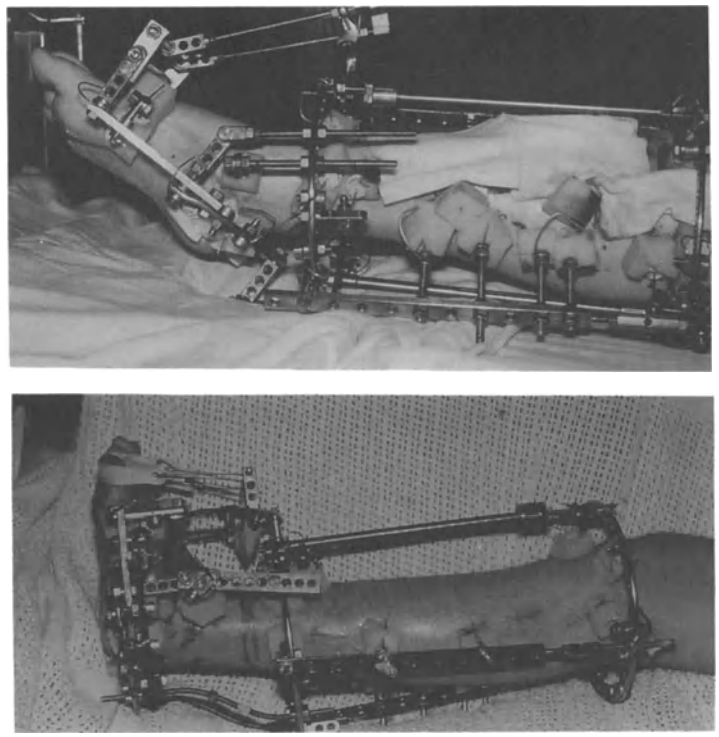
FIGURE 11.4. U osteotomy. A: Equinus deformity with flattop talus. The U osteotomy passes across the neck of the talus through the sinus tarsi and under the subtalar joint to exit posteriorly in the calcaneus. B: Correction of the equinus by slight distraction followed by rotation around the center of rotation of the ankle. C: For acute corrections through the dome-shaped U osteotomy, the head of the talus translates proximally in front of the ankle joint. D: Construct used for U osteotomy with the foot in the uncorrected position.







A

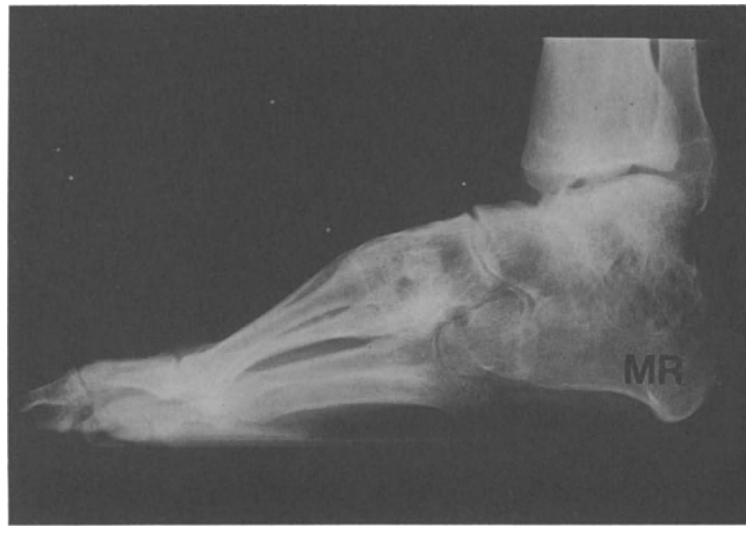


B

FIGURE 11.5. A: A 15-year-old girl with postclubfoot flattop talus and 8 cm of discrepancy. There is a subtalar congenital coalition. B: The appearance at the onset of treatment (top) and at the end of the deformity correction (bottom). This leg was also lengthened and widened. C: The final radiograph demonstrates a plantar grade foot with restoration of foot height through the U osteotomy. D: The appearance of the leg at the onset of treatment. Note the extremely thin calf and the fixed equinus deformity (left). The appearance of the leg at the end of treatment (right) with widening and reshaping of the calf. The foot is now plantar grade.

osteotomy permits complete mobility. If the foot does not shift, the osteotomy is probably incomplete. When the osteotomy is shown to be complete, the incision should be closed. Since the incision is carried straight down to the bone, there are no soft tissue flaps, which is important in a foot that has been the subject of multiple surgeries. Placement of the apparatus is the next procedure.

The apparatus consists of a proximal block of two rings, just as described for the supramalleolar procedure. Modify the apparatus if a proximal tibial lengthening is performed at the same time. The foot plate is made of a half-



C

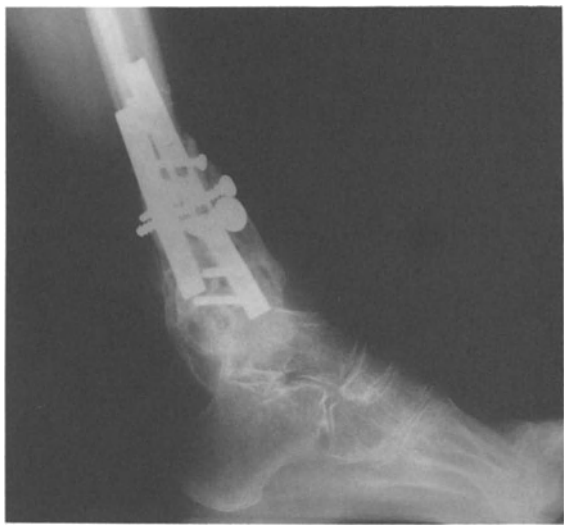




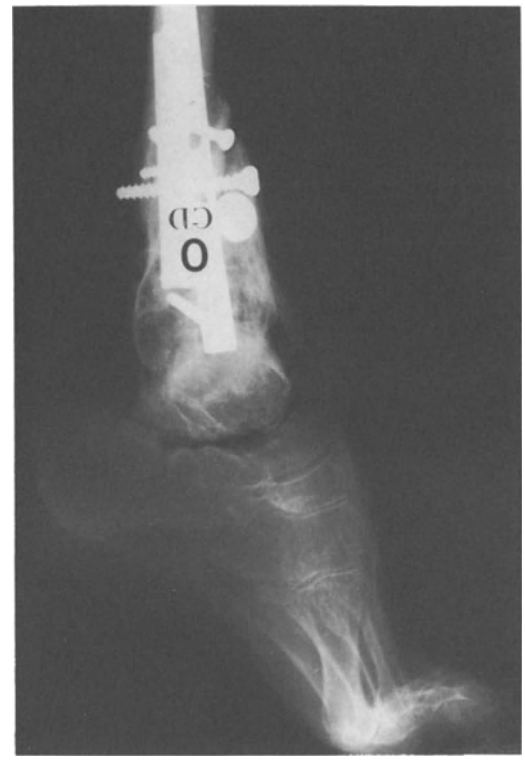
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FIGURE 11.5 (cont.)

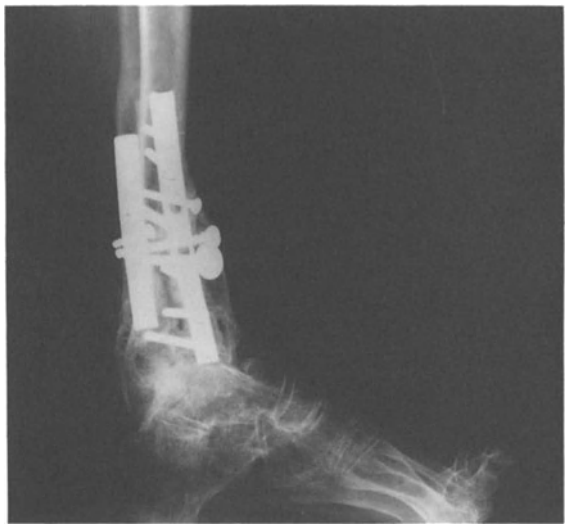
ring, two plates with threaded extensions, and a second half-ring set 90° to the plates. The angular deformity of the foot can be resolved into one plane and a single hinge.[10] Once the direction of the hinge is established, the foot assembly can be connected to the tibial ring by a single hinge. Another possibility is to ignore one plane of deformity and correct equinus first, then varus. The first method allows simultaneous correction of equinus and varus through the true oblique plane of deformity. Fixation to the tibia is accomplished by two wires on each ring with olives placed to facilitate angular correction. Since most corrections at this level are for equinovarus, an olive wire is required anterolaterally on the tibia. An additional olive should be placed posteromedially to permit posterior translation of the foot on the tibia if that is needed. Foot fixation consists of two wires in the calcaneus, two



A



B



C

FIGURE 11.6. A: Lateral standing radiograph of fixed equinus deformity in a woman with juvenile rheumatoid arthritis and a triangular-topped talus. B: The U osteotomy. C: The lateral radiograph after correction, demonstrating the acute correction around the U osteotomy. Note the step in the neck of the talus.

more wires in the metatarsals, and (very important) one wire in either the head or neck of the talus distal to the osteotomy. One wire is needed in the body of the talus and another in the floating fragment of the calcaneus, because if these fragments are not transfixed during the distraction, the joints—subtalar, talonavicular, and tibiotalar—are likely to separate rather than the osteotomy. The separation always occurs through the path of least resistance which, if left unconstrained, is the joint rather than the osteotomy.

V osteotomy (Figure 11.7)

The V osteotomy is performed before application of the apparatus. An image intensifier is used to mark the osteotomy site on the skin, so that the osteotomy parallels the anterior cut more than the posterior cut. An Ollier-type incision is generally recommended. The anterior cut crosses the calcaneus, sinus tarsi, and talar neck. The posterior cut must meet with the anterior cut on the plantar surface of the calcaneus. The surgeon may choose to prophylac-

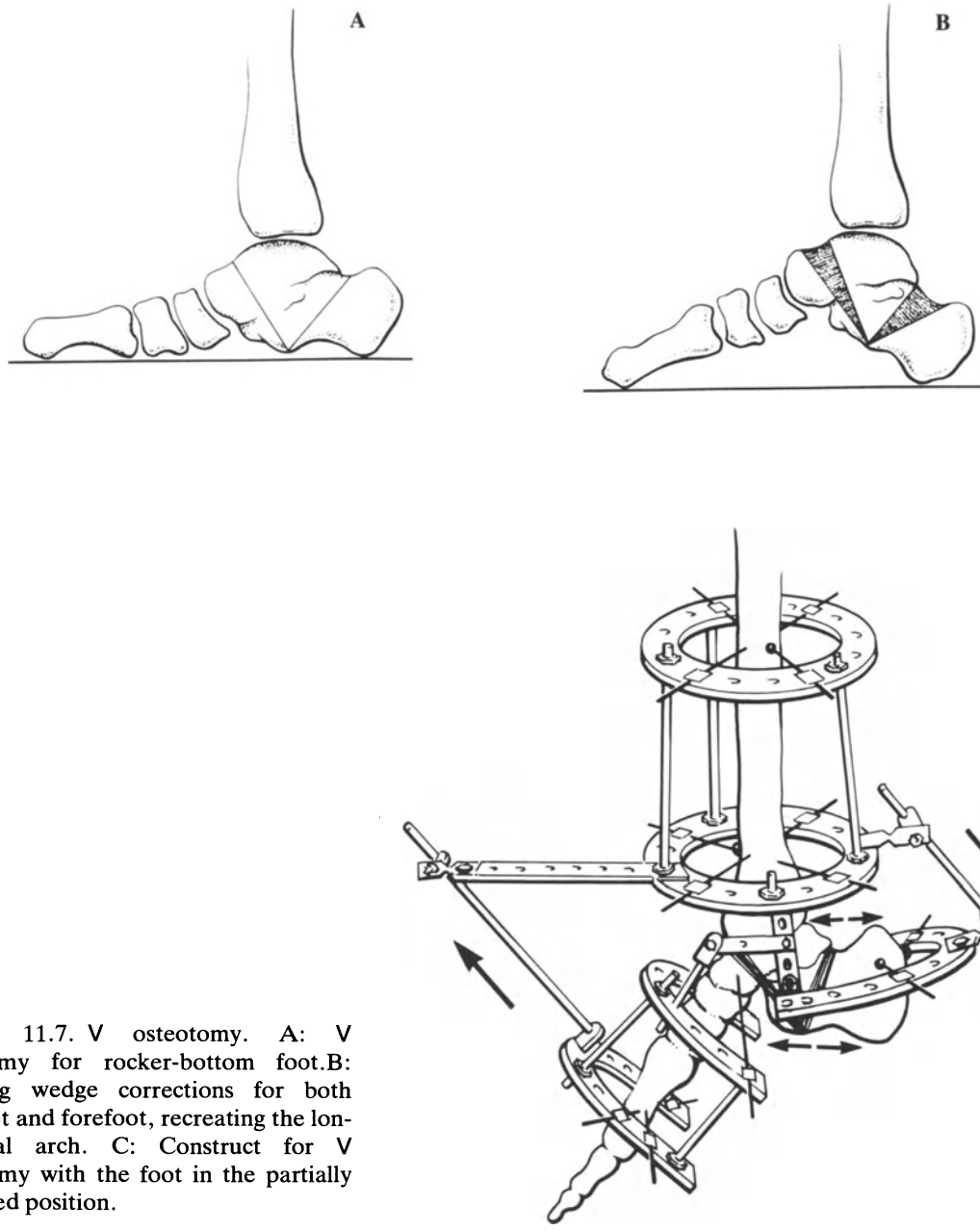
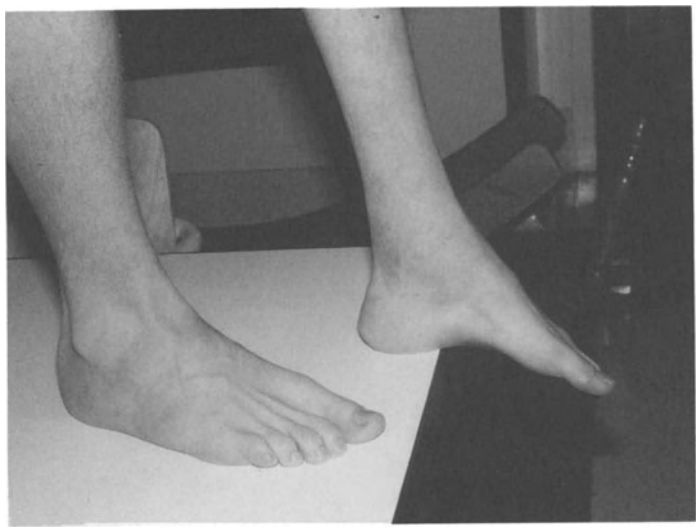


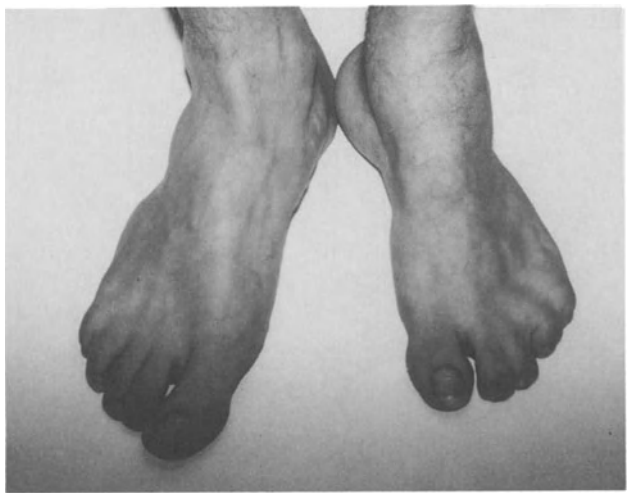
FIGURE 11.7. V osteotomy. A: V osteotomy for rocker-bottom foot.B: Opening wedge corrections for both hindfoot and forefoot, recreating the longitudinal arch. C: Construct for V osteotomy with the foot in the partially corrected position.

tically decompress the posterior tibial nerve and feel for the osteotome as it exits medially. As with the previously described procedures, the osteotomy is judged to be complete when the osteotome can be twisted, spreading the two surfaces apart. An x-ray is then taken to confirm separation. To decrease bleeding, a temporary Kirschner wire can be inserted into the calcaneus across the osteotomy site. The apparatus is then applied, with one posterior and one anterior hinge located at one end or the other of each limb of the V osteotomy, depending on the type of correction desired. It is often difficult to apply the apparatus for the V osteotomy because there is so little space in which to connect all the necessary wires.

The proximal block of two-ring fixation on the tibia is prepared similar to that described



A

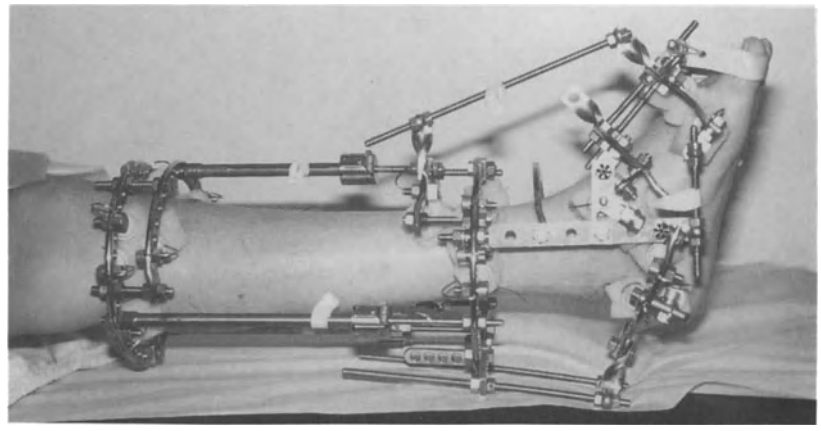


B



C

FIGURE 11.8. A: A 16-year-old boy with residual left clubfoot deformity; he also has hindfoot equinus and forefoot cavus of different degrees. B: His left foot also has an adductus deformity. C: The lateral radiograph demonstrates a flattop talus. A V osteotomy was performed to correct the hindfoot and forefoot deformities *independently*. One can see the V osteotomy on the radiograph prior to apparatus application. D: The apparatus is quite complex. The anterior and posterior hinges are marked with asterisks. The tibia was simultaneously lengthened. E: The lateral standing radiograph after distraction demonstrates the foot is plantar grade. Opening wedges of new bone were generated anteriorly and post-



D



E



F



G

eriorly in the talus and calcaneus. F: The foot is plantar grade postoperatively. The normal longitudinal arch is restored and the equinus deformities of both hindfoot and forefoot are eliminated. G: The adductus deformity has also been corrected through the talocalcaneal neck portion of the V osteotomy.



A



B

FIGURE 11.9. A: A rocker-bottom foot deformity in an 11-year-old girl who had an abnormally stiff ankle joint and a short hindfoot and forefoot. B: Both hindfoot and forefoot deformities were corrected by opening wedges using the V osteotomy, re-creating the longitudinal arch of the foot.

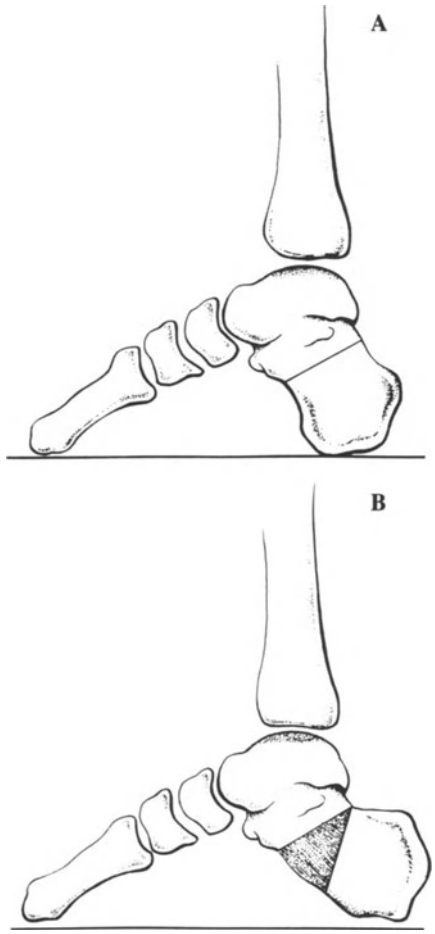


FIGURE 11.10. A: The posterior calcaneal osteotomy applied to calcaneocavus deformity. B: A plantar opening wedge is performed for the correction of this deformity.

for the U osteotomy. Hinges connect a posterior half-ring (which is connected to the calcaneus) to an anterior half-ring on the forefoot. The forefoot may also have a second half-ring over the midfoot for better stability of fixation. Alternatively, a second level of fixation for the forefoot can be suspended from posts. The hinges are placed relative to the apex of the deformity posteriorly and anteriorly. Two transverse wires and one axial half-wire are used to fix the calcaneus. Two metatarsal wires and one talar neck wire are used to fix the forefoot. The body of the talus and the floating fragment of calcaneus must be fixed to the tibial ring.

Other Osteotomies

The posterior calcaneal and talocalcaneal neck osteotomy, if used alone, are performed as described for each separate limb of the V osteotomy. A midfoot osteotomy may be performed through either one dorsal incision or through two incisions, one medial and one lateral. Care must be taken to follow the arch of the foot so that the osteotome does not exit on the plantar aspect and injure the neurovascular structures. A periosteal elevator may be inserted dorsally and on the plantar aspect of the foot to protect the osteotome. The Ilizarov device should be similar to that used for talocalcaneal neck osteotomy, except that one should insert a wire into the split bones on either side of the osteotomy to lock the talonavicular and calcaneocuboid joints and the midfoot tarsometatarsal joints. If this is not done, distraction will occur through the adjacent joints rather than through the osteotomy. Remember that joints, rather than osteotomies, are usually the path of least resistance to distraction.

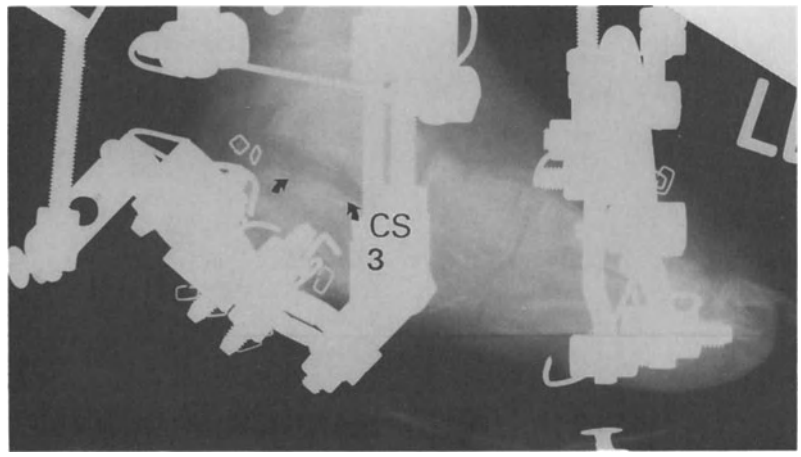
Results

The results of Ilizarov distraction osteotomy treatment were reported by the author and are summarized here.[12] There were 23 patients with 25 severely deformed feet; 19 feet had had previous multiple operations for recalcitrant leg and foot deformities. Preexisting foot stiffness was uniformly present. There were 10 males and 13 females, with ages ranging from 6 to 63 years with a mean age of 25 years. The foot deformities treated included a variety of etiologies; the osteotomies chosen included 12 supramalleolar, two U osteotomies, two V osteotomies, two talocalcaneal neck osteotomies, two midfoot osteotomies, and one panmetatarsal osteotomy. Treatment also included leg lengthening in 20 of the limb segments and foot lengthening in five cases. Associated treatments included leg widening for cosmesis in seven cases, distraction of forefoot deformities in four cases, and tibial and/or femoral mechanical axis realignment in three cases.

Mean treatment time was 6.4 months (range 3 to 11.3 months). In most cases, the primary factor responsible for the length of treatment was the consolidation time of the tibial limb



A



B

lengthening gap rather than completion of correction and healing of the foot osteotomies. The results are briefly summarized at the end of the next section.

Complications

All but seven patients experienced one or more relatively important complications (20 complications in 18 feet). The minor complication of pin track infection occurred in at least one pin in every patient. This rarely caused additional problems and was easily treatable by local measures and oral antibiotics, although three patients had deep soft tissue infections of their pin sites that required pin removal and an operative intervention for wire insertion or debridement. After a pin cut through the metatarsal shaft into a joint, one patient developed an osteomyelitis with septic arthritis of the 5th metatarsophalangeal joint. This problem required two serial debridements; healing was without further complications. The same patient simultaneously developed a pin track abscess of the lateral wall of the calcaneus, which was successfully treated by debridement and antibiotics.

Next to pin track infections, the most common problem was incomplete osteotomy, or



C

FIGURE 11.11. A: Lateral radiograph of a 7-year-old girl who presented with a varus heel and rocker-bottom, secondary to Streeter's syndrome. Her insensate foot was developing an area of breakdown under the prominent rocker-bottom apex. B: A posterior calcaneal osteotomy was performed with simultaneous opening wedge correction of the calcaneus. The calcaneal osteotomy consolidated prematurely due to lack of fixation of the anterior portion of the calcaneus. The path of least resistance was distraction of the subtalar joint rather than at the osteotomy. Note the diastasis of the subtalar joint (arrows). A repeat osteotomy was necessary in order to complete the treatment. C: The final lateral radiograph demonstrates a plantar grade appearance to the plantar aspect of the foot. The heel ulcer promptly healed.

failure of separation, which occurred in nine cases. The causes were incomplete surgical osteotomy in three and premature consolidation due to an insufficiently constrained construct in six cases, usually the lack of one locking wire. In these cases, distraction resulted in diastasis of adjacent joints instead of the osteotomy.

Acute tarsal tunnel syndrome developed within 24 hours of the surgery in two patients. In one patient, this was discovered in the recovery room, and the patient was immediately taken back to the operating room where the tarsal tunnel was decompressed. In the second case, the tarsal tunnel syndrome did not develop a day later, and it was treated by immediate decompression, which was followed by complete recovery within 3 months.

Toe contractures were common, especially following correction of equinus and cavus and in all foot lengthenings. All but three of the toe contractures recovered. Two of these were treated with percutaneous release during or at the end of the treatment. In one case, the patient refused further treatment, although he remained symptomatic with clawed toes. This patient had previously experienced the 3-month recovery from tarsal tunnel syndrome. It is possible that this patient had an element of neuromuscular dysfunction that caused both the claw toe and the abnormal muscle tension during the foot lengthening. Prophylaxis of toe contractures was carried out through the use of toe slings and elastic bands. But, more recently, I have used a 1-mm wire inserted across the base of the distal phalanx and connected to the apparatus to prevent contracture of the toes. This additional wire has eliminated toe contractures during lengthening.

Other problems with wires and incomplete correction included the following: In one case, the wires began to cut through the heel and additional wire had to be inserted. In another patient, who was peripatetic and had an anesthetic foot, several wires broke. This patient literally walked bearing full weight without



A



B

FIGURE 11.12. A: Congenital deficiency of calcaneus and supinated forefoot. B: A posterior calcaneal osteotomy was used to regenerate a heel. The forefoot was treated by distraction alone.

support throughout the treatment, which caused repeated wire fractures. One patient who had a supramalleolar lengthening and deformity correction developed a buckle fracture due to premature removal of the device. Since the treatment was bilateral and the fracture happened on only one side, the patient was left with a 1.5-cm difference in leg lengths. Another patient who had multiple osteochondromas developed a nerve injury due to the proximal tibial osteotomy. The distal tibial supramalleolar osteotomy did not lead to any complications, and the nerve injury recovered. One case resulted in skin breakdown after a talocalcaneal neck reosteotomy following a premature consolidation. This healed uneventfully after the wound was left open.

With the exception of the one persistent toe contracture and the small leg length discrepancy, none of these complications led to permanent sequelae. Altogether, 19 secondary surgical procedures were necessary in 13 of the 23 patients for complications of 25 foot corrections; two more secondary procedures were required for complications of the proximal tibial osteotomy.

When fixation was removed, 24 feet were plantar grade; in follow-up, only 22 of the feet were still plantar grade. The one foot that was not plantar grade at the time the Ilizarov was removed was a foot that had an unrecognized preoperative 5° heel deformity; the leg length discrepancy and midfoot cavus in this patient were treated successfully. A supramalleolar osteotomy corrected the remaining varus successfully. One deformity recurred because of an unrecognized ball and socket ankle joint. This patient had preoperative posttraumatic ball and socket ankle joint with a varus heel deformity; treatment was a posterior calcaneal osteotomy with gradual valgus distraction. The deformity corrected by everting the unconstrained ball and socket ankle rather than by opening a wedge in the calcaneal osteotomy. This situation could have been avoided by constraining wires in the talus; this patient had a subsequent reosteotomy by conventional techniques.

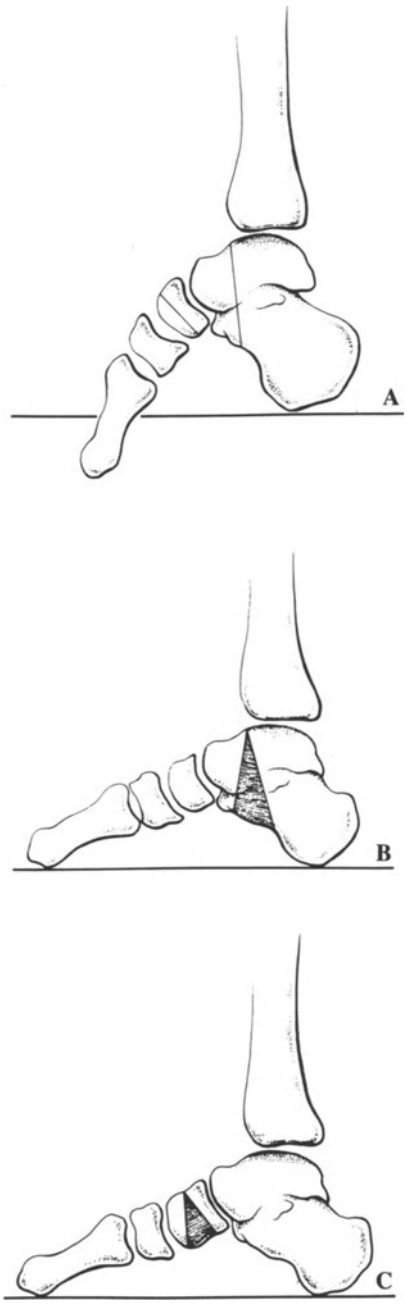


FIGURE 11.13. A: Demonstration of how talocalcaneal neck (or midfoot) osteotomies can be used for forefoot cavus. B: Demonstration of how talocalcaneal neck osteotomies are used when the subtalar joint is stiff. C: Demonstration of how midfoot osteotomies across the navicular and cuboid (and the cuboid and cuneiforms) are used when the subtalar joint is mobile.

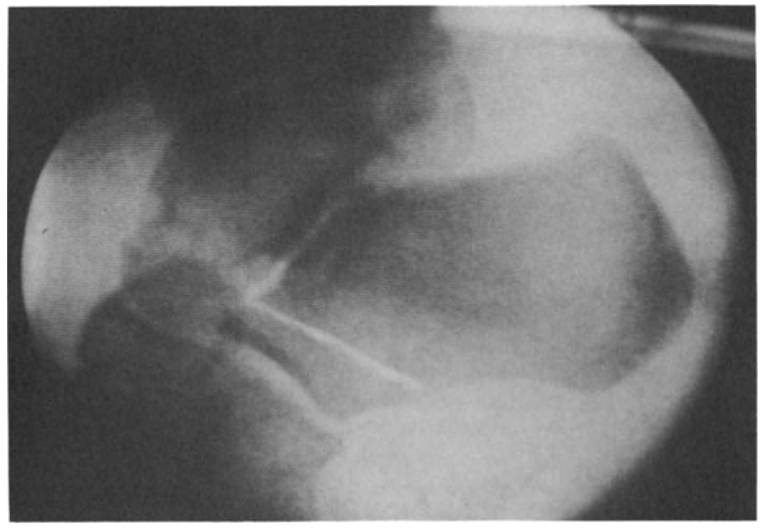
These two patients were judged initially as unsatisfactory foot results even though they had significant improvements in pain and gait, as well as elimination of leg length discrepancies and deformities. Further problems have converted them to satisfactory results. Finally, one boy who was treated successfully for postclubfoot cavus developed mild supination of the forefoot, which was caused by a previous arthrodesis of the foot. This secondary deformity was not related to the Ilizarov distraction treatment, and the result was rated as satisfactory.

Pain was a preoperative complaint in only eight of the patients. After surgery, three patients complained of pain: one who had partial recurrence of deformity, one who had successful resolution of equinovarus but who had arch pain, and one who had rocker-bottom deformity with associated ankle pain.

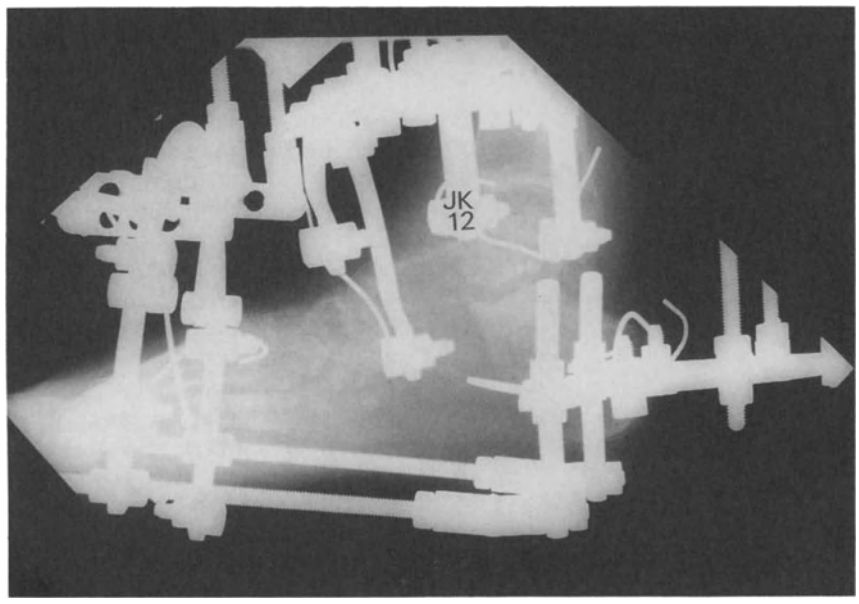
Gait was improved in all 23 patients. The patient who had a stiff rocker-bottom foot complained of a stiff gait and insisted on foot lengthening after the completion of the Ilizarov distraction. The final result was a plantar grade stiff foot with a longer platform to step over, which resulted in more stress on the ankle. Her ankle was painful preoperatively but was equally symptomatic postoperatively. She was therefore graded an unsatisfactory result. Altogether, there were 21 satisfactory (84%) and four unsatisfactory (16%) results at the time of follow-up. Subsequently, with additional procedures the latter number was reduced to only one. Foot stiffness was difficult to assess because the majority of the patients (19 of 25) had stiff feet before surgery. Preexisting levels of ankle, subtalar, and midfoot range of motion were preserved; toe motion was decreased in two patients who had foot lengthenings.

Advantages of the Ilizarov Technique

The Ilizarov method is known for limb lengthening and for correction of long bone deformities, but it is relatively unknown as a method for correcting complex foot deformities through the use of specialized distraction osteotomies.[9–11] The method is minimally invasive, requires minimal dissection, and, therefore, involves less risk of neurovascular and

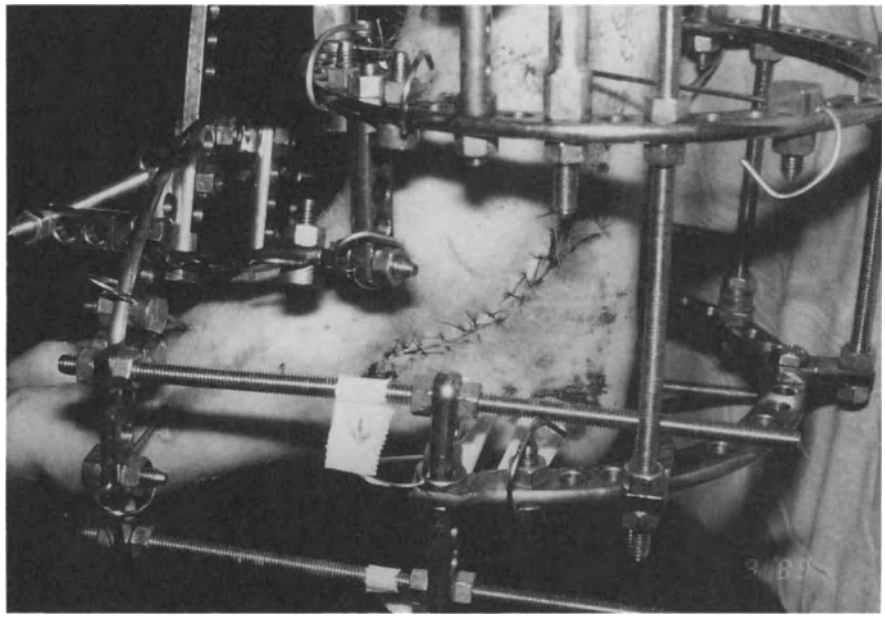


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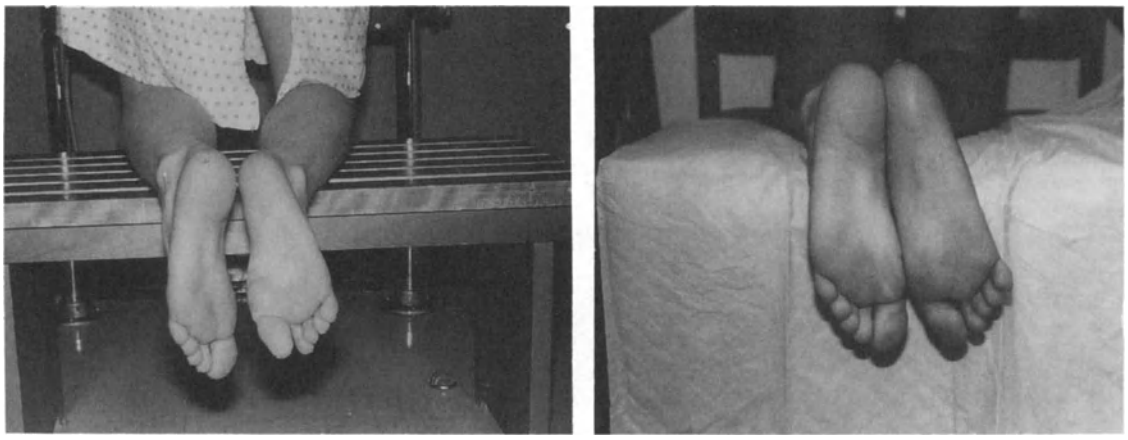


B

FIGURE 11.14. A: Talocalcaneal neck osteotomy. B: Lengthening of the foot through a talocalcaneal neck osteotomy. Note the regenerate bone between the anterior and posterior portions of the calcaneus. This boy had a ball and socket ankle joint and subtalar coalition in addition to a short foot. The foot was lengthened 3 cm. C: The patient developed a postoperative tarsal tunnel syndrome, which was treated by an emergent release. D: The appearance of the foot before (left) and after lengthening (right). Note that the foot length discrepancy has been eliminated.



C



D

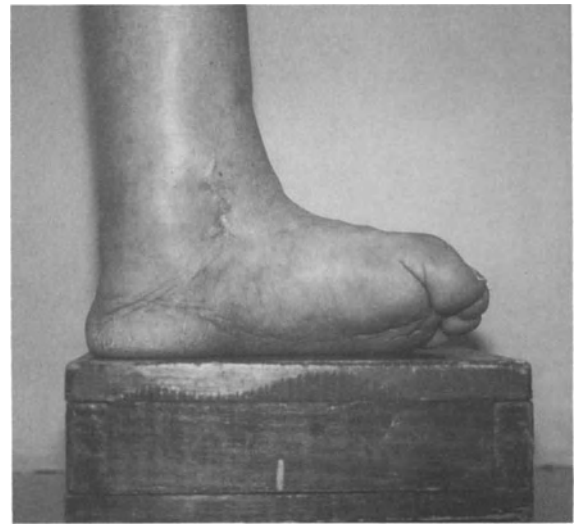
soft tissue injury and infection. This is particularly advantageous in the multiply operated foot.

Conventional treatment of complex foot deformities has many limitations. Neurovascular structures are acutely stretched; the needed exposure risks important collaterals in an already-compromised circulation. Reexploration and osteotomy must be considered a high-risk procedure. Moreover, conventional osteotomies tend to sacrifice foot and leg length to correct angular deformities, which further shortens already short legs and feet.

The Ilizarov technique is not limited by the magnitude of the deformity and relies on bone regeneration rather than bone resection. Therefore, there is no need to shorten the leg or foot. Also, correction can be completed through bone, joint, or arthrodesis. Conventional osteotomies often resect, fuse, or cross normal foot joints,[2,8] further stiffening already stiff feet.



A



B

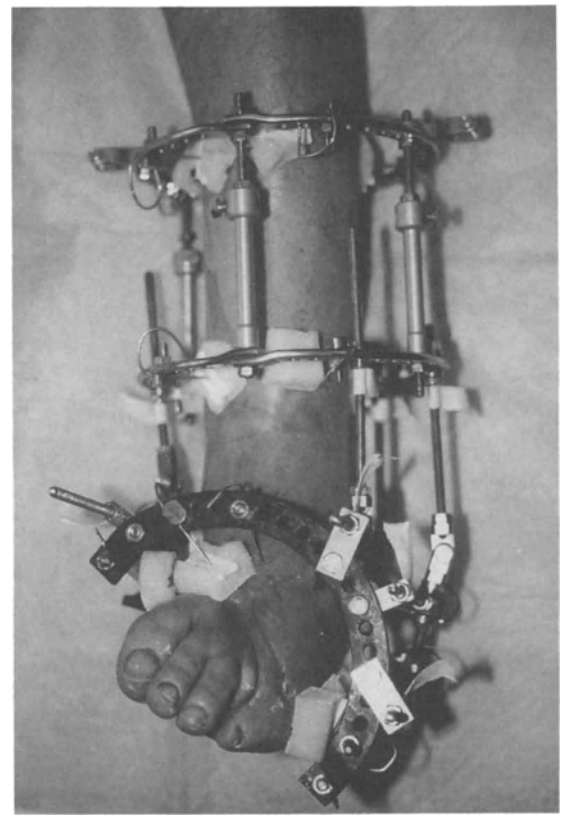


C



D

FIGURE 11.15. A and B: Frontal (A) and side (B) views of the leg and foot of a 63-year-old man who suffered an injury at the age of 6. He previously was told that nothing could be done to correct the very severe supination deformity of the forefoot and equinovarus malunion of his ankle arthrodesis. C and D: Pre- and postoperative radiographs. The deformity was corrected through a midfoot osteotomy and a supramalleolar osteotomy in combination. The foot was lengthened and derotated through the forefoot osteotomy, which went across the cuboid and cuneiforms. The equinovarus deformity as well as 4 cm of lengthening were corrected through the supramalleolar osteotomy. E: Shows the apparatus in place during correction. F and G: The final clinical appearance of this man's foot, demonstrating the complete correction of the equinovarus and the supination.



E



F



G

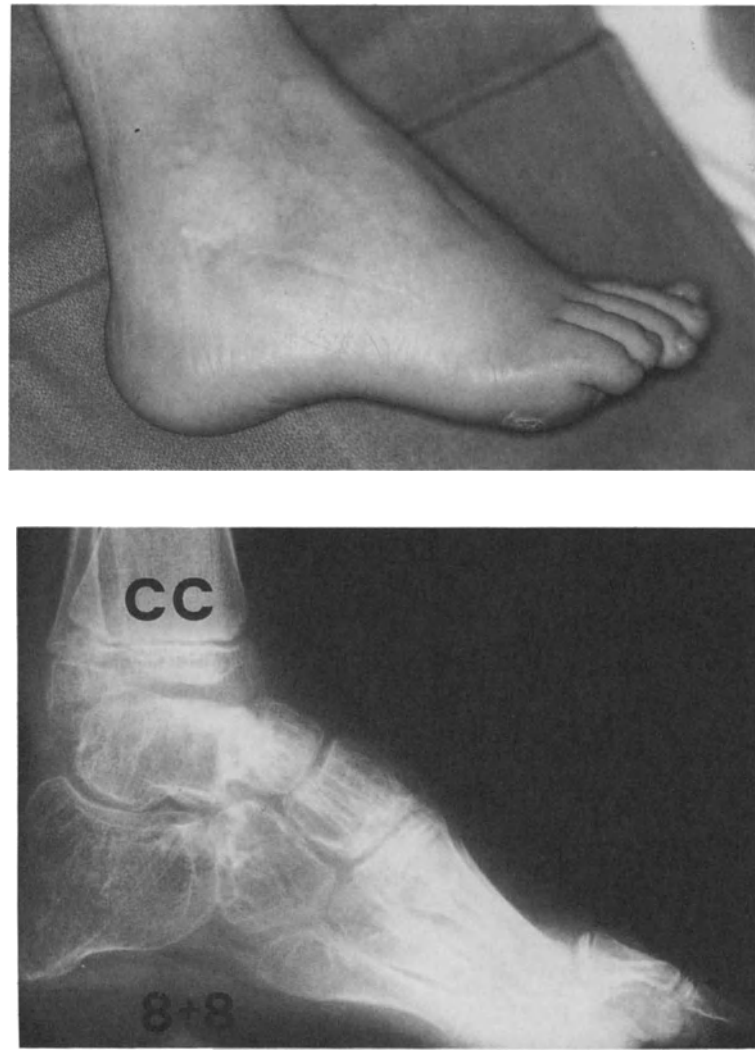
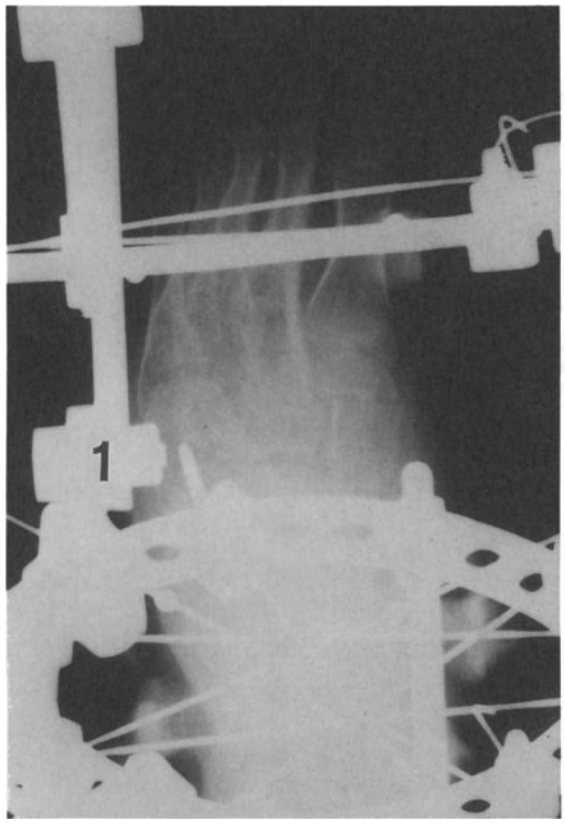


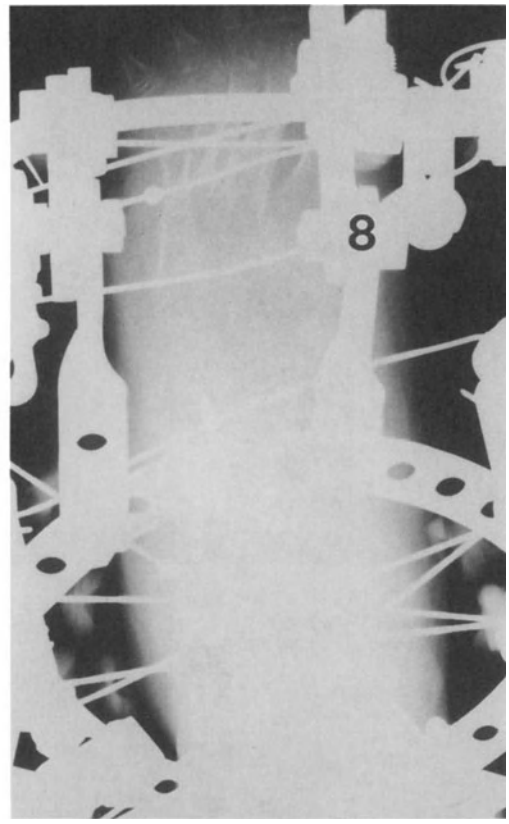
FIGURE 11.16. A and B: Preoperative photograph (A) and radiograph (B), demonstrating forefoot cavus secondary to previously treated clubfoot deformity. C and D: An osteotomy was performed across the cuboid and cuneiforms (C). Due to the lack of constraint, the distraction force led to separation of the adjacent joints. The osteotomy never separated (C). Therefore, one wire was inserted on each side of the osteotomy to concentrate the forces across the osteotomy and to lock adjustment joints (D). E and F: At the end of the correction the foot is plantar grade and longer. Due to the abnormal growth in this foot from previous arthrodeses and surgery, the patient developed a supination deformity of his foot 3 years later.

Another advantage of the Ilizarov method is that it permits a comprehensive approach to foot deformity correction through treating not only the foot, but also the tibia, length problems, and even the thin calf. Foot lengthening, although rarely necessary, can be combined with some of the foot osteotomies.[4,5,13] Since no length is sacrificed on deformity correction, a significant amount of foot length is regained simply by correction by the opening wedge technique.

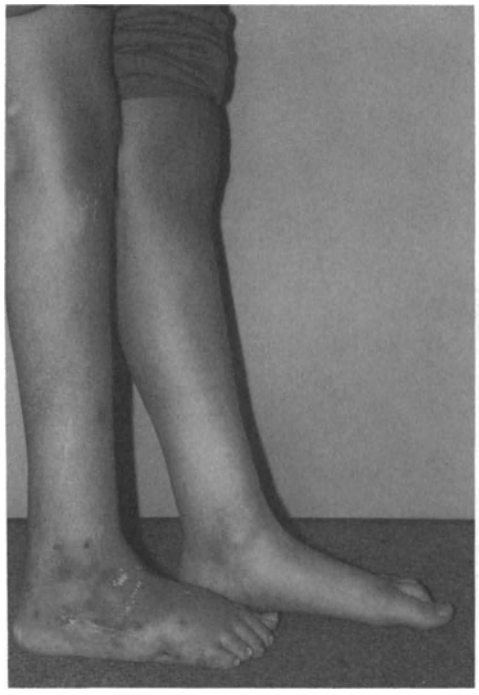
Further, although conventional surgical correction must be completed within the time frame of the operation, the Ilizarov method is



C



D



E



F

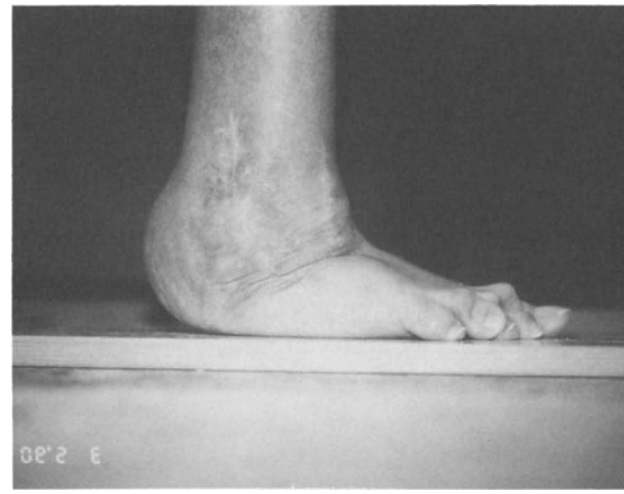


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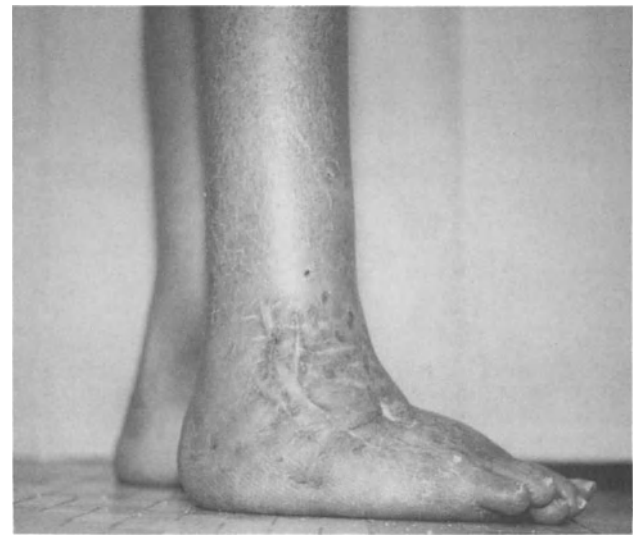


B

FIGURE 11.17. A: Severe shortening of the foot following talectomy for a clubfoot deformity. Note the equinus deformity of the heel and painful nonunion of the tibia and navicular. B: The foot was osteotomized across the calcaneus and metatarsals. The nonunion was debrided and decompressed. Final radiograph after correction of the foot deformity demonstrates the plantar grade foot with reestablishment of the heel and a longer forefoot. C and D: The appearance of the foot before (C) and after (D) the correction of deformity. This patient also had a simultaneous leg lengthening and calf widening procedure.



C



D

four-dimensional, as time is one of the variables that can be adjusted. Manipulation of a three-dimensional deformity in time provides safer correction of foot deformities in many cases, compared to a single surgical intervention.

Finally, the Ilizarov method offers an advantage that is impossible in the more common surgical approaches: adjustments can be made after an acute correction is completed. Achieving a plantar grade foot in the operating room is not simple, whether with an osteotomy or an arthrodesis; the Ilizarov permits the surgeon to obtain the desired correction either acutely in the operating room or gradually postoperatively, while at the same time making sure that the patient is comfortable with the foot position before accepting it as the final result.

The patients reported in Grill's series and in my series represent some of the most difficult, complex, and recalcitrant foot deformities that are seen by orthopedic surgeons. Although complex problems demand complex solutions, simple problems often allow simple solutions. For simpler foot deformities, the conventional methods may be preferable, although the Ilizarov method can also be used to correct simple problems with minimal invasiveness.

Disadvantages of the Ilizarov Technique

The disadvantages of the Ilizarov technique are obviously those of an external fixation device, especially pin-site problems. The Ilizarov method requires long treatment times and joint immobilization, and patients often experience mild-to-moderate pain during distraction. The problems attendant on joint immobilization are to some extent counteracted by the possibility of loading and even full weight-bearing during treatment. The primary limitation of this technique (as with any approach to the clubfoot) is the foot with which the surgeon is presented. A stiff equinovarus foot that is corrected into plantar grade position is still a stiff foot. Patients do not always take this into consideration, and their expectations are often unrealistic in spite of significant cosmetic and functional improvements. The surgeon must make every effort to communicate realistic expectations.

Conclusions

The surgeon who considers using the Ilizarov circular external fixator with osteotomies must pay strict attention to (a) the indications, (b) the appropriate choice of construct, and (c) the correct osteotomy. Using the Ilizarov properly requires *extensive experience*, especially on an anatomic structure as three-dimensionally complex as the foot. *Ilizarov correction of the foot should be undertaken only by surgeons who have previous experience with this method on long bones.* When properly planned and applied, this method—in spite of its complications—can accomplish the objectives of treatment in almost all cases.[11]

Summary

The use of the Ilizarov apparatus for the correction of deformities of the foot by combining both distraction and osteotomies is presented. Distraction with osteotomies is primarily indicated in children over the age of 8 years in whom there is fixed bony deformity with stiffness. The various osteotomies are described and classified by anatomic location. The deformities that they can be expected to correct are outlined, along with their advantages, prerequisites, and limitations.

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The Results of Talar Neck Osteotomy in Resistant Congenital Clubfoot

S. Ozeki, K. Yasuda, H. Iisaka, K. Kaneda, J. Monji, and S. Matsuno

In 1866, Adams[1] described the abnormal shape of the neck and the head of the talus from autopsies of an infant with clubfoot. In 1974, Hjelmstedt and Sahlstedt[7] studied deformity of the talus in congenital clubfoot by arthrography and dissection. Kameshita[8] also reported deformities of the talar neck using arthrography. Our simultaneous arthrographic analyses of the ankle and talonavicular joints in clubfeet have also revealed medial deviation and shortness of the talar neck.[11]

Until 1978, we routinely performed posterior release for residual equinus deformity in congenital clubfeet (CTEV), after a period of conservative treatment using corrective casts. We also performed posteromedial release for more severe residual or recurrent forefoot adductus deformity and in-toeing gait.[11] One cause of these residual or recurrent deformities was thought to be hypoplasia and deformity of the talus.

Talar neck osteotomy is a procedure used to correct medial deviation and shortness of the talar neck by osteotomy with iliac bone graft. We have tried to correct these deformities and to lengthen the medial ray of the foot with this procedure. When Katoh[9] first reported this procedure, there were many critical comments concerning problems with talar circulation and increased pressure on the medial ray. In our previous short-term follow-up, the results of this procedure were favorable. In this study, we report longer-term results and problems with the talar neck osteotomy based on 8 to 15 years of follow-up data.

Indications

The principle of talar neck osteotomy is correction of adduction deformity of the resistant clubfoot by open wedge osteotomy of the medially deviated talar neck and by lengthening the hypoplastic talar neck (Figure 11.18). Our indications for such osteotomy are as follows: (a) the angle of the axis of the body and neck is smaller than 130° in the arthrogram (Figure 11.19), (b) the nucleus of the talus has grown to a size sufficient for osteotomy (the child should be 3 years old or older), (c) there is no contracted scar from previous operations that disturbs elongation of the soft tissue on the medial side of the foot.

Surgical Technique

If the calcaneus is in an abnormally rotated position relative to the talus, subtalar release should be performed through the posterolateral approach immediately prior to talar neck osteotomy.

The procedure for talar neck osteotomy is as follows: A medial longitudinal incision centered over the talonavicular joint is made from a point just distal of the navicular to a point just above the medial malleolus. The tibialis posterior tendon is lengthened by Z-plasty. If there is medial subluxation of the navicular, the talonavicular joint is opened, except for the dorsal capsule, and the navicular is repositioned laterally. The neck of the talus is exposed, taking care not to damage the vascular

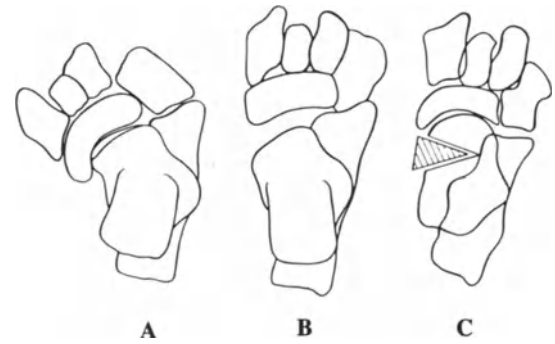


FIGURE 11.18. The principles of talar neck osteotomy. A: Resistant clubfoot. B: Clubfoot after soft tissue release operation. C: After talar neck osteotomy with iliac bone graft.



FIGURE 11.19. Arthrogram revealed medial deviation of the talar neck.

branches from the dorsalis pedis artery (Figure 11.20). Osteotomy using a thin osteotome is carried out in a vertical plane just anterior to the medial malleolus (Figure 11.21). After osteotomy, adductus of the distal foot is corrected and the osteotomy line is opened 4 to 8 mm. A one-piece cortical wedge-shaped iliac bone graft is put into the opened osteotomy and is fixed with a Kirschner wire through the axis of the talar neck. A short leg cast is applied; the Kirschner wire is removed at 4 weeks and the cast at 6 weeks after surgery (Figure 11.22). After removing the cast, a Denis Browne splint is used at night for 6 months.

Materials and Methods

Talar neck osteotomy was performed on 44 feet of 38 patients between 1975 and 1981. The age at surgery ranged from 1 year 8 months to 8 years 1 month and averaged 3 years 10 months. Thirty-seven feet of 31 patients were followed for 8 to 15 years; the average follow-up was 11 years 8 months.

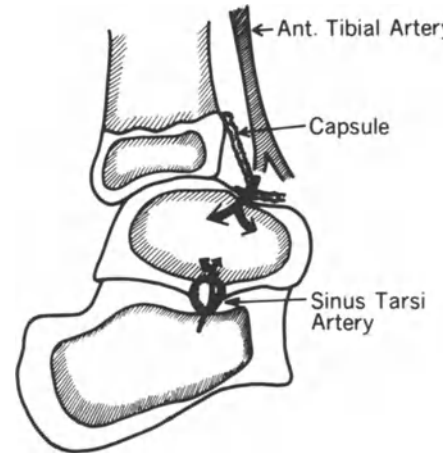


FIGURE 11.20. Blood supply to the talus.

Treatment Before Talar Neck Osteotomy

Talar neck osteotomy was the first operation in three feet of two cases and was performed as a salvage operation in the remaining cases. Sixteen feet in 14 cases had unsatisfactory results from previous posterior releases, 12 feet of 9 cases had unsatisfactory results from previous posteromedial releases, and the other cases involved unsatisfactory results from operations such as Achilles tendon lengthening (Table 11.2).[9]

TABLE 11.2. Treatment before talar neck osteotomy.

Type of treatment	Number of patients	Number of clubfeet
Conservative treatment only	2	3
Achilles tendon lengthening	5	5
Achilles tendon tenotomy	1	1
Posterior release	14	16
Posteromedial release	9	12
Total number of clubfeet	31	37

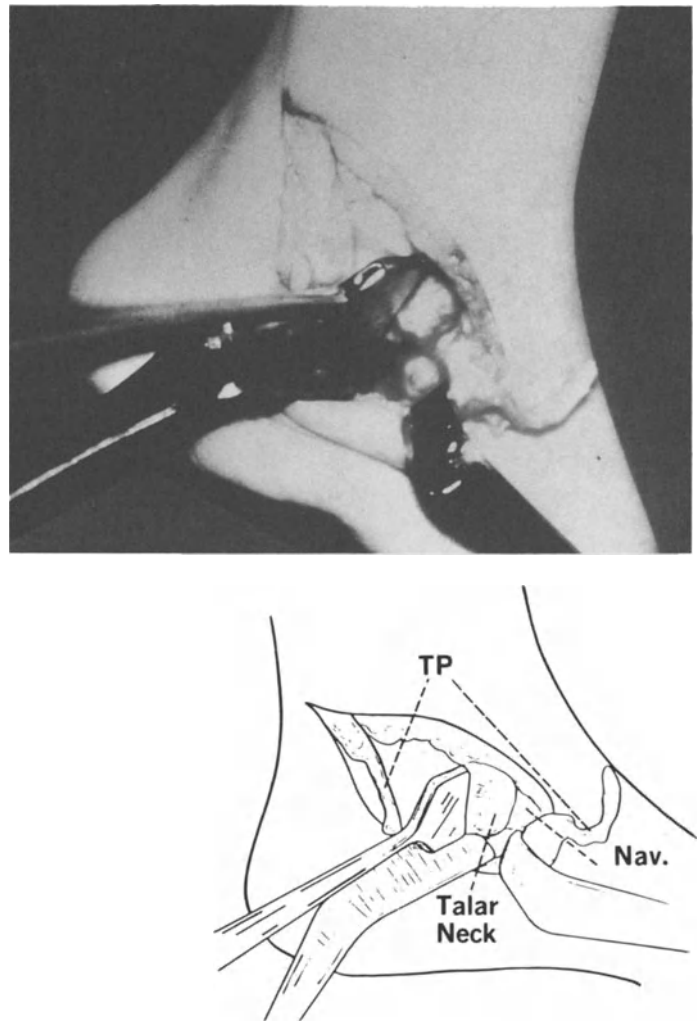


FIGURE 11.21. Talar neck osteotomy. TP, tibialis posterior.

Procedures Combined with Talar Neck Osteotomy

Posteromedial release was combined with talar neck osteotomy in eight feet of eight cases in the early phase of the series; posterolateral release was combined with talar neck osteotomy in 24 feet of 20 cases later in this series. Lichtblau's lateral excision of the distal part of the calcaneus was combined with talar neck osteotomy in 28 feet in the beginning of this study (Table 11.3).

TABLE 11.3. Procedures combined with neck osteotomy.

Type of procedure	Number of clubfeet
Posteromedial release	8
Posterolateral release	24
Lichtblau's lateral excision of the calcaneus	28

Clinical Evaluation

Ankle range of motion was evaluated clinically. Gait, shape, function, and radiographs were also evaluated.

Gait was evaluated both clinically and by examining footprints on long rolls of paper. Shape was evaluated clinically; the angle between the axis of the hindfoot and the axis of





FIGURE 11.22. Radiograph of a 3-year-old boy. Talar neck osteotomy was performed 1 month previously.

the second metatarsus was measured using a pidoscope.* Forefoot adductus over 30° to the femoral axis was rated "severe"; between 30° and 16°, "mild"; between 15° and 0°, "slight"; and 0° to −15°, "normal." Function was evaluated by testing strength of the triceps, flexor hallucis longus function, ankle pain, subtalar pain, sports activities, and shoe wear.

Since the talus of the small child is composed mainly of cartilage, which Fuji computerized radiograms (FCRs) cannot visualize, arthro-

*The patient stood on the pidoscope with the patella facing forward.

graphy was used to evaluate the shape of the talus preoperatively in the young child. The angle between the axis of the talar body and the axis of the talar neck and the angle between the axis of the talar body and the axis of the calcaneus were measured.

FCRs were examined as part of the postsurgical follow-up since the talus of the older child has become ossified to a larger extent, and thus it can be visualized by FCR. Therefore, we used its advanced imaging capability to obtain clear images of the talus and the calcaneus in the older child in spite of the overlapping bones. The same angles were measured on the FCR as were measured on the arthrograms.

Results

Additional Operations

Five feet underwent an additional operation within a short time after the talar neck osteotomy. Pantalar fusion was required in one foot which became infected. Japas' V-osteotomy was combined with Dwyer's calcaneal osteotomy in two feet of one patient. Posterolateral release was performed in two feet in one patient. However, repeat talar neck osteotomy was not performed in any patient.

Postoperative Clinical Evaluation

Excluding the five feet in three patients described above, the following evaluation was performed on 32 feet of 28 patients.

The range of dorsiflexion of the ankle was from −20° to 30° with an average of 12.2°. Plantar flexion of the ankle ranged from 0° to 55° and averaged 37.5°. The arc of the ankle joint ranged from 5° to 65° and averaged 50.5°.

Severe in-toeing gait was absent in all cases, but slight in-toeing gait was present in 16 feet.

Forefoot adductus was present prior to talar neck osteotomy in all 37 feet. Heel varus deformity was present in 28 feet. Equinus was observed in 17 feet.

Postoperatively, we found no severe forefoot adductus deformity, although we did find mild adductus deformity in nine feet and slight adductus deformity in two feet. Heel varus deformity was present in eight feet postoperatively. (The correction of heel varus depends on the soft tissue release procedures combined with the talar neck osteotomy.) Equinus remained in two feet (two patients) after surgery.

Seven patients (11 feet) could not support their weight on the toes of one foot only, but needed both feet. Activity of the flexor hallucis longus was preserved in all cases.

Eight patients (nine feet) complained of slight pain in the ankle at the end of the day. Five feet were slightly painful (subtalar) at the end of the day. Thirteen patients could not perform well in sports. Two feet of two patients required orthopedic shoe inserts.

Radiographic Evaluation

In the preoperative arthrographic examination, the angle between the axis of the talar body and that of the talar neck ranged from 116° to 137° with an average of 124.3° ±4.7°. The angle between the axis of the talar body and that of the calcaneus ranged from −26° to 5° and averaged −12.9° (Figure 11.23).

In FCR examination postoperatively, the angle between the axis of the talar body and that of the talar neck ranged from 135° to 175° with an average of 153.9°, and the angle between the axis of the talar body and the calcaneal axis ranged from −10° to 15° with an average of 4.0° (Tables 11.4 and 11.5)

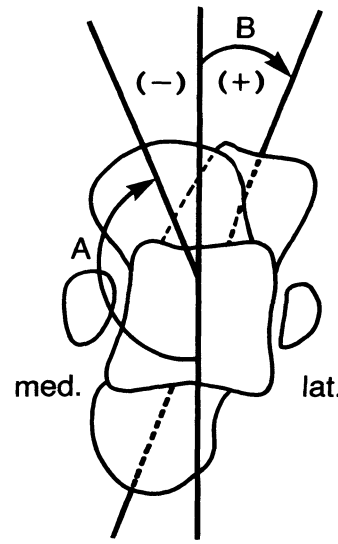


FIGURE 11.23. Arthrographic measurements. A: The angle between the axes of the talar neck and body. B: The angle between the axes of the talar body and the calcaneus.

TABLE 11.4. Arthrographic and FCR measurements: normal values for talar neck–body angle and talar body–calcaneal axis angle.

	Arthrogram ($n = 24$)	FCR ($n = 114$)
Talar neck–body angle	152.4° ± 5.2°	159.1° ± 4.5°
Talar body–calcaneal angle	6.9° ± 1.8°	6.8° ± 3.6°

Mean ± S.D.

TABLE 11.5. Arthrographic and FCR measurements: ranges and average values (for patients in study) of talar neck–body angle and talar body–calcaneal axis angle.

	Arthrogram ($n = 24$)	FCR ($n = 128$)
Talar neck–body angle	124.3° ± 4.7°	153.9° ± 10.9°
Talar body–calcaneal angle	−12.9° ± 7.9°	4.0° ± 9.2°

Mean ± S.D.



FIGURE 11.24. Flattening of the articular surface of the talar head.



FIGURE 11.25. Shortening of the talar neck.



FIGURE 11.26. Dorsal navicular subluxation.

Thus, talar neck osteotomy improved the talar neck-body angles to near-normal range. But when the averages of these angles were measured in follow-up, there was a statistical difference from the average angle in normal feet using the Student's t-test ($p < .05$). Soft tissue release procedures combined with talar neck osteotomy corrected the adducted position of the calcaneus. The average of the angles between the talar body and the calcaneal axis measured in follow-up was not statistically different from the averages of this angle in normal feet using the Student's t-test ($p < .05$).

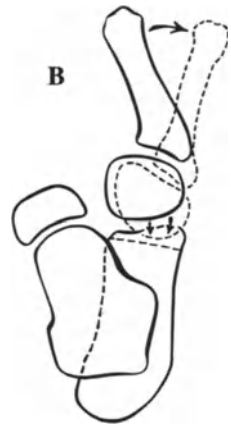
Talar neck osteotomy corrected the angular deformity of the talus but failed to lengthen the medial ray of the foot. Soft tissue release procedures combined with this osteotomy corrected the calcaneal adduction in the horizontal plane.

FCR examination revealed no talar neck or talar body necrosis, but flattening of the articular surface of the talar head was observed in 16 feet (Figure 11.24). Flattening of the trochlea of the talus was seen in 20 feet. Shortening of the talar neck was present in 13 feet (Figure 11.25). Dorsal subluxation of the navicular occurred in seven feet (Figure 11.26). Flattening of the navicular was present in five feet (Figure 11.27). Deformity of the talonavicular joint was seen in 26 feet of 24 cases. Cavus deformity associated with a long talar neck was



FIGURE 11.27. Flattening of the navicular.





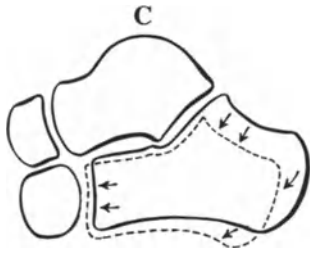


FIGURE 11.28. A: A shorter calcaneus after Lichtblau's procedure. The calcaneus was displaced anteriorly. B: Our expected result for Lichtblau's procedure; posterior displacement of the cuboid. C: The actual result with anterior displacement of the calcaneus and subluxation of the posterior facet joint.

found in one foot. FCR of the foot in patients treated with Lichtblau's[10] procedure revealed a shorter calcaneus, as well as anterior movement of the calcaneus shortening the lever arm of the Achilles tendon (Figure 11.28). (Contrary to our expectations that the *cuboid* would move posteriorly, the *calcaneus* moved anteriorly beneath the talus. One reason for this phenomenon may be instability of the subtalar joint. This phenomenon is seen in the anterior drawer x-ray of the patients with an injured cervical ligament between the talus and the calcaneus.)

Discussion

Our results with early posterior release and posteromedial release were evaluated as good using Fredenhagen's[4] evaluation system; however, there were cases with in-toeing gait.[11] The real utility of talar neck osteotomy is as a salvage operation for recurrent and severely deformed resistant clubfeet.

In this decade, our understanding of the morbid anatomy of congenital clubfoot has improved by means of arthrographic techniques, computed tomography (CT), echography, and computerized radiography.[2,3,5–8,11] Accurate understanding of pathoanatomy, advances in early operative treatment, and the concept of complete subtalar release, in particular, have reduced the rates of postsurgical recurrent clubfoot.[12–16] In fact, the need for talar neck osteotomy has decreased since 1981.

In this follow-up study, we realized how difficult it is to normalize a hypoplastic and severely deformed talus. One of our aims in talar

neck osteotomy was to elongate the medial ray of the foot. In postoperative analysis, however, the neck in 12 feet remained short. In addition, flattening of the articular surface of the head, subluxation of the navicular, and flattening of the navicular were found in 24 of 26 feet. These procedures all tend to shorten the medial ray.

We don't believe that talar neck osteotomy is the only cause of these deformities, although we do believe one of the more important causes is increased pressure on the medial ray. The talus and the navicular are mainly composed of chondral bone in young children. Therefore, these bones are deformed easily by compression forces. If the talonavicular joint is opened, the navicular will dislocate dorsally in some cases. We now think it is important to decrease the tension in the adjacent soft tissues of the medial side of the foot before this procedure. It may be better to gradually elongate the soft tissues using external fixation, such as an Ilizarov device, before talar neck osteotomy. The operation should be delayed until talar and navicular ossification have progressed substantially, i.e., over 10 years of age. Finally, talar neck osteotomy should be limited to cases with severely deformed talar necks in children older than the patients in this study.

Conclusion

Osteotomy to correct a deformed talar neck may be theoretically correct, but involves high risk of increased pressure on the talonavicular joint if performed in young children. We believe this procedure should be limited to children over 10 years of age with severe deformity of the talar neck. The most important thing in the surgical treatment of congenital clubfoot is to achieve complete correction of the relationship between the talus and the calcaneus with the initial soft tissue operation. If this can be achieved, the need for talar neck osteotomy will be minimized.

Summary

Talar neck osteotomy to correct medial deviation and shortness of the talar neck by osteotomy and insertion of an iliac bone graft was performed on 44 feet (38 patients) between 1975 and 1983. The age at surgery ranged from 1 year 8 months to 8 years 1 month and averaged 3 years 10 months. Thirty-seven feet of 31 patients were followed for 8 to 15 years.

We found no severe forefoot adduction deformity, although there was mild adduction deformity in nine feet and slight adduction deformity in two feet. A slight toe-in gait was present in half the cases. Roentgenograms revealed flattening of the articular surface of the talar head in 16 feet. Dorsal subluxation of the navicular occurred in seven feet. Flattening of the navicular was present in five feet. Osteotomy to correct a deformed talar neck produces problems in the talonavicular joint complex in young children.

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Brachymetatarsia of the First Metatarsal Treated by Surgical Lengthening

H. Peterson

Brachymetatarsia of the 1st metatarsal is uncommon. It may occur as a congenital condition (Figure 11.29), as a complication of previous surgery, such as osteotomy followed by nonunion (Figure 11.30), or as a result of injury to the growth plate (physis) of the 1st metatarsal (Figure 11.31). Congenital shortening, when present, is usually in association with other congenital abnormalities, such as polydactyly and syndactyly. Injury of the physis resulting in premature growth arrest may occur in many situations, such as fracture, infection, tumor, irradiation, and thermal injury, or may result from a surgical procedure, such as subperiosteal dissection in the vicinity of the physis, pin placement across the physis, or osteotomy across the physis.[2,4,7]

The severity of the relative shortening may be expressed as a comparison between its contralateral member, if normal; as a percentage of the length of bone relative to the length of the other metatarsals; or as a percentage of the expected length of bone. When the 1st metatarsal is significantly shorter than the lateral metatarsals, weight is transferred to the neck of the 1st metatarsal and to the heads of the lateral metatarsals; this change predisposes the foot to transfer metatarsalgia, chronic pain, and shoe-fitting problems.[5]

Methods of surgical management of relative shortening of the 1st metatarsal have included resection of the heads of the lateral four metatarsals, proximal osteotomy of the 2nd, 3rd, and 4th metatarsals, and insertion of a polytef (Teflon) prosthesis in the 1st metatarsal (the prosthesis eventually eroded through the sole and was removed.)[1] Chiappara[1] described a technique in which surgical shortening of the proximal ends of the first proximal phalanx is combined with shortening of the proximal ends of the middle three metatarsals and lengthening of the medial cuneiform. This result is to allow the hallucal interphalangeal joint to substitute for the metatarsophalangeal joint. Skirving and Newman[6] reported a case in which gradual distraction achieved 1st metatarsal lengthening with use of a mini-external fixator without bone grafting.

Surgical lengthening of the relatively short 1st metatarsal addresses the abnormality directly, whereas other methods address the abnormality indirectly. Lengthening can be accomplished by one-stage distraction and bone grafting or by a two-stage procedure in which osteotomy and gradual distraction are followed by bone grafting. Alternatively, the technique of Skirving and Newman[6] (sometimes referred to as "callostasis") can be used to gradually lengthen the 1st metatarsal without bone grafting.

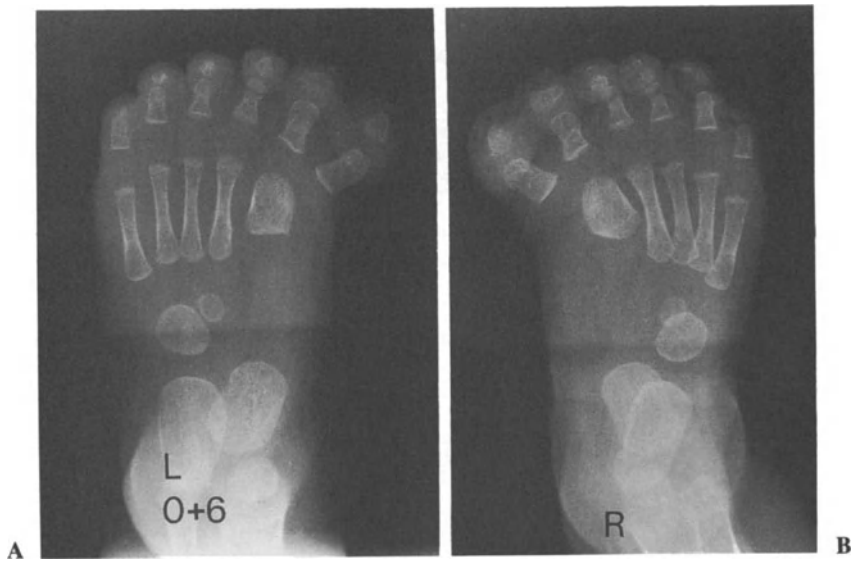


FIGURE 11.29. Case 1: congenital relative shortening of the 1st metatarsal in a 6-month-old girl with polydactyly (duplication of the great toe) and syndactylism of the medial three toes bilaterally. A: Left foot. B: Right foot.

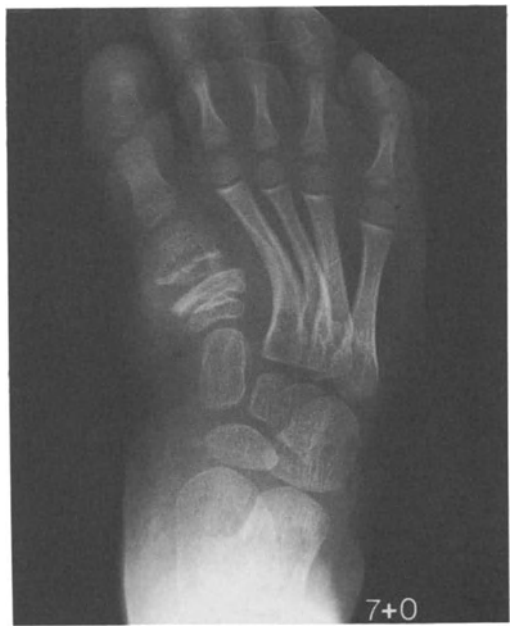


FIGURE 11.30. Case 3: nonunion with shortening of the 1st metatarsal as a result of metatarsal osteotomies.

Materials and Methods

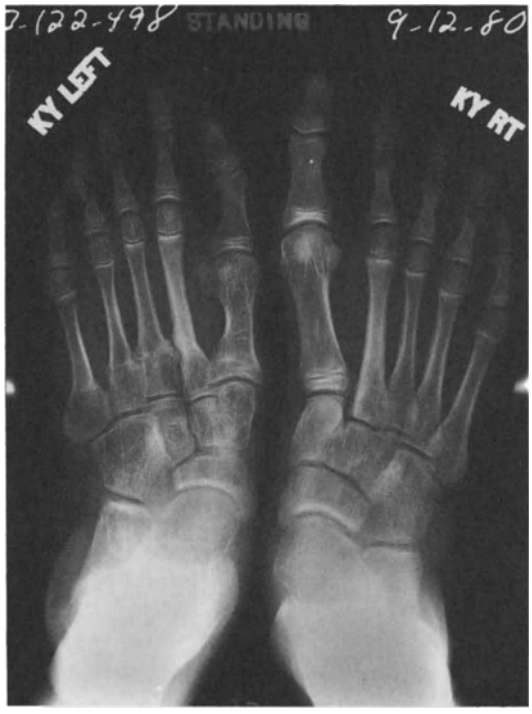
Gradual distraction of the 1st metatarsal was performed on six feet (four patients) in an attempt to restore length. In four feet, the shortening of the 1st metatarsal was noted at birth and was associated with other congenital abnormalities. In the other two cases, the children were born with clubfeet: one sustained premature closure of the physis of the 1st metatarsal during treatment (pins placed across the physis on three occasions), and one developed shortening because of diaphyseal nonunion following metatarsal osteotomy. In all six feet, diaphyseal osteotomy and insertion of four pins secured to an external fixator were combined with gradual distraction and subsequent bone grafting.

Case Report

Case 1 in Table 11.6 is a child who was seen at age 6 months because of congenital duplication of the great toes (Figure 11.29) and little



A B



C

FIGURE 11.31. A: Left clubfoot treated in infancy by serial casts and posteromedial release. B: Residual metatarsus adductus was treated at age 6 years with metatarsal osteotomies. Note that the pin crosses the physis and that the osteotomy is close to the physis. C: Premature complete closure of the proximal left 1st metatarsal physis 6 years after osteotomy and pin placement across the physis.

TABLE 11.6. Surgical lengthening of the 1st metatarsal.

Patient	Sex	Etiology	Foot	Age at lengthening (years + mos.)	Fixator	Days lengthened	Amount lengthened (mm)	Bone lengthened (%)	Healed (days)	Follow-up (years + mos.)
1	F	Congenital	L	2 + 7	mini-Hoffman	8	13	68%	60	10 + 4
			R	3 + 9	mini-Hoffman	6	8	36%	57	9 + 2
2	F	Congenital	L	2 + 11	mini-Hoffman	8	8	28%	86	3 + 0
			R	2 + 11	mini-Hoffman	8	7	26%	86	3 + 0
3	M	Clubfoot	R	7 + 0	mini-Hoffman	12	20	46%	150	6 + 4
4	M	Clubfoot	R	14 + 4	Orthofix (EBI)	30	6	12%	184	1 + 6

EBI, Electro-Biology, Incorporated.

fingers bilaterally. She also had a single, short, thick 1st metatarsal on each foot and syndactyly involving the accessory, first, second, and third toes (Figure 11.32A).

Her duplicated fingers and toes were excised. The result was satisfactory, but the first metatarsals remained relatively short (Figure 11.32B). At age 2 years 6 months, metatarsus adductus was present on the left (Figure 11.32C). At age 2 years 7 months, a two-stage lengthening of the left 1st metatarsal was carried out (Figure 11.32D–F). The mini-Hoffman device was used. Fourteen months later (age 3 years 9 months), the right 1st metatarsal was lengthened in a similar fashion (Figure 11.32G). Ten years after the initial lengthening, the patient had a good cosmetic and functional result. She had a mild left hallux valgus deformity that was asymptomatic (Figure 11.32H,I).

Results

Results are presented in Table 11.6. In all instances, improvement in the appearance of the foot was achieved, although only a partial correction of the shortening was accomplished in one foot (case 4). One deformity was accompanied by preexisting or concomitant 1st metatarsal physeal bars (case 2) and another by pseudoarthrosis of the 2nd metatarsal (case 3). Neither of these affected the ultimate outcome, although both required an additional surgical procedure. (Cases 2, 3, and 4 have been published.[7])

Discussion

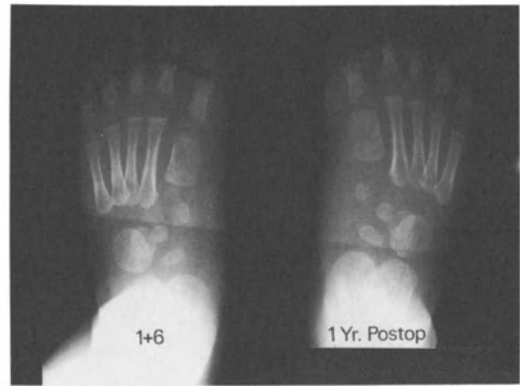
In his monograph on the human foot, Morton[5] proposed that shortness of the 1st metatarsal relative to the 2nd allows transmission of the bulk of the weight load to the 2nd metatarsal or to the 2nd and 3rd metatarsals. This altered transmission of weight is manifested by calluses beneath the 2nd or 2nd and 3rd metatarsals and thickening of the shaft of the 2nd metatarsal on radiographs. Harris and Beath,[3] in a study of Canadian army recruits, refuted this theory and concluded that "a short first metatarsal seldom, if ever, is the cause of foot disability" (p. 563). It should be noted that the relative shortening in most of their subjects with a short 1st metatarsal was only 1 to 4 mm and that all of their subjects were healthy young men. There is no longitudinal or long-term study to document potential disability in patients with a short 1st metatarsal, and no study documents disability with more significant relative shortening like that in the patients in the study presented here. Thus, the prognosis for these patients, if left untreated, is speculative.

Physeal arrest in one patient (case 4) and in another patient (Figure 11.31) not treated may have been caused by pin placement across the physis. Therefore, pin placement across the physis should be avoided if possible. Because relative shortening from physeal damage takes years to appear, long-term follow-up is necessary after such pin placement.

These four cases demonstrate that the 1st metatarsal can be surgically lengthened by osteotomy, gradual distraction by an external



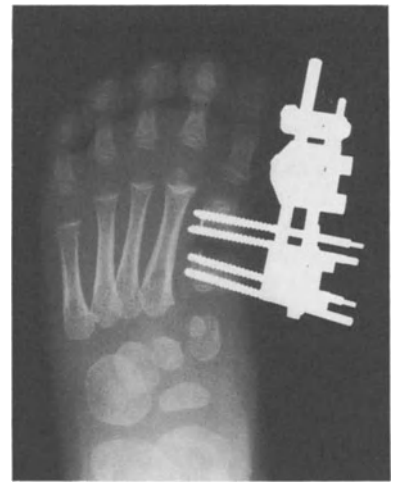
A



B



C



D



E



F



G



H



I

FIGURE 11.32. Case 1: Reduplication of the great toes. A: Age 6 months. The accessory great toes were excised at this time. B: Both feet age 1 year 6 months. One year after excision of the accessory great toes. Note the relatively short 1st metatarsal and shortening of the first ray. The proximal epiphysis of the 1st metatarsal has not yet ossified. C: Radiograph during standing at age 2 years 6 months with metatarsus adductus and inversion on the left. Note ossification of the epiphysis at the proximal end of the 1st metatarsals. D: Radiograph on the day of surgery shows operative length gained. An attempt was made to avoid pin penetration of the proximal physis. E: Age 2 years 7 months. After 8 additional days of lengthening, a fibular bone graft 15 mm long was inserted. The mini-Hoffman apparatus stayed in place and was removed 24 days later. F: Age 2 years 8 months. One month after osteotomy and 24 days after lengthening, the mini-Hoffman apparatus was removed. A short leg walking cast was applied and was worn for 4 weeks. G: Age 3 years 10 months. Subsequent metatarsus adductus on the right side was similarly treated with a 10-mm fibular graft. The radiograph was taken at the time of cast removal 2 months postoperatively. H: Age 12 years 10 months. Radiographs of both feet in the standing position 10 years 4 months after surgery (left) and 9 years after surgery (right). Note the excellent incorporation of fibular grafts and the continued growth of the 1st metatarsals. I: Both feet at age 12 years, 10 months. Ten years (left foot) and 9 years (right foot) after operation. Patient was normally active and asymptomatic with no foot problems.

device, and subsequent bone grafting. Five feet were lengthened with a mini-Hoffman device, and on one foot an Orthofix lengthener was used. Either lengthener is satisfactory. The mini-Hoffman is more versatile, and its small size is adaptable to small bones. The Orthofix is sturdier, but the distance between the pins may require insertion of the two pin ends into the first cuneiform and proximal phalanx to avoid the metatarsal physis. Its use is limited to older children with larger feet.

In all six feet, a segment of fibula was used as the bone graft once the length had been achieved. In five feet, the fibular graft was placed between the 6th and 12th postoperative days after gradual daily distraction. In two feet, the graft was fixed with a longitudinal Kirschner wire and the lengthener was removed. In three feet, the lengthener was removed and a cast applied with no internal fixation. In these five feet, the lengthener was removed and a cast applied with no internal fixation. In these five cases, the fibular graft gave good stability, maintained the length, and was promptly incorporated into the adjacent bone. In one foot (case 4), the bone graft was

inserted after maximal length was achieved at the time of surgery and then additional lengthening obtained. The intention was to allow this additional length to heal spontaneously. This, however, did not occur; additional bone grafting resulted in union but some loss of the length gained. This one case of gradual distraction and maintenance of external fixation should not be used to condemn callostasis, since this was not a standard utilization of this concept.

Thus, from this experience in these six feet, osteotomy followed by gradual lengthening and bone grafting after length is achieved worked best. However, the method of osteotomy, lengthening, and allowing the bone to fill in spontaneously, as is now commonly done with other long-bone lengthenings (callostasis), is possible. One factor against doing that in the foot is that it would preclude weight bearing for a considerable length of time, and if the procedure was done bilaterally, the patient would be nonambulatory for a prolonged period. Extended use of an external fixation device on the foot might also result in a higher rate of pin track infection.

The metatarsals that were short and abnormally thick at birth and were subsequently lengthened appeared to do best. Although the physis was not visualized at the time of lengthening, the growth plate was present and eventually grew. Thus, in two patients, the 1st metatarsals grew significantly after the lengthening had been completed. This was a pleasant surprise, and in two feet (case 1) the growth appeared to be normal, exceeding the relatively inefficient growth before lengthening.

Summary

Care should be taken to avoid trauma to the physis of the proximal 1st metatarsal during surgery for clubfoot, metatarsus adductus, or any other condition. Growth arrest of this physis may take years to become manifest. Thus, long-term follow-up is necessary. Surgical lengthening of the 1st metatarsal is feasible and can provide excellent results. The procedure has many advantages over procedures that shorten other metatarsals and remove or destroy joints.

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Discussion

Watts (Los Angeles): Dr. Paley, in several of your calf widening cases, the calf did not seem to be as wide as the normal side. Did you stop prematurely because you were fooled by swelling in the involved calf, or was there some other reason?

Paley (Baltimore): There are several factors. Swelling is one of them. In one case, the size of the legs looked completely equal while the apparatus was on. Three years later, it was a little thinner. So one can be fooled by swelling. The last thing that one wants to do is to end up with a larger calf than the normal side. Secondly, the foot frequently will noticeably differ in size; the sizes of the two limbs can never be completely equalized. The third factor is that widening of the calf increases pain substantial-

ly. If the patient is having a lengthening procedure, a foot correction procedure, and a calf widening procedure simultaneously, there may be a significant amount of pain and they may not want you to continue with the widening. So, you may be restricted by that.

McKay (Ville Platte, Louisiana): How long have you been following these cases? You say that they did not become narrow again with further growth.

Paley: The first one was done in 1987 and they have not become narrower with further growth.

McKay: Dr. Paley, in regard to your calcaneal osteotomies, couldn't you have accomplished the same thing with just a simple triple arthrodesis?

Paley: Every triple arthrodesis shortens the foot. These are already short feet. Cosmetically all these feet look better than any triple I've seen. In addition, since all patients had a leg lengthening the osteotomies were done in combination with a total lower leg reconstruction. We examine the extremity carefully, make a list of the problems, and treat as many of them as possible at the same time.

Tachdjian (Chicago): Have any lost nerve function?

Paley: No. Because most of these have been either polio, traumatic nerve injuries, or clubfeet, their nerve function was not normal to begin with.

Goldner: Do you think that if there was normal function, you might run the risk of developing a compartment problem?

Paley: No. I don't think they develop compartment problems, and fortunately, we haven't had any nerve problems either, but I am always worried about passing the olive wires into the fibula.

Tachdjian: Don't you lose muscle strength when you lengthen the limb?

Paley: No one has documented that well enough. The only paper I am aware of was written by Ilizarov around 1985 on single and double level lengthening in which he reported that muscle strength returned to normal over a period of 3 years.

Carroll (Chicago): Dr. Paley, what is hard edema, where does it come from, and how long does it take for it to go away?

Paley: That's the term used by Professor Cattaneo (Lecco, Italy). He likes to call swelling "hard" edema or "soft" edema, which is very common following foot corrections. Venous edema is "soft" edema and lymphedema is "hard" edema. As you know, lymphedema is really a harder, woodier type of edema, and it takes much longer to subside. Pitting edema is venous edema. It goes away with elevation rather quickly. Lymphedema will decrease with elevation, but only after prolonged elevation. It takes a year or more for lymphedema to go away after these foot corrections.

McKay: Dr. Ozeki, do I conclude correctly from your paper that you no longer perform the talar neck osteotomy?

Ozeki (Sapporo): We do it in some older patients.

Hansson (Uppsala): Dr. Hjelmstedt in Uppsala has been performing osteotomies of the talar neck. He published his cases recently but seemed unhappy with the results. He has stopped doing it.

Drvaric (Atlanta): Roberts (Springfield, Massachusetts) has performed about 30 talar neck osteotomies; however, none recently that I know of.

Turco (Hartford): I remember when Roberts first presented his paper. I told him that Wishingham first performed the operation in 1885 and every generation someone else rediscovers it; they try it for a while and then stop. So, history repeats itself.

Peterson (Rochester, Minnesota): In discussing the causes of physeal arrest of the 1st metatarsal in clubfeet, there are five factors regarding the pins: the use of threaded versus smooth pins is the most important factor; position is another; a pin passing through the center of the physis is less likely to cause closure of the physis than if it passes through the outside of the physis; the angle of the pin crossing the physis is probably important, especially if it's more acute; the size of the pin compared to the size of the physis is obviously a factor; and finally, time and place may be factors, but are less important.

Tachdjian: I learned from Professor Dibastiani how to do 1st metatarsal lengthenings. The first pin is inserted into the medial cuneiform bone, the second pin into the metaphysis away from the proximal physis of the 1st metatarsal, and the third pin into the metatarsal head. It is surprising when the metatarsal is lengthened how quickly the distal phalanx may develop a contracture. Insert a pin into the first phalanx to prevent this. I also learned that fibular grafts take a long time to heal and it is preferable to use iliac bone grafts. There were problems with infection if the foot was lengthened gradually in a child, so I now do instantaneous lengthenings. Recently, I achieved 1.25 cm of lengthening immediately. If an intramedullary pin is used, it should be smooth and it is taken out at about 4 weeks. The iliac graft will have already incorporated by that time; the foot should then be protected by a cast for another 3 or 4 weeks.

Editor's Comments

Paley has presented an excellent two-part paper on distraction of soft tissues using the Ilizarov apparatus both with and without osteotomies. In the first part (Chapter 10), he defines the use of the constrained versus the unconstrained apparatus.

Paley's complications were considerable, as were the advantages and disadvantages of the osteotomy technique when combined with Ilizarov distraction. The advantages are as follows: (a) less likelihood of neurovascular compromise; (b) improved foot-length maintenance; (c) the probability of less stiffness than with other procedures that require bone resection, arthrodesis, etc.; (d) the possibility of correcting the associated deformities simultaneously with the main deformity; (e) the likelihood of this being a safer procedure than surgery performed in previously operated feet, and, finally, (f) the adjustability of the Ilizarov apparatus even after an acute correction is performed. Thus, one is able to improve foot position following surgery. This greater adjustability makes it possible to achieve the exact position of the foot desired by the patient.

The disadvantages involve (a) the presence of an external fixation device with its inherent pin track complications, (b) long duration of foot immobilization in the fixator, (c) mild-to-moderate pain during the lengthening process, and (d) inability of the procedure to improve stiffness.

I have just seen excellent results following bilateral Ilizarov distraction without osteotomy performed by **Paley** in Baltimore on one of my 4-year-old patients with bilateral teratologic clubfeet associated with arthrogryposis. This child had previous extensive releases with subsequent recurrence of deformities. Consequently, I cannot conceal my enthusiasm for the potential of the Ilizarov technique, or similar techniques, for young children with CTEV in the future.

Ozeki and his colleagues very honestly report their complications following talar neck osteotomy, although the striking complication that one would expect following talar neck osteotomy, i.e., avascular necrosis of the talus, was not a problem in their experience. However, they did notice changes such as flattening of the talar head, shortening of the talar neck, dorsal subluxation of the navicular with flattening of the navicular, and deformity of the talonavicular joint—all of which could be attributed to increased pressure on the medial column following their osteotomy. They also found cavus deformity associated with a long talar neck in one patient and recommend that the osteotomy should be limited to patients with severely deformed talar necks in the older age group (i.e., over 10 years).

In the Discussion section of this chapter, several authors indicate their apprehension with the use of femoral neck osteotomy. Several proponents of the procedure in other countries apparently have stopped using it, presumably because of the complications noted by **Ozeki et al.**, i.e., complications related to in-

creased pressure in the medial ray. **Ozeki** and his colleagues suggest a way that these complications can be prevented, i.e., that talar neck osteotomy be preceded by lengthening of the medial column with an external fixator to stretch the severe soft tissue contracture. They recognize the all-important issue of achieving complete correction during the first operative intervention, thereby minimizing the need for talar neck osteotomy later.

12
Surgical Complications: Valgus/ Calcaneus/Cavus/Dorsal Bunion

Introduction

Exner describes several cases of tourniquet-associated skin lesions that apparently resulted from penetration of antiseptic skin preparations between the tourniquet and the skin. He describes a method for preventing leakage of the prep solutions beneath the tourniquet.

McKay discusses the causes and treatment of overcorrected clubfeet in a brief, but very fine, paper. He describes the causes of the following complications and suggests treatment for each: dorsal bunion, nonfunctional toe flexor tendons, dorsiflexion contracture of the ankle, and heel valgus.

Coleman describes the treatment of the cavus component in congenital talipes equinovarus (CTEV) and describes the use of Meary's angle to determine the type of surgery he will use.

Weiner and Weiner present a paper on the Akron midtarsal dome osteotomy for the treatment of rigid pes cavus. This paper represents a follow-up of an earlier paper on a small number of cases, i.e., about 20. In this paper, 100 feet are evaluated.

Kuo describes a "reverse Jones" procedure for correction of dorsal bunions occurring as a complication of previous surgical treatment. As pointed out in the discussion, this is not truly a "reverse Jones" procedure as the interphalangeal (IP) joint of the toe is not fused and additional procedures were frequently used in association with the flexor hallucis longus tendon transfer to the base of the 1st metatarsal, e.g., a split anterior tibial tendon transfer.

Causes and Prevention of Tourniquet Lesions in Congenital Talipes Equinovarus Surgery

G. Ulrich Exner

Surgical correction of a clubfoot requires careful exposure in order to keep the surgical trauma as minimal as possible. This is best performed in a bloodless field, provided by tourniquet hemostasis after exsanguination with an Esmarch (Martin) bandage. However, several harmful effects may result from the use of a tourniquet. The best known negative effects are posttourniquet paralysis and compartment syndromes related to ischemia and often to direct compression beneath the tourniquet. Many publications have dealt with such important factors as cuff pressure, duration of tourniquet time, exsanguination of the limb with an Esmarch bandage, and the safe reproducible results with appropriate use. An excellent review of the technique and problems with the use of a tourniquet has been given recently by Green[5] and the reader is referred to this article and the review of the literature given therein. Fewer articles deal with skin lesions that may occur beneath the tourniquet, related to pinching of the skin[2] or chemical burns from penetration of prep solution[1,3,4] between the cuff and the skin. It is stressed by Green[5] that seepage of scrub solution beneath the tourniquet cuff during skin preparation is to be avoided, and a figure in his book shows a case of skin necrosis that was related to iodophor penetration.

Three cases of severe skin lesions in children with CTEV have been observed in the past 3 years at our institution following the use of a tourniquet on the lower extremity. These are reported here to draw attention to the problem. The technique that has helped us to prevent the problem is demonstrated.

Materials and Methods

In 1988, we had three patients with severe second- and third-degree burns after removal of the tourniquet following surgery for CTEV. The patients were between 3 months and 3 years of age. The most severe case is illustrated in Figure 12.1 with almost a circumferential lesion. This patient was 3 months of age when a posterior medial release was performed. The lesion healed without grafting and without functional impairment; however, scar formation remains a significant cosmetic problem.



FIGURE 12.1. Skin necrosis in the area of the tourniquet documented 2 weeks after clubfoot surgery.



A



B



C



D

FIGURE 12.2. Technique to minimize the risk of seepage of scrub solution underneath the tourniquet. A: The tourniquet is applied and secured with an elastic bandage. B: The sleeve is cut off of a surgical glove of appropriate size and pulled over the distal end of the tourniquet. C: The skin is prepped. D: Proximally there remains a dry margin close to the tourniquet.

Technique Used During the Period of Occurrence of Skin Lesions

The type of tourniquet used has not been changed since the occurrence of the skin lesions. The tourniquet was applied directly to the skin. The skin was cleaned with towels soaked in 70% isopropyl alcohol and squeezed out before wiping the skin. Then sponges were applied, using a solution containing 50% isopropyl alcohol and 1% Polyvidonium-Iodum (containing 10% iodine and approximately a 0.1% Braunoderm solution). After draping and exsanguinating with an Esmarch bandage, the tourniquet was inflated to between 200 and 250 mm Hg. The tourniquet time was limited to 2 hours.

Technique Now Used

The technique that is now used is illustrated in Figure 12.2. The only change is the careful prevention of the prep solutions from penetrating beneath the tourniquet. The skin is padded with three to four layers of cotton wrap. The tourniquet is applied snugly to the padded area, being careful not to squeeze the skin. The tourniquet is secured with an elastic bandage. The sleeve, which has been cut off of a surgical glove, is pulled over the distal end of the tourniquet in order to tightly "seal" the tourniquet against the skin to prevent penetration of the prep solutions. After the skin preparation is completed, the region adjacent to the tourniquet is wiped with a dry sponge; the sleeve is then carefully removed, avoiding contamination of the prepped skin.

Results

After introduction of this technique, we have had no further cases of skin lesions or irritations.

Discussion

Adverse effects from the use of the tourniquet appear to be related to several factors: (a) contact between the cuff or padding material and the skin, (b) pressure forces of the tourniquet

directly affecting the skin and soft tissue structures beneath the tourniquet, and (c) the peripheral effect caused by blocked circulation.

The exact nature of the skin lesions that appeared as second- to third-degree burns is not known. From the location beneath the tourniquet, it is assumed that they were certainly related to factor (a), above, and it is very likely that factor (b) also has an important role. Furthermore, it is extremely likely that factor (c), the penetration of the alcoholic iodophor prep solution beneath the tourniquet, has also been a significant factor, since, after carefully avoiding penetration by the prep solution, such lesions have not occurred.

Conclusion

The lesions described were most likely caused by penetration of the prep solution beneath the tourniquet and were probably related to pressure forces exerted by the tourniquet directly upon the underlying skin. We believe that these lesions can be prevented by a meticulous skin prepping technique. There are other possible causes of temporary or permanent injury. These include allergic skin reactions related to the cuff or padding material, skin ischemia, electric currents, etc. These could be avoided with certainty only by not using a tourniquet. In light of the great advantages made possible only in the bloodless field of tourniquet hemostasis, with cautious use the benefits of a tourniquet far outweigh the risks that occasionally occur with the best techniques.

Summary

Three patients are reported who developed severe lesions beneath the tourniquet, which was applied for clubfoot surgery. The cause was most likely penetration of scrub solution beneath the tourniquet in combination with pressure forces exerted by the tourniquet. A technique to minimize the risk of seepage of prep solution beneath the tourniquet by sealing the area beneath the tourniquet with the sleeve of a surgical glove is reported.

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Correction of the Overcorrected Clubfoot

Douglas McKay

Unfortunately, with clubfoot surgery we all have overcorrected clubfeet at one time or another. Overcorrection is quite common following revision surgery. Clinically, the foot has the appearance of a flatfoot or rocker-bottom foot. The child walks with a plantar grade gait. The arch may have a large callus and the heel is in valgus. There generally is limited ankle motion with excessive motion at Chopart's joint. Muscle testing may reveal an absence of function of the posterior tibial, flexor hallucis longus, and flexor digitorum muscles.

Why do these previously operated feet gradually develop these deformities? Obviously, the foot could have been overcorrected or corrected imperfectly at the time of the initial

surgery. Furthermore, the child may have residuals of a tight Achilles tendon, which may result in the development of the rocker bottom and, subsequently, a very loose flatfoot. The posterior tibial muscle may have been nonfunctional or may not have been repaired at the time of surgery. The flexor hallucis longus or the flexor digitorum longus muscles may have scarred down and become nonfunctional. The intrinsic muscles may have been overlengthened if a plantar release was performed. Consequently, I think one of the major causes of the overcorrected foot, which gradually develops deformity after 2 years, has to be muscle imbalance. Also, the incongruous subtalar joint in a corrected clubfoot allows the calcaneus to gradually drift into a deformed position. If the surgical correction is through the subtalar joint, as I have proposed, and the resulting subtalar incongruity does not correct itself with growth, then the posterior calcaneus can slip laterally back to its original position, while the anterior calcaneus remains in its corrected lateral position.

My concept is that a rotational deformity is present in the subtalar joint and the portion of the calcaneus that is posterior to the interosseous talocalcaneal ligament is rotated toward the fibula. Thus, prior to treatment, the subtalar joint has accommodated the calcaneus in this position. With surgical correction, the posterior calcaneus is moved medially, which causes incongruity of the subtalar joint. It is very simple to see how the posterior calcaneus could slip back into the original groove adjacent to the fibula, causing valgus of the heel and subsequent flatfoot.

I have tried for several years to prevent these causative factors—first, by understanding the pathoanatomy of the foot; second, by developing a surgical correction that did not lend itself to the development of a sloppy flatfoot; third, by starting early ankle motion; and fourth, by attempting to preserve the function in the posterior tibial, flexor hallucis longus, and flexor digitorum muscles by sheath resection. I have also tried to prevent recurrent calcaneal rotational deformity by creating a ligament between the posterior portion of the talus and the calcaneus. The results of this last technique are too recent for comment.

The other possible solution is for the child to wear a supportive shoe. I have never been a strong believer in corrective shoes or the support that the shoe lends to the foot. Holding the child in a cast for a long period of time would defeat the purpose of trying to establish early ankle motion. I also have an extreme lack of enthusiasm for placing a screw, pin, or other metal or plastic device in the subtalar joint to prevent it from shifting.

I have not yet determined whether the age at surgery is important. For example, what is the result of early range of motion combined with weight-bearing; e.g., if the child is operated on at 3 months and does not start bearing weight for 6 months following surgery, what effect does this have on preventing subsequent overcorrection? From the few cases that I have reviewed, I believe that it may decrease the incidence of overcorrection, but one has to remember that this calcaneal shift does not occur for about 2 years after the operation and, of course, it does not appear in the majority of cases.

Correction of the postoperative deformities depends upon the particular deformity that develops. A significant number present with dorsal bunion. I correct this by performing an intrinsic transfer of the flexor hallucis brevis and the adductor and abductor hallucis tendons to the dorsum of the 1st metatarsal neck. When due to nonfunctional toe flexors, some will respond to release of the scar tissue under the sustentaculum tali, which is the most common place for the toe flexor tendons to become scarred down. If the deformity is due to a lack of plantar flexion, i.e., dorsiflexion contracture at the ankle, which is frequently seen following previous revision surgery, a release of the anterior capsule of the ankle joint and lengthening of the extensor tendons is appropriate. The treatment of heel valgus depends upon the degree of the deformity and the age of the patient. In young adults or adults, the calcaneus can translate far enough laterally to cause impingement between the calcaneus and the fibula which may be painful. The treatment for this is relocation of the calcaneus with subtalar fusion. In the younger patients, if there is no clinical or radiographic evidence of impingement and the patient has no pain, then a calcaneal osteotomy will correct the deformity.

To my knowledge, Dwyer[1,2] was the first to present the concept of calcaneal osteotomy. His procedure was performed on cavovarus

feet. A wedge of bone was removed laterally to correct the heel varus. This created a problem in that it shortened the heel and shortened the lever arm for the Achilles tendon. I soon discovered that cutting the calcaneus obliquely and approximately parallel to the peroneal tendons makes it possible to correct most deformities of the heel. Thus, varus, valgus, calcaneus, or equinus deformities may be corrected by simply cutting the calcaneus and moving it in any direction one chooses. Samilson[5–7] osteotomized the calcaneus in a curved direction. Louis and Cipriano[3] performed a calcaneal osteotomy for residual varus deformity by removing a wedge from the lateral side and placing it on the medial side. However, he reported problems with skin sloughs of the heel following this procedure. Mitchell[4] designed a calcaneal osteotomy for calcaneus deformity that is similar to my technique.

My calcaneal osteotomy is performed through a lateral incision, being very careful to preserve the sural nerve. The calcaneal periosteum is stripped from the lateral side. The calcaneal periosteum must be stripped circumferentially in order to allow it to move. Frequently, the Achilles tendon has to be lengthened a little to put the heel in the proper position. After the osteotomy, the deformity is corrected by moving the calcaneus in the opposite direction. In other words, if the child has a valgus deformity, it is moved medially. If there is no arch in the foot, the posterior calcaneus is moved inferiorly (or caudally), creating an arch and then pinning the calcaneus with a Kirschner wire. I leave the wire in approximately 3 weeks. It takes approximately 6 to 8 weeks for this osteotomy to heal.

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The Cavus Component in Congenital Talipes Equinovarus

S.S. Coleman

Of all the complex deformities occurring in clubfoot, when considering surgical correction, the cavus component appears to have been given the least attention. The importance of the deformity, the methods by which it can be recognized and quantified, and an approach to its treatment are the purposes of this paper. The author feels that failure to identify this deformity and treat it appropriately have been major factors associated with results that are less than satisfactory in clubfoot surgery.

Clinically, the physical signs suggesting significant cavus in the clubfoot consist of the presence of a substantial plantar crease, which, although present in many clubfeet, can be very impressive in feet with a major cavus compo-

nent. Furthermore, the foot is much shorter than the usual clubfoot, and the forefoot equinus is usually rather rigid, being resistive to passive efforts at correction.

Radiographically, it is not difficult to identify the cavus deformity in the lateral view of the foot. In nonwalkers, the radiograph must be taken in a simulated weight-bearing position; this requires considerable expertise on the part of the radiographic technician in order to avoid distortion of the x-ray beam. In walkers, a standing lateral view should always be taken. The talo–1st metatarsal angle (Meary's angle)[1] quantifies the degree of cavus. The normal angle is 0°. Anything greater than that denotes cavus. The 1st through 5th metatarsals show substantial divergence, which confirms the cavus deformity.

Minor degrees of cavus can be corrected during the accomplishment of a one-stage posteromedial peritalar release, accompanied by plantar fasciectomy. However, the talometatarsal angle may occasionally reach 45°, and in severe instances, may approximate 90°. In these cases I have had far better results in performing the surgical correction in two stages. The first stage, consisting of a plantar-medial release, corrects the cavovarus component of the foot deformity. Six weeks later a posterior release corrects the ankle equinus.

The operative casts are changed weekly after each surgical procedure in order to gain increasing and safer correction. Also, a better, well-molded cast can be applied. When maximum correction is achieved, a holding cast is applied and later appropriate bracing or splintage is implemented. This splintage or bracing is gradually eliminated over the ensuing months or years.

To date, I have been very satisfied with this surgical program. Slight overcorrection is a common result, but "recurrent" deformity has been rare, and repeat surgical correction is almost never required. Conversely, prior to instituting this regimen, mild persistence of cavus deformity was not uncommon, and the need for subsequent corrective procedures was rather frequent.

The questions that are difficult to answer without any satisfactory data are these: (a) What degree of cavus profits from the two-stage procedure? and (b) Is the two-stage procedure unnecessary and can satisfactory correction be achieved *safely* and effectively by a one-stage operation? In my own hands, I intuitively feel that the clubfoot with forefoot equinus in which Meary's angle[1,2] exceeds 30° is best treated by this two-stage procedure.

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The Akron Midtarsal Dome Osteotomy in the Treatment of Rigid Pes Cavus

B.K. Weiner and D.S. Weiner

In 1970, the Akron midtarsal dome osteotomy was devised for the surgical correction of the rigid pes cavus or cavovarus deformity. The preliminary results of the first 22 patients were reported in 1985 by Wilcox and Weiner.[21] This paper analyzes the results of the first 100 feet treated by a single surgeon (D.S.W.) with this consistent therapeutic regimen.

Managing the rigid pes cavus deformity often proves to be a frustrating endeavor. The complex pathoanatomy commonly includes forefoot equinus, high longitudinal and trans-

verse arches, toe contractures, callosities under the metatarsal heads, plantar fascia contracture, hindfoot varus, forefoot adductus, and muscle imbalances. Historically, the response to treatment has been, all too often, less than desirable.

Previous Treatment Procedures

Numerous procedures have been devised to address the cavus foot deformity. These can be divided into three basic categories: (a) soft tissue procedures, (b) tendon transfers, and (c) bony procedures. Most surgical procedures have been directed at specific anatomic deformities that represent only a single component of the cavus foot deformity. Few of the various operative procedures provide a composite approach to the complete deformity.

Soft Tissue Procedures

Soft tissue procedures have been primarily directed at the release or resection of tight plantar fascia and contracted toe flexors and extensors. The success of these procedures is predicated upon the presence of a supple foot that can be readily corrected to a neutral position after soft tissue release.

Tendon Transfers

Tendon transfers are designed to balance the dynamic forces adversely contributing to the pes cavus deformity. These transfers are generally divided into forefoot and hindfoot procedures. All of the soft tissue transfer procedures are intended to be used on feet exhibiting a satisfactory passive range of motion at the affected joints.

Bony Procedures

Three basic bony approaches have been used: calcaneal osteotomy, hindfoot or midfoot arthrodeses, and midfoot osteotomy. All of the procedures address a specific region of the fixed bony deformity. The calcaneal osteotomy was designed to address a varus or valgus deformity of the hindfoot accompanied by a component of equinus. Dwyer[9] popularized an osteotomy in which a lateral wedge is removed from the calcaneus to correct the heel varus. Samilson[14] introduced a sliding crescentic osteotomy that, combined with a plantar fasciotomy, is intended to restore the architecture of the foot without compromising any joint motion.

Arthrodeses

Many different arthrodeses have been described. Adelaar et al.[1] reported that "triple arthrodesis provided a durable and symptom free foot in 68% of cases." Brewster and Larson[3] recommended the Hoke triple arthrodesis, stating that the best results are obtained in these feet treated by triple arthrodesis combined with transplantation of the long extensor tendons to the metatarsal necks. Scheer and Crego[16] described a two-stage arthrodesis designed to preserve the vascular supply to the neck of the talus and to maintain anatomic integrity of the anterior capsular and ligamentous structure of the ankle joint. Arthrodesis is considered a late salvage/stabilizing procedure that relieves pain and corrects deformity while sacrificing motion of the foot and ankle. The triple arthrodesis often lies proximal to the apex of the cavus deformity and, therefore, leaves residual midfoot deformity and forefoot equinus uncorrected.

Osteotomies

Several midfoot osteotomies have been described to correct the cavus foot deformity. Steindler[17] recommended removal of a dorsal wedge from the talar neck in combination with a plantar fascia stripping. Stuart[18] used Steindler's approach but included resection of the midtarsal joints. Saunders[15] and Cole[5] both described an anterior closing tarsal wedge resection that sacrificed the midtarsal joints. Brockway[4] thought that these joints were essential for lateral motion of the foot and thus described a tarsal wedge osteotomy sparing the midtarsal joints. He reported superior results, except in the most severe deformities. McElvenny and Caldwell[13] described a fusion of the first metatarso-cuneiform-navicular joints for correction of the flexible cavus foot. Swanson et al.[19] and Wang[20] described proximal metatarsal osteotomies to be used in addition to plantar fascia release and tendon transfers.

Wang reported satisfactory results in 12 of 14 patients. Jahss[11] reported a truncated wedge osteotomy of the tarsometatarsal joints to correct depression of the metatarsal heads without violating the subtalar joint. This procedure is designed to correct the forefoot equinus, but generally lies distal to the apex of the cavus deformity. All of these midfoot procedures were biplanar osteotomies.

The tarsal V-osteotomy described by Japas[12] in 1968 allows for correction of the anterior pes cavus while the hind part of the foot maintains its normal relationship to the axis of the leg. This correction is accomplished without shortening of the foot. The location of the osteotomy is well conceived as it lies at the apex of the cavus deformity and allows for some multidirectional correction. It permits good dorsoplantar revision and does not limit subtalar motion. However, this procedure allows for only limited correction of abduction or adduction and rotation of the forefoot. Japas[12] reported satisfactory results in 12 of 17 patients in his primary review. All of his patients were 8 years of age or older.

In summary, apart from Japas' approach, each of these midfoot osteotomies fails to address the cavus deformity in three dimensions, thereby attempting to correct a three dimensional deformity with a biplanar approach. This requires the surgeon to take dissimilar angular cuts during his osteotomy in order to correct for abduction, adduction, and rotational deformities. This rather difficult feat may significantly diminish the surfaces for the bony union, significantly shorten the foot, and often results in less than satisfactory reduction of the deformity.

Clearly, however, the nature of the cavus deformity requires surgical correction. These children are prone to fatigue and foot discomfort if left untreated and are likely to eventually suffer significant disability. Painful plantar callosities form beneath the metatarsal heads. Shoe fitting becomes extremely difficult. The available plantar grade surface that is in contact with the ground gradually diminishes.

Etiology

The etiology of pes cavus has been discussed by numerous authors. Duchenne[8] related three forms of calcaneovarus deformity to muscle imbalance between the long extensors and flexors and the intrinsic muscles of the foot. This proposed mechanism was also supported by Dekel and Weismann[7] and Garceau and Brahams.[10] Saunders[15] suggested that cavus is a structural deformity involving the entire tarsus

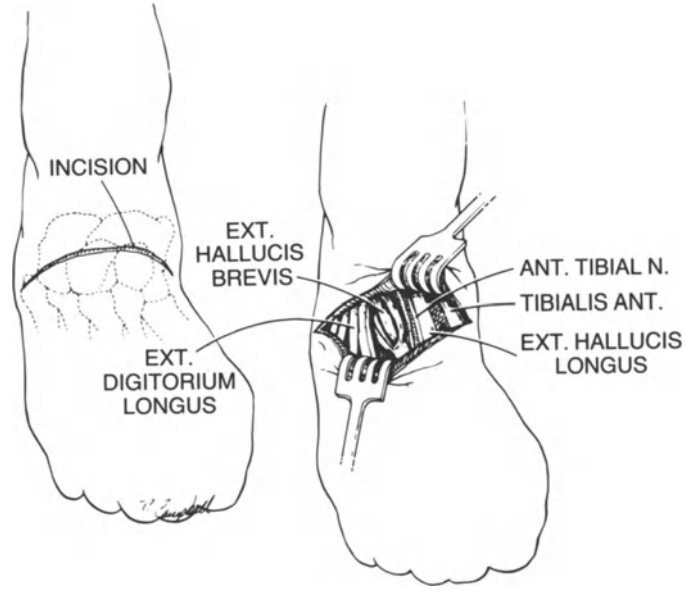


FIGURE 12.3. Incision and surgical approach to the midtarsal region. EXT, extensor; ANT, anterior; N, nerve. (Reprinted with permission from Wilcox and Weiner.[21])

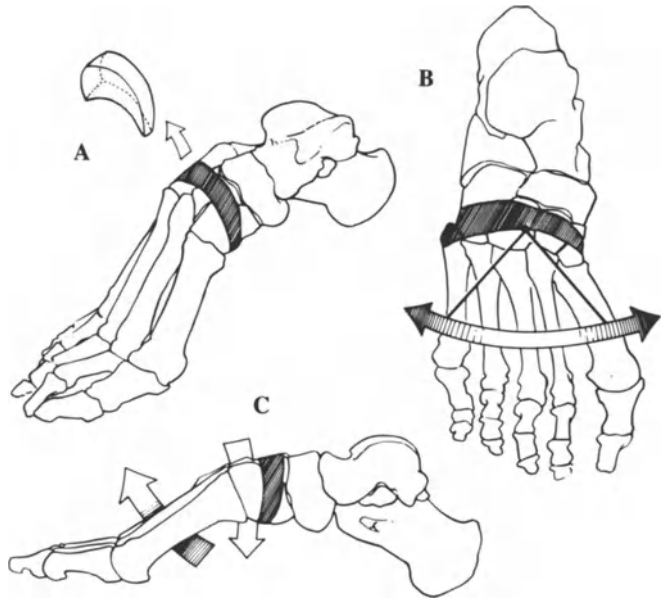


FIGURE 12.4. Akron midtarsal dome osteotomy. Note the potential for the three-dimensional correction of the deformity. (A) shows larger wedge anteriorly than posteriorly. (B) shows larger wedge laterally than medially. (C) shows movement of the mid- and forefoot to the corrected position. (Reprinted with permission from Wilcox and Weiner.[21])

and metatarsus, with claw toes and plantar fascia contractures being secondary. He did not think that muscle weakness caused the deformity, but suggested that the usual etiology is a lesion in the spinal cord disturbing the synergetic control of muscular tone. Brewerton et. al.[2] reviewed the etiological factors and determined that a central nervous system defect was present in 66% of patients. The most common of the neuromuscular disorders were found to be Charcot-Marie-Tooth disease, Friedreich's ataxia, myelodysplasia, poliomyelitis, and cerebral palsy. The rest were classified as idiopathic pes cavus, a category that included the group represented by residuals of congenital clubfeet not fully corrected with previous early treatment.

Operative Procedure

If deemed necessary due to contracture of the plantar fascia, a horizontal incision is made over the medial border of the foot overlying the plantar fascia. The plantar fascia is identified and a $\frac{1}{2}$-inch transverse section is excised. Great care is taken to resect the fascia over the entire width. The incision is closed and a second incision is made transversely over the dorsum of the foot at the apex of the greatest deformity (Figure 12.3).

The dissection is deepened, taking care to protect the long extensor tendons and dorsalis pedis artery. Multiple segments of capsule are then raised and retracted from the midtarsal joints through longitudinal incisions between the long extensor tendons.

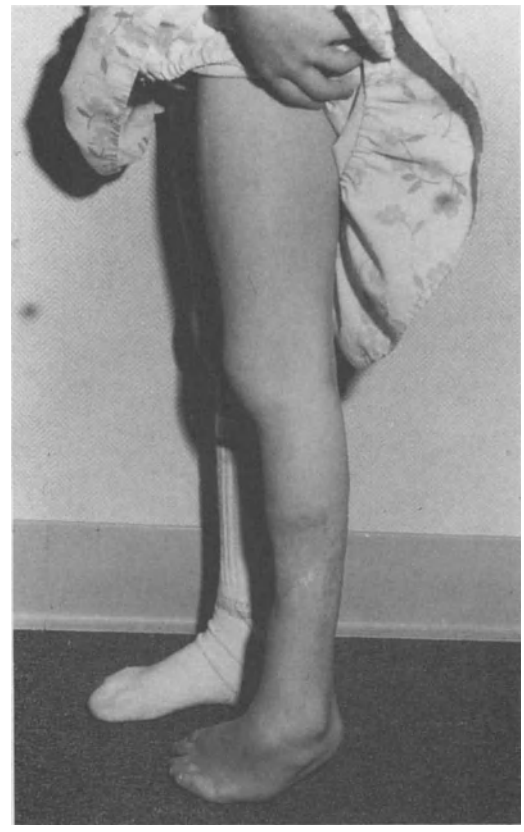
Using a curved osteotome, two parallel dome-shaped midtarsal osteotomy cuts are then fashioned through the bone and joints of the midfoot at the apex of the deformity. This facilitates dorsoplantar positioning as well as varus/valgus correction and, most importantly, rotational correction while maintaining good bony contact through the site of the osteotomy (Figure 12.4). The curved osteotomy cuts, with appropriate architectural wedging, allow for accommodation of maximum derotation of the forefoot on the hindfoot.

The foot is then positioned in the desired conformation, reducing whatever deformities exist, and two smooth pins are percutaneously driven obliquely through the osteotomy site in a crossed fashion to anchor the reduction.

A short leg cast is applied for 6 weeks, then the cast is removed and the smooth pins are extracted. A short leg walking cast is applied for an additional month. The patient is then placed in a hinged ankle foot orthosis (AFO) with a 90° posterior strap.



A



B

FIGURE 12.5. A and B: Preoperative anteroposterior (AP) and lateral photographs, showing the paradiagnostic foot upon which the procedure was performed.

Materials and Methods

The Akron midtarsal dome osteotomy has been performed on 100 feet in 67 children (Figure 12.5). All surgeries were performed by the senior author (D.S.W). Evaluation of results was based upon (a) the quality of the plantar grade surface obtained, (b) the presence or absence of pain, and (c) the degree of residual deformity. Coleman[6] has emphasized that such clinical evaluation (as opposed to radiographic analysis) of the cavus foot represents the most accurate method to analyze surgical results. If any of the above three criteria were deemed less than desirable, the results were graded "unsatisfactory," and, accordingly, in need of further surgery. Thus, the results of this study have been biased to maximize the amount of negative results.

The pathobiology included 75 clubfeet, 17 feet with neuromuscular disorders (primarily Charcot-Marie-Tooth disease), and 8 feet with rigid metatarsus adductovarus with a cavus component. The average age of patients at the time of surgery was 7.82 years with a range of 1 to 21 years. The average follow-up was 29 months with a range of 2 to 96 months.

Results

The results using the previously defined evaluation criteria demonstrated 84% satisfactory and 16% unsatisfactory. For those patients older than 7 years of age, the results were 98% satisfactory and 2% unsatisfactory (Figure 12.6).

Complications included occasional serous drainage during early wound healing of significant degree and three cases of painful late-



A



B

FIGURE 12.6. A and B: Postoperative AP and medial photographs, showing an example of a satisfactory result.

appearing sequestered bone fragments that required surgical excision. All failures required additional surgical procedures including repeat dome osteotomies, hindfoot arthrodesis, or distal forefoot osteotomies; the latter two procedures were a reflection of failure secondary to the disease process itself, rather than a failure of the midfoot osteotomies.

Discussion

The Akron midtarsal dome osteotomy has proven to be the most successful procedure for correction of the rigid cavus foot. This appears to be due to (a) the ability to control varus and valgus as well as plantar flexion, dorsiflexion,

and rotational deformities with a single, simple osteotomy; (b) positioning the osteotomy at the apex of the deformity; (c) the presence of a broad bony contact surface to promote rapid union of the osteotomy; (d) minimal loss of foot motion; and (e) minimal loss of foot length.

Failures of the dome osteotomy appear to be related to (a) the age of the patient (i.e., younger patients were more likely to have recurrence of the deformity with continued growth); (b) the severity of the initial deformity (increased severity correlating with inability to obtain satisfactory early correction and the need for midfoot osteotomy at an earlier than desirable age); (c) neuromuscular disease (which may involve progressive muscle weakness and further deformity); and (d) the presence of coexisting distal forefoot or hindfoot deformities requiring additional surgery.

Summary

The Akron midtarsal dome osteotomy represents the most direct and reliable surgical procedure available for the treatment of rigid pes cavus deformity and is particularly recommended in children older than 7 years of age.

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"Reverse Jones" Procedure for Dorsal Bunion Following Clubfoot Surgery

K.N. Kuo

The dorsal bunion was first described by Lapidis[7] in 1940. It consisted of a plantar flexion contracture at the metatarsophalangeal joint with a dorsiflexion contracture of the tarso–1st metatarsal joint. It was classically described in the postpolio patient,[1,4] in patients with hallux rigidus,[2] patients with severe congenital talipes planovalgus, and in previously treated congenital clubfeet.[5] Many procedures have been described for its correction. Tachdjian[9,10] described flexor hallucis longus transfer and osteotomy. McKay[8] described transfer of the flexor hallucis brevis, adductor hallucis, and adductor hallucis tendon.

Materials and Methods

In a retrospective study from 1971 through 1989, at Shriner's Hospital for Crippled Children in Chicago, there were nine patients with 11 feet referred with dorsal bunion deformity following clubfoot soft tissue surgery. The average age of the patients was 7.6 years, with ages ranging from 2.1 to 16.4 years. Previous treatment included six patients with previous posteromedial releases, three with Achilles tendon lengthening, and two with a two-stage medial and posterior releases.

The procedure of choice for dorsal bunion at our institution has been the "reverse Jones" procedure[6] or flexor hallucis longus transfer to the head of the 1st metatarsal. Occasionally a plantar flexion osteotomy of the 1st metatarsal, capsulorraphy, triple arthrodesis, or split anterior tibial tendon transfer were also performed. Plantar flexion osteotomy of the 1st metatarsal was done on those patients with rigid deformity at the medial cuneiform 1st metatarsal joint that prevented plantar flexion following flexor hallucis longus transfer. Capsulorraphy was done for rigid flexion deformity at the metatarso phalangeal (MP) or inter phalangeal (IP) joints. Triple arthrodesis was done for hindfoot deformity. Split anterior tibial tendon transfer was performed for dynamic supination deformity of the forefoot with overpowering of the anterior tibial tendon. The average age at the time of the procedure was 13.9 years and average clinical follow-up 2.1 years.

For clinical evaluation we ascertained the patient's satisfaction with the correction of the bunion, correction of the elevated 1st metatarsal, the correction of supination deformity of the forefoot, relief of pain, and the presence of a plantar grade gait. The radiological evaluation[3] consisted of the evaluation of standing lateral radiographs, measuring the tibiocalcaneal angle and the angle of the 1st metatarsal with the horizontal plane of the ground.

The muscle testing showed, in general, that there was weakness of the gastrocsoleus and peroneus longus muscles with strong anterior tibial and flexor hallucis longus muscles.

Results

Patient satisfaction was present in 10 feet; there was one dissatisfied patient. Eight feet had complete correction of the dorsiflexed metatarsal, two had a mild residual elevation of the metatarsal, and one remained uncorrected. Failure was due to an unrecognized rigid medial cuneiform 1st metatarsal joint that prevented plantar depression of the 1st metatarsal. All feet presented with supination deformity: seven had complete correction of the supination, one had partial improvement, and three remained uncorrected. In five feet with presurgical pain, only three had pain after surgery. However, in two of the feet the pain was in the sinus tarsus and was not thought to be related to the dorsal bunion. All patients obtained plantar grade feet postoperatively. The radiological study showed a definite improvement of the 1st metatarsal horizontal angle; this was especially true in patients with a 1st metatarsal osteotomy. The tibiocalcaneal

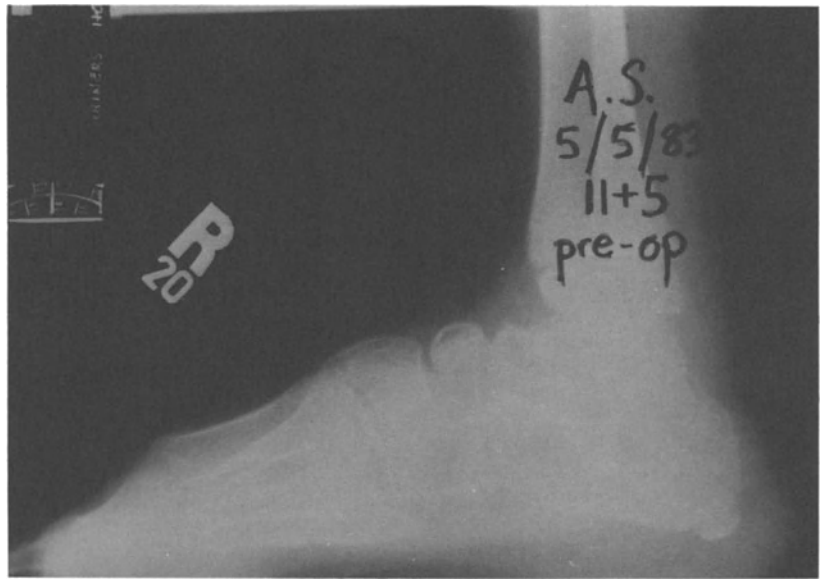


FIGURE 12.7. Preoperatively, patient has dorsal bunion with mobile tarsometatarsal joint following previous soft tissue surgery.

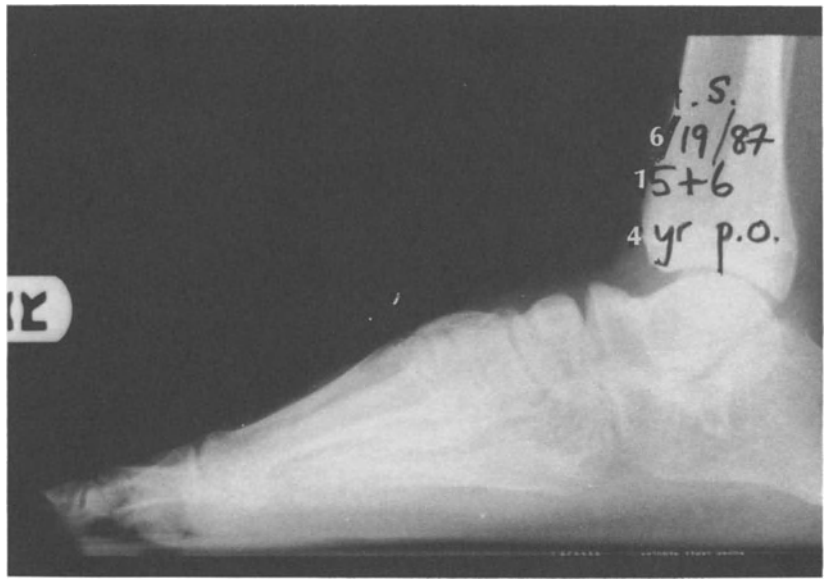


FIGURE 12.8. Same patient as in Figure 12.7. Postoperatively, patient following "reverse Jones" procedure and anterior tibial tendon transfer.



FIGURE 12.9. Preoperatively, patient has dorsal bunion following two previous soft tissue procedures. The tarsometatarsal joint is fixed.

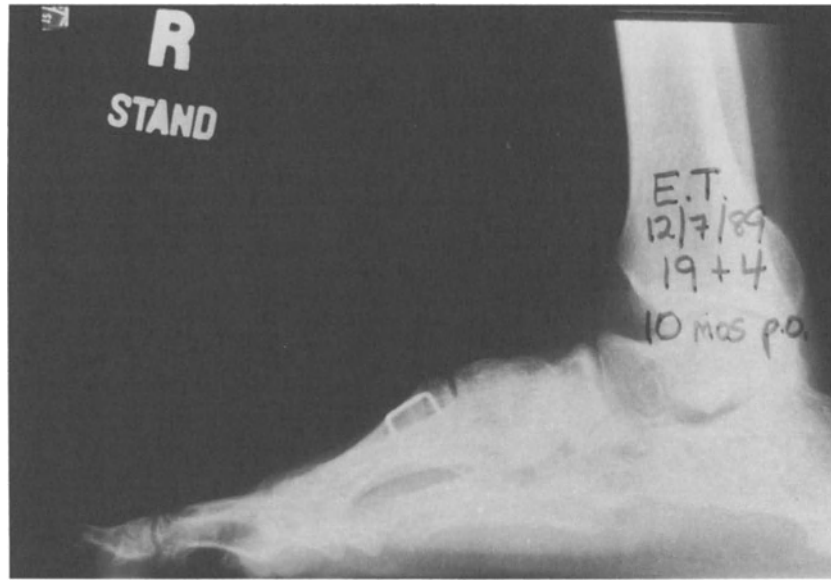


FIGURE 12.10. Same patient as in Figure 12.9. Postoperatively following "reverse Jones" procedure and 1st metatarsal osteotomy.

angle did not reveal any significant change postoperatively. This is a hindfoot measurement and, therefore, showed that the hindfoot was not surgically changed by this forefoot procedure.

Case Examples

A.S. had two soft tissue procedures between 6 and 11 months (Figure 12.7). At age $11\frac{1}{2}$ the patient had a "reverse Jones" procedure and anterior tibial tendon transfer, which resulted in good correction (Figure 12.8).

E.T. had two bilateral soft tissue releases, which resulted in dorsal bunion deformity in one foot (Figure 12.9). At age $18\frac{1}{2}$ a "reverse Jones" procedure and a 1st metatarsal osteotomy were performed with a good result (Figure 12.10).

Summary

It is our opinion that the major factors leading to dorsal bunion formation following clubfoot surgery include weakness of the Achilles tendon, overpowering by the flexor hallucis longus, forefoot supination with a strong anterior tibial tendon, and weakness of the peroneal longus tendon. In our study, we showed that the "reverse Jones" procedure with or without metatarsal osteotomy and with or without split anterior tibial tendon transfer is an excellent procedure for correction of the dorsal bunion deformity resulting from CTEV.

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Discussion

Ryoppy (Helsinki): Dr. McKay asked about the time needed for remodeling of the foot following surgery. We all know that the remodeling capacity diminishes progressively from birth onward. We learned about this phenomenon and the time it took to occur when we developed a method of neonatal operative treatment in Helsinki. Recurrences during the first year forced us to lengthen the time of immobilization. Now we have come to the conclusion that, if a very severe clubfoot is corrected totally in one single operation at the age of 2 weeks, it usually takes 6 months to remodel enough that the risk for recurrence is minimal if immobilization is discontinued at that time. Naturally it would be better to have a functional splint during this time than to keep the child in a cast. The problem is that all clubfeet are different, so one never knows how long it should take.

Coleman (Salt Lake City): Dr. Exner, I was involved in a lawsuit a couple of years ago because of tourniquet burns. Since then, I have not used antiseptics above the knee. I found that, as the tourniquet was applied to the baby's calf, exsanguination of the skin occurred. This can be simulated by squeezing the skin together on the back of your hand. If the extremity is then wrapped with an exsanguination bandage and the tourniquet is inflated to 250 mm, blisters develop where the two prominences of skin touch. In the Hand Society, three cases of upper extremity blistering without the use of antiseptic were reported. They now recommend (a) that a sterile tourniquet be used, and (b) that the doctor put the tourniquet on the extremity after the extremity has been prepped.

Catterall (London): What do you use underneath your tourniquet?

Exner (Zurich): We use cotton. I am not very sure about the causes for these tourniquet lesions, although several factors are important: (a) the surface defect, (b) the pressure itself, (c) the stiffness of the cuff, and (d) the disinfectant.

Handelsman (New Hyde Park, New York): Dr. McKay, you commented that the flexor hallucis longus was not an etiologic factor in dorsal bunion. In my experience, the flexor hallucis longus is the major deforming force. If you dorsiflex the foot before lengthening the flexor hallucis longus, very often a mild dorsal bunion appears. This will disappear as you lengthen the flexor hallucis. We have measured the amount of lengthening in the long toe flexors in clubfoot and found that, for both the flexor hallucis longus and the digitorum longus, in order to get the foot plantar grade with the toe straight, over 2 cm of lengthening is needed in these tendons.

Goldner: Dr. Kuo, my only objection to your analysis of the dorsal bunion is that we did not find weakness of the peroneus longus as you did. A dorsal bunion may occur in polio with a normal peroneus longus if you don't have an extensor hallucis longus and if you have an overactive anterior tibial.

Drennan: Dr. Kuo, the tibiocalcaneal angle looked fairly good in your films of patients with a dorsal bunion. Were those heels in neutral, were the subtalar joints fairly stiff, and did the ankle joints have limited motion?

Kuo (Chicago): The ankle joint had limited motion but all ankle joints have a decreased range of motion in clubfeet. Most of the heels were in slight valgus.

Simons: Dr. Kuo, you claim that there are four causes for dorsal bunion. In our experience, the cause may be any factor that produces a loss of the medial longitudinal arch. This loss of the arch results in increased tension on the flexor hallucis brevis. This then flexes the metatarsophaloangeal (MTP) and over time the MTP joint becomes fixed. Ligamentous laxity, plantar release, rocker-bottom deformity, and release of the posterior tibial tendon are examples of things that will cause loss of the arch. Also, Achilles tendon overlengthening puts tension on the long toe flexor, which may be contracted to start with. It usually requires two or more of these factors to produce the dorsal bunion in my experience.

McKay: Feet with dorsal bunions due to CTEV often have good function of the peroneus longus. I have also found patients who had absolutely normal function in the flexor hallucis longus that got a severe dorsal bunion, just as Dr. Goldner found. It was due to the anterior tibial tendon and the flexor hallucis brevis.

Barnett: I think the heel cord lengthening is terribly important. The dorsal bunions, cavus feet and calcaneus feet are often accompanied by devastating weakness of the gastrocsoleus which I believe for the most part, is surgically produced. I personally would like to repair the heel cord exactly as it was found. It must be repaired tightly so that the sutures almost pull out when the foot is dorsiflexed.

Thometz (Milwaukee): Dr. Coleman, do you feel that the sliding osteotomy is a better procedure for residual heel varus then a closing wedge Dwyer osteotomy?

Coleman (Salt Lake City): I think the Dwyer osteotomy is inappropriate for CTEV. First of all, it's a lateral closing wedge and not a sliding wedge. It shortens the foot which is already foreshortened and it often leaves you with a more prominent base of the 5th metatarsal.

The sliding calcaneal osteotomy described by Hall and Calvert[1] is the one that I prefer. I have used it many times and I think it works very well for either valgus or varus deformity.

McKay (Ville Platte, Louisiana): I have used the sliding calcaneal osteotomy for many years. I think it is a very fine operation. However, if the calcaneus has slipped laterally to a severe degree and is actually impinging on the fibula, it can become very painful. If I can't get my osteotome underneath the fibula to remove that bony impingement. I then recommend relocation of the calcaneus (i.e., sliding osteotomy) with subtalar fusion in older patients. In the younger patient, if there is no impingement, a calcaneal osteotomy will correct the deformity.

Dias (Chicago): I would like to make a comment about the sliding osteotomy of the calcaneus. We've been using this procedure for the last 9 years at Children's Hospital in Chicago. It is an excellent procedure for marked valgus of the hindfoot. You can push the calcaneus medially about 1 to 2 cm. We found that if you try to use the same osteotomy for the varus deformity, you cannot shift the calcaneus medially as much as you can when you try to shift it laterally because the medial structures are so tight. In these cases, one should take a wedge like a Dwyer and after taking the wedge, one can shift the calcaneus further laterally and get a good hindfoot correction.

Dr. Coleman, in the cavus foot that doesn't passively correct, I understand that you don't do a posterior ankle capsular release but just correct the cavus.

Coleman: Yes. If the cavus is the only deformity, no ankle release or posterior approach is necessary.

Handelsman: Don't you create rocker-bottom deformity in some of them?

Coleman: We've had some slight overcorrections but I don't mind slight overcorrection. I leave the ankle in equinus and then change the cast two or three times postoperatively in order to get the cavus fully corrected. Then we go posteriorly at 6 weeks if there is also deformity in the hindfoot.

Goldner (Durham): For the cavus foot, I don't do the subtalar release. I do the subtalar release anteriorly. I seldom open the middle underneath the sustentaculum tali. You'd be surprised how well the calcaneus comes around as the subtalar joint has inherent motion in it. If you look at the lateral impingement, you won't get the navicular riding up and you won't have these valgus problems. In doing the cavus foot, I do the forefoot first. After I get the forefoot up, I fix it so it doesn't drop and then do the hindfoot at the same procedure. I do the same thing with clubfeet, plantar dissection first, medial, lateral, and then end up doing the posterior aspect of the foot.

The dorsal wedge resection is a good operation, but I still do a soft tissue release first and then I won't have to remove as much bone.

Coleman: Dr. Weiner, you do your tarsal osteotomy as a salvage procedure and I think that's important to emphasize. You say that 75% of your patients had clubfeet and yet there is no way you could approach the hindfoot with this procedure. Therefore, I'm assuming that the hindfoot was corrected and this is strictly a midfoot procedure.

Weiner (Akron, Ohio): Absolutely! That point is to be clearly made. This is not a hindfoot operation. It will take care of everything from the midfoot distally except for the distal end of the 1st metatarsal.

Thometz: Dr. Weiner, your poor results were all under the age of 7 years. Do you recommend waiting until the age of 7?

Weiner: No. I wouldn't because there are times when you are faced with a 4- or 5-year-old who has such severe midfoot and forefoot deformity and is developing pressure sores. In this situation, you have to make a choice. Seventy percent of those cases were satisfactory. In about 10% of the cases, we'll do a plantar fasciectomy and then do the bone work.

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Editor's Comments

McKay believes that the gradual development of the valgus deformity over a 2-year period following surgery is a postoperative complication that results from incongruity at the subtalar joint. In my experience, most cases of valgus occur during surgery as the navicular is improperly placed and imprecisely pinned on the head of the talus. Placing the navicular too far laterally on the talar head causes the navicular to push the cuboid laterally, which then pushes the anterior calcaneus laterally, resulting in a rotary valgus deformity. Furthermore, failure to correct significant degrees of calcaneocuboid subluxation also causes valgus (see Thometz and Simons, Chapter 8). Finally, in some cases where there is a gradual drift into a translatory or rotatory valgus the main cause seems to be ligamentous laxity. In translatory valgus, the whole calcaneus shifts laterally, whereas in rotatory valgus the anterior calcaneus rotates too far, while the posterior portion lies medially. The cases of valgus due to lateral overcorrection of the navicular and to calcaneocuboid subluxation are preventable.
rection of the navicular and to calcaneocuboid subluxation are preventable.

With cavus deformity, where Meary's angle is greater than 30°, **Coleman** recommends a two-stage release: a first-stage plantar medial release followed 6 weeks later by a posterior release. When Meary's angle is less than 30°, he performs a conventional one-stage posteromedial release, accompanied by plantar fascial release and myotenotomy.

In a paper by **Weiner** and **Weiner** on the Akron midtarsal dome osteotomy for pes cavus, the authors present an excellent review of the senior Weiner's first 100 cases. They explain why their procedure has advantages over all other previously described procedures for pes cavus, i.e., it is mobile in three planes. The procedure is also accompanied by plantar fasciectomy in severe cases, but the authors do not cite their indications for the associated plantar fasciectomy. The fasciectomy is performed as a part of the major procedure and not as the first of two stages. Their results are excellent, particularly when the procedure is performed on children over 7 years of age. As brought out in the discussion (but not in the body of the paper), the procedure is designed purely for cavus and not for any associated deformity of the hindfoot, which must be dealt with separately.

13
Surgical Complications: Adduction/ Supination

Introduction

Abberton describes a soft tissue procedure for the correction of mild metatarsus adductus and supination. This involves release of the medial half of the anterior tibial tendon with tarsal capsulotomies.

Smith and **Weiner** describe tarsometatarsal capsulotomies in combination with anterior tibial transfer to correct mild-to-moderate forefoot adduction. This procedure is not described for the correction of supination.

Kling, **Conklin**, and **Schmidt** report on their experience with opening wedge osteotomies of the first cuneiform bone associated with metatarsal osteotomies of the 2nd through 4th metatarsals, and anterior tibial tendon transfer. These were performed for the residuals of metatarsus adductus without supination.

Schoenecker, **Anderson**, et **al.** describe the use of closing-wedge cuboid osteotomy with opening-wedge cuneiform osteotomy for the correction of metatarsus adductus in children over 5 years of age.

McHale and **Lenhart** also describe the same combination of osteotomies for metatarsus adductus, and they claim that they work equally well when supination is also a component of the deformities.

Anteromedial Soft Tissue Release for Persistent Adduction and Supination in Congenital Talipes Equinovarus

M.J. Abberton

Despite a recent trend toward increasingly comprehensive primary surgical correction of congenital talipes equinovarus (CTEV), persistent internal rotation of the foot frequently is a major cause of dissatisfaction after surgery. Some of the children with an internally rotated gait have feet in which all aspects of the initial correction have been inadequate or have re-



FIGURE 13.1. The forefoot deformity when the heel is controlled in neutral.

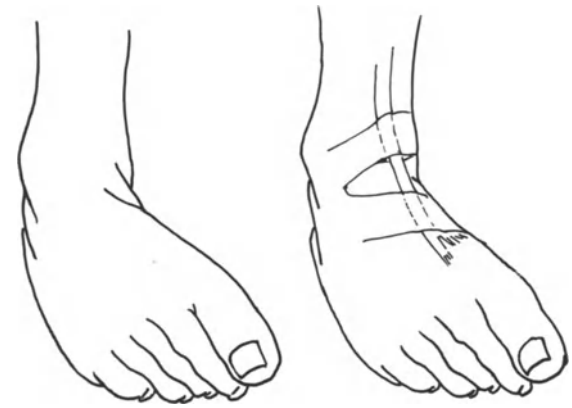


FIGURE 13.2. The role of the anterior tibial tendon in maintaining the deformity.

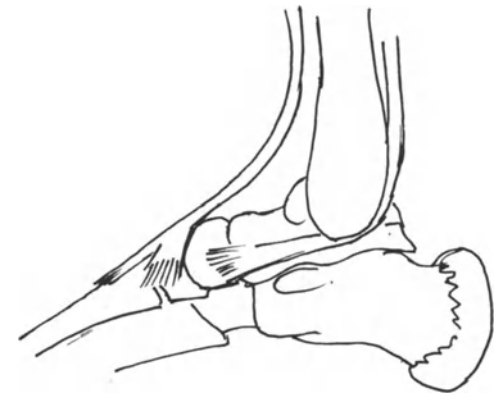


FIGURE 13.3. Insertion of the anterior tibial tendon into the dorsum of the 1st metatarsal and inferior and medial cuneiform.

lapsed. It may be possible to revise the soft tissue correction, but often such a child needs a total salvage procedure.

The aim of this paper is to consider an aspect of this problem and to describe a less extensive procedure that may be used in certain cases where deformity is localized.

Certain feet are relatively straightforward when the heel is in the neutral position (with respect to valgus and varus). It is well centered with respect to the malleoli, and the hindfoot is placed plantar grade; the deformity is seen to be adduction and supination of the forefoot alone (Figure 13.1).

Anteromedial release may be appropriate for such feet. This relatively small procedure is based upon the observation that the insertion of the anterior tibial tendon is a broadly triangular or bifid insertion into the medial and plantar cuneiform. Traction upon the tendon will move the forefoot in the direction of supination and adduction (Figure 13.2).

I have observed that there is also a variable insertion of the anterior tibial tendon into the dorsal surface of the base of the 1st metatarsal (Figure 13.3). At the Leeds General Infirmary, this procedure has been performed, in selected cases, for a number of years. The purpose of this paper is to review the results of the procedure over the 5-year period of 1984 to 1989.

The Procedure

The child is placed in a supine position and the lower limb draped so that the relationship of knee, ankle, and foot is continuously visible. A medial longitudinal incision is made from the midpoint of the shaft of the 1st metatarsal to the tubercle of the navicular. Many of these children have previously undergone medial release and the distal part of the scar may contribute, by contracture, to the deformity. Such cases will require a Z-plasty closure of the skin.

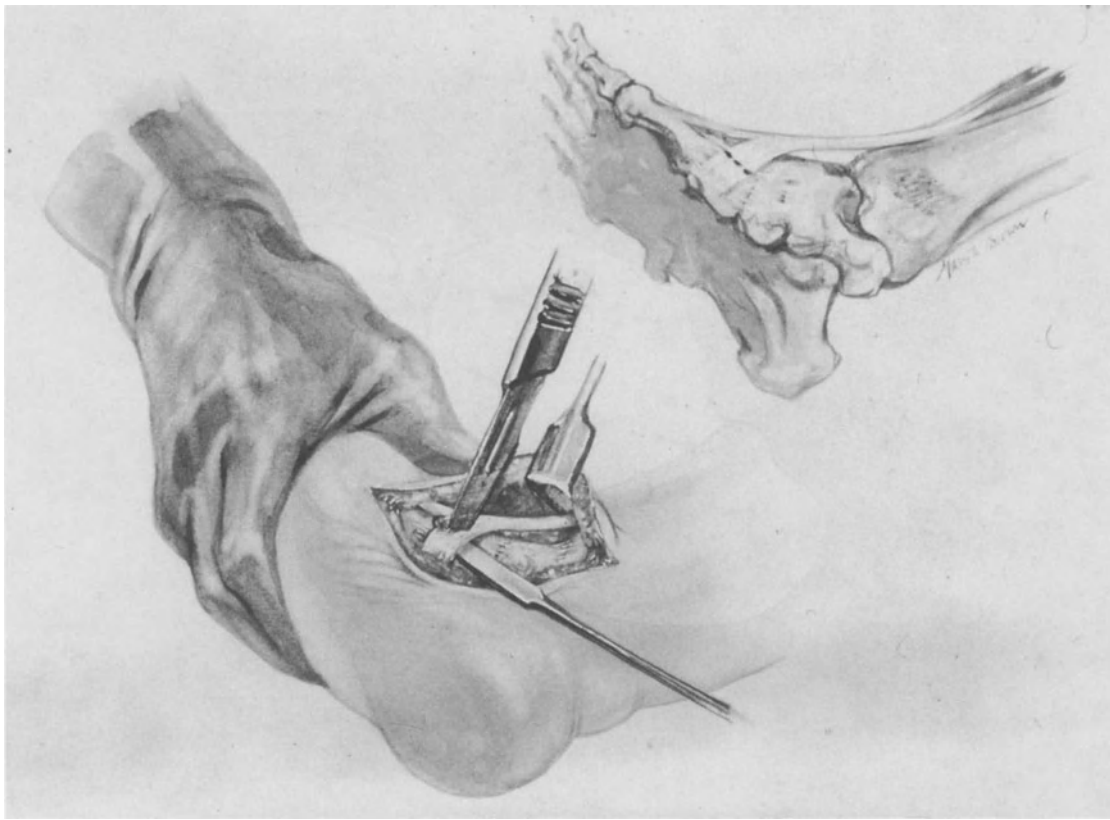


FIGURE 13.4. Division of the posterior inferior aspect of the triangular insertion of the anterior tibial tendon.

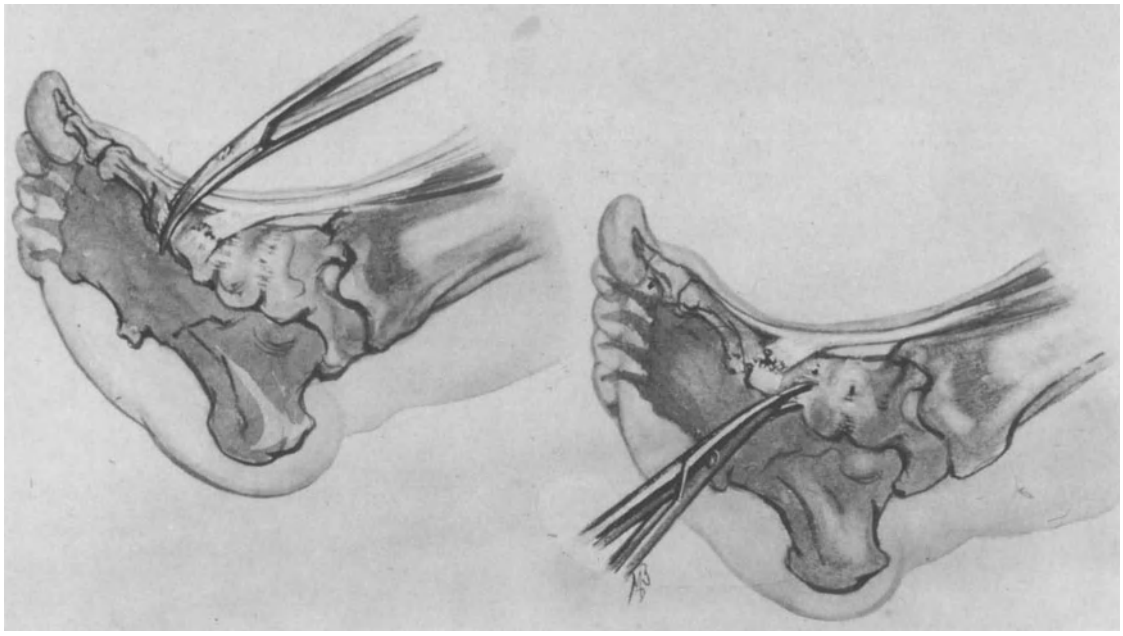
The only significant underlying structure is the belly of the abductor hallucis, which is readily displaced upward. The inferomedial limb of the inferior extensor retinaculum is often abnormally well developed and appears short, contributing to the deformity. It is divided in the line of the first ray, away from the tunnel of the anterior tibial tendon.

The anterior tibial tendon and its broadly triangular insertion is readily observed. The posterior edge of this triangle is relatively free. A dissector passed under this free edge permits the release of the medial and plantar insertions (Figure 13.4). Lateral transposition of the tendon occurs; however, a substantial portion of this tendon insertion into the dorsum of the base of the 1st metatarsal remains to prevent a total detachment.

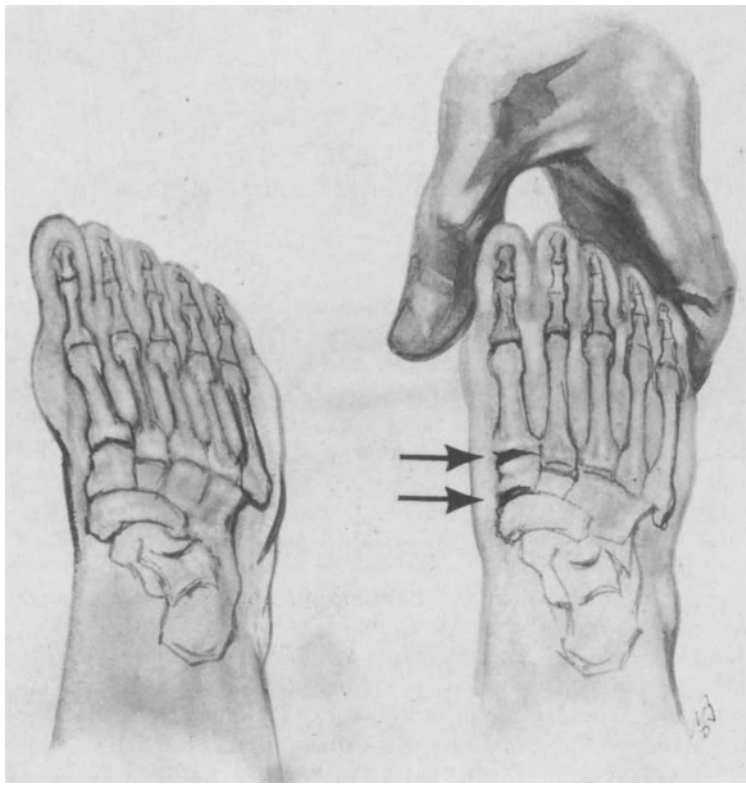
The procedure is completed by medial, dorsal, and plantar capsulotomy of the naviculocuneiform and metatarsocuneiform joints (Figure 13.5). Care should be taken to avoid damage to the peroneus longus tendon. Very occasionally, undue tightness of the anterior tibial tendon requires a z-lengthening. The foot remains in a long leg cast in the full, corrected position for 6 weeks. I do not use night splints.

Contraindications

The main prerequisite is that the deformity must be confined to the forefoot. Thus, contraindications are (a) fixed varus of the hindfoot, (b) imperfect reduction of calcaneocuboid subluxation, (c) imperfect reduction of talonavicular subluxation, and (d) rigidity of the forefoot, which also diminishes the correction obtained. Also, the procedure is less successful when there is bony deformity of the medial cuneiform (this is a relative contraindication).



A



B

FIGURE 13.5. A: Capsulotomy of naviculocuneiform and metatarsocuneiform joints. B: Opening of joints and correction of deformity following capsulotomies and tenotomy.



A B

FIGURE 13.6. A: Preoperative radiograph. B: Postoperative radiograph. Entrapped air delineates the joints. Forefoot deformity has been corrected.

Results

Between 1984 and 1989, the procedure was used 25 times as a revision procedure after soft tissue release in CTEV. The numbers are small; the operation is opportunistic and has been offered in differing surgical circumstances. For those reasons, a strict statistical analysis is not applicable.

The value of the procedure can only be assessed in the very broadest of terms in regard to the expectations of the parents, the child, and the surgeon. The surgeon's assessment should be more critical than that of the parents, for the surgeon has the ability to recognize certain points of technical failure that the parents cannot.

All of the operations are revision procedures and, thus, no foot should be subsequently described as "excellent." The parents are specifically counseled on this point. They are cautioned to expect no more than an improvement in the naked appearance of the foot, an improvement in the gait of the child, and a reduction in the demand for special footwear. Grounds for dissatisfaction with the procedure are failure to achieve the hoped-for benefits, a postoperative complication, pain or discomfort, and increased stiffness. The permitted grades are "good," "improved," "no change," or "worse" (Figure 13.6). Certain complications and dissatisfactions are incompatible with a "good" or "improved" result, even if other aims of treatment are satisfactorily met.

In these terms, the family rated the results in 25 cases as "good" in 18, "improved" in 3, and "no change" in 4. The surgeon's rating was "good" in 14, "improved" in 6, "no change" in 5 (Table 13.1). No child was rendered worse by the procedure and there were no complications. In the "no change" group, one child underwent a repeat procedure and subsequent-

TABLE 13.1. Results of anteromedial release (1984–1989).

Grade	Parental assessment	Surgeon's assessment
Excellent	0	0
Good	18	14
Improved*	3	6
No change	4	5
Worse†	0	0

* Any case that failed to benefit, had a complication, or resulted in a relapse was graded no change or worse.
† Any case that had an increase in pain, diminished function, or resulted in stiffness was graded "worse."

ly achieved a "good" rating on both scales. Two of the others in the "no change" group were later found to have a neurological basis for the CTEV deformity.

Discussion

This technique of relaxation of the anterior tibial tendon has, for many years, been practiced at the Leeds General Infirmary as part of the plantar release of the CTEV deformity.[1] Of the cases of residual deformity described above, there were no cases in which a full plantar release, including this step in the procedure, had been carried out.

The procedure has also been used for many years as a restricted procedure for the correction of adduction and supination associated with CTEV.[2] The procedure, which, of course, is a limited one, addresses only one of several possible factors of persistent internally rotated gait after CTEV surgery. The degree to which other causes are additionally present diminishes satisfaction with the procedure. Poor hindfoot and midfoot correction, rigidity, and an underlying neurological basis for the CTEV deformity are strong contraindications. With these provisos, this minor procedure can be cautiously recommended under restricted circumstances for selected cases.

Summary

A simple procedure for the correction of mild adduction and supination in young children is described. The release of the medial and plantar insertions of the anterior tibial tendon removes the adduction-supination component from the anterior tibial tendon's action, while the flexor component remains. This procedure is contraindicated in the presence of uncorrected deformity of the midfoot or hindfoot.

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Tarsometatarsal Mobilization Combined with Anterior Tibialis Transfer: A Salvage Procedure for Residual Clubfoot Deformity

M.J. Smith and D.S. Weiner

There are a significant number of children (15% to 30%) with idiopathic clubfoot who do not obtain or maintain satisfactory results through standard nonoperative and early full posteromedial operative release. Management of these residual or recurrent deformities has always been a challenge to orthopedic surgeons. Several surgical approaches have been employed, but no single salvage operation for rigid metatarsus adductovarus has been universally accepted.

At Children's Hospital Medical Center of

Akron, we have found that approximately 25% of our patients fail the initial standard full posteromedial release.[18] The most common cause for failure in our experience has been recurrent forefoot adduction and supination. When standard therapies have failed, it has been the senior author's (D.S.W.) preference to perform a tarsometatarsal (TMT) mobilization combined with anterior tibial transfer (ATT).[9,19]

We are reporting the preliminary results of a combined operation (not previously described in the literature) that addressed the failed clubfoot with persistent rigid adductovarus. The rationale, indications, surgical techniques, and results are reported.

Materials and Methods

The data base for this study comprises all patients who underwent both ATT and TMT mobilization at our tertiary referral teaching hospital from 1960 to 1989. All had severe adductovarus of the forefoot subsequent to treatment for clubfoot deformity. We included those with recurrent clubfoot adductovarus (surgical failures) and those with resistant clubfoot deformity (nonsurgical failures). Fifty-eight feet in 41 patients were included in our study population.

Exclusion criteria were (a) any neuromuscular disease, (b) myelomeningocele, (c) arthrogryposis, (d) any known syndrome, and (e) any patient with less than 2 full years of follow-up. Two patients were excluded because of myelomeningocele, 17 had follow-up of less than 2 years, and 3 patients were unavailable for follow-up.

Our sample population included 31 feet in 21 patients. Eleven cases were unilateral and 10 were bilateral. Twenty-three of these feet had full posteromedial one-stage release prior to salvage surgery. The majority of these children had their initial surgery at approximately 6 months of age.[18]

Surgical Technique

All of our study patients had a uniform surgical technique and postoperative management directed by the senior author.

In the tarsometatarsal mobilization, we essentially followed the technique described by Heyman et al.[19] with a few modifications. We used a transverse incision across the dorsum of the foot while protecting the dorsal neurovascular bundle (Figure 13.7). The dorsal and volar capsular, and intermetatarsal ligaments of the tarsometatarsal joints were divided while avoiding damage to the articular surfaces.[22] A transverse osteotomy of the base of the 2nd metatarsal was performed in a plane with the 1st and 3rd metatarsal cuneiform joints (Figure 13.8).

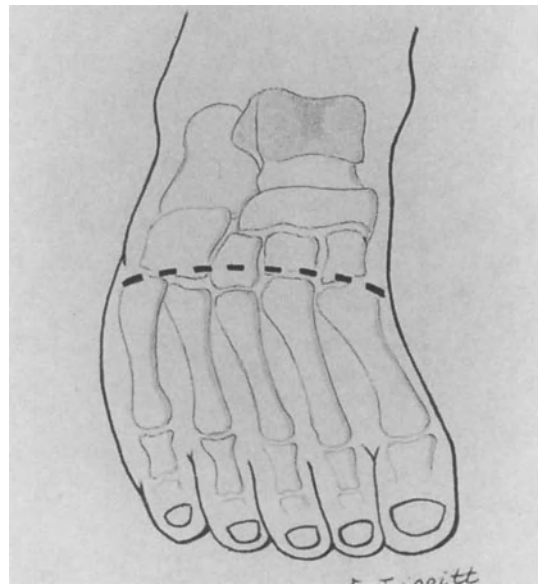


FIGURE 13.7. A dorsal skin incision is made.

The anterior tibialis tendon transfer was performed by the method described by Garceau[9,13,14] (Figures 13.9–13.15). The anterior tibial tendon is always left intact on the initial posteromedial release at our institution. Generally, the point of reinsertion is opposite and just proximal to the base of the 4th metatarsal. A Bunnell-type suture was threaded through the tendon and passed dorsal-to-volar through a cylindrical bony tunnel and tied over a felt-button combination on the plantar aspect of the foot (Figures 13.10–13.15). Postoperatively, a smooth Kirschner wire was percutaneously placed from the plantar surface of the foot across the tibiotalar joint (and the end bent to prevent migration) to decompress the tension of the tendon transfer. A second percutaneous pin was placed obliquely from the base of the 1st metatarsal obliquely across the osteotomy site at the base of the 2nd metatarsal (Figures 13.16 and 13.17). Each child was then placed in a long leg cast for 6 weeks, after

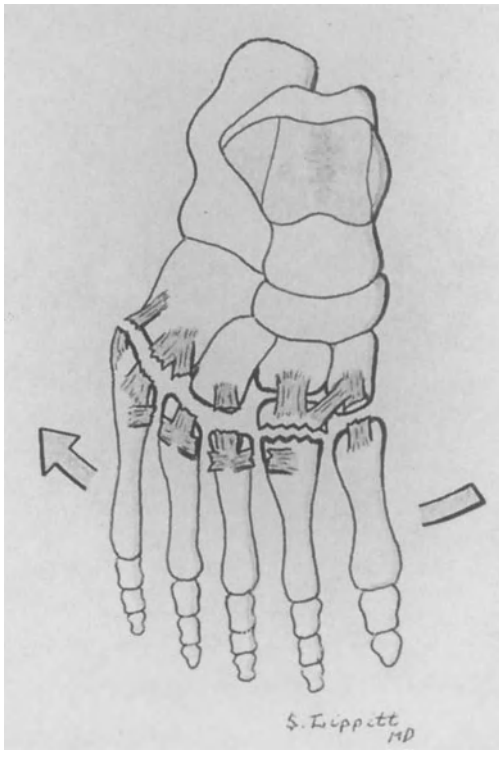


FIGURE 13.8. Tarsometatarsal capsulotomies are performed along with an osteotomy of the base of the 2nd metatarsal.

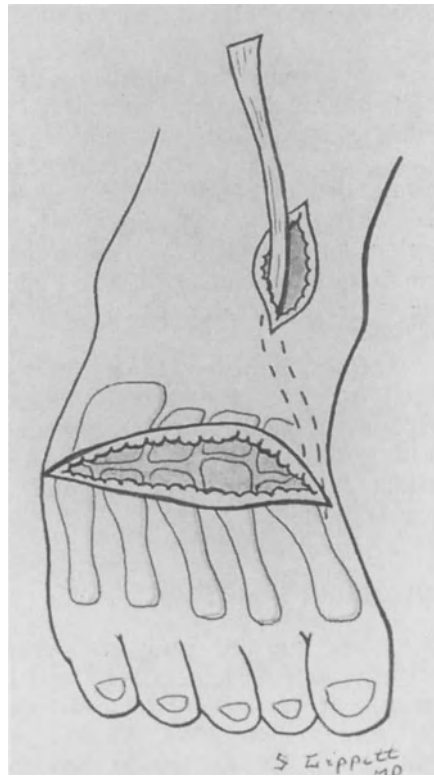


FIGURE 13.9. The anterior tibialis tendon is released from the base of the 1st metatarsal.

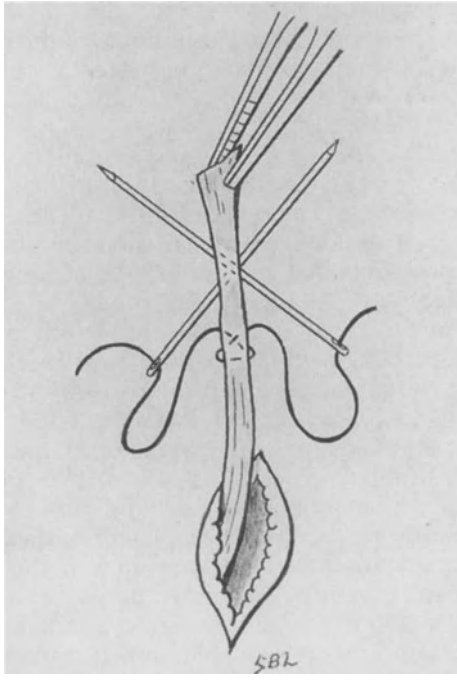


FIGURE 13.10. A Bunnell-type suture is placed in the tendon.

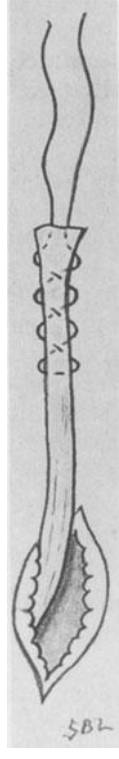


FIGURE 13.11. The Bunnell-type suture in place.

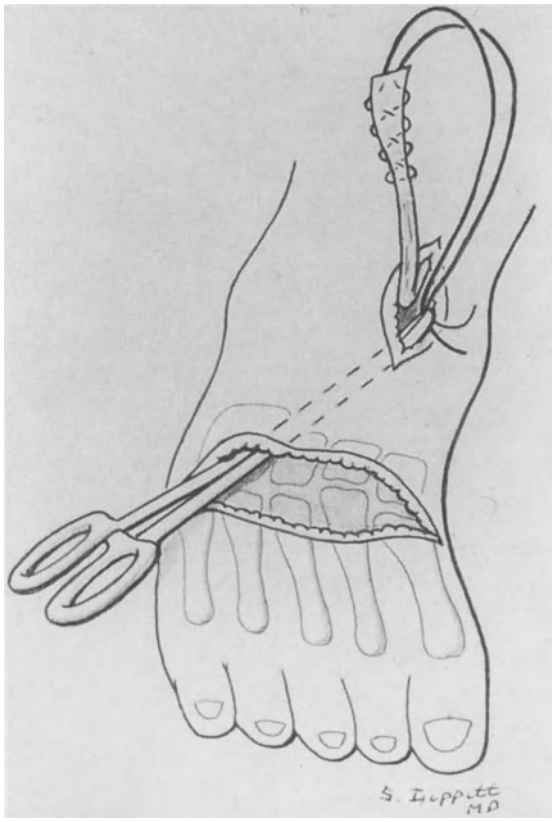


FIGURE 13.12. A hemostat is passed subcutaneously.

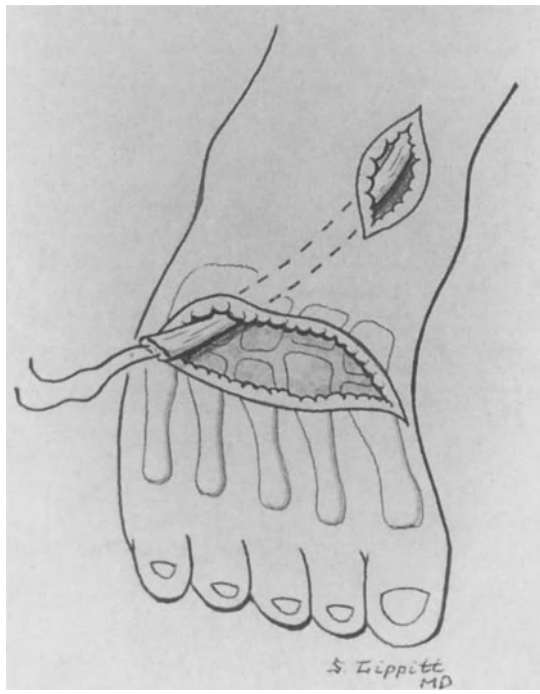


FIGURE 13.13. The tendon is passed subcutaneously.

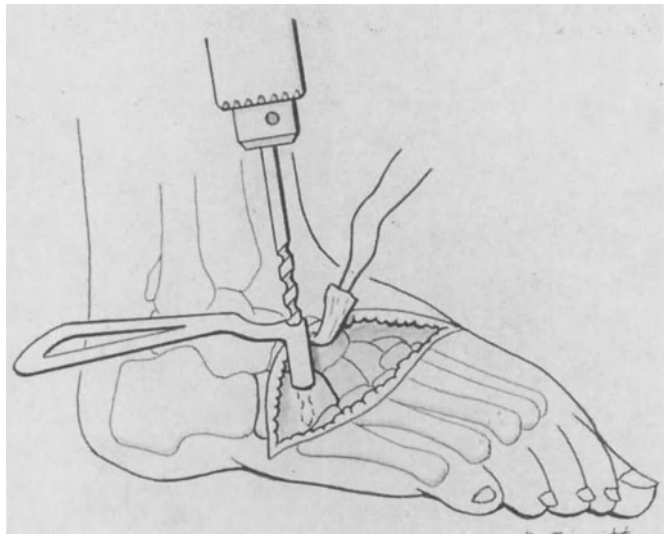


FIGURE 13.14. A bony tunnel is made in the cuboid or third cuneiform.

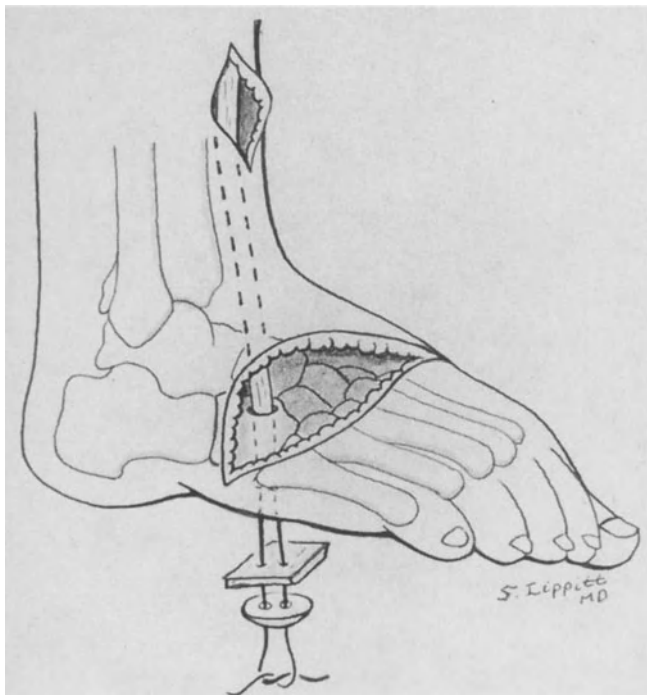


FIGURE 13.15. A felt button is tied with the foot in neutral.

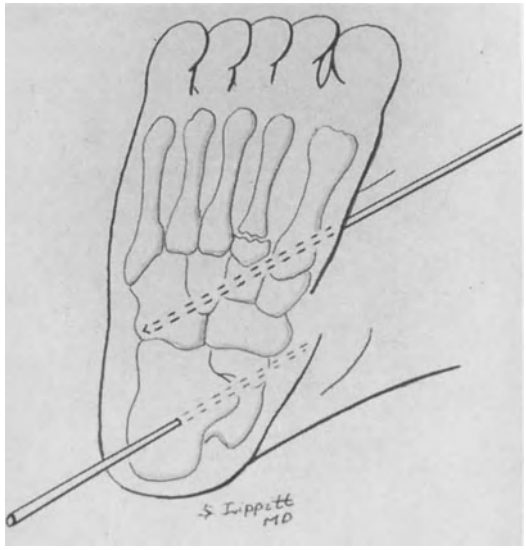


FIGURE 13.16. Two K wires are passed for stabilization.

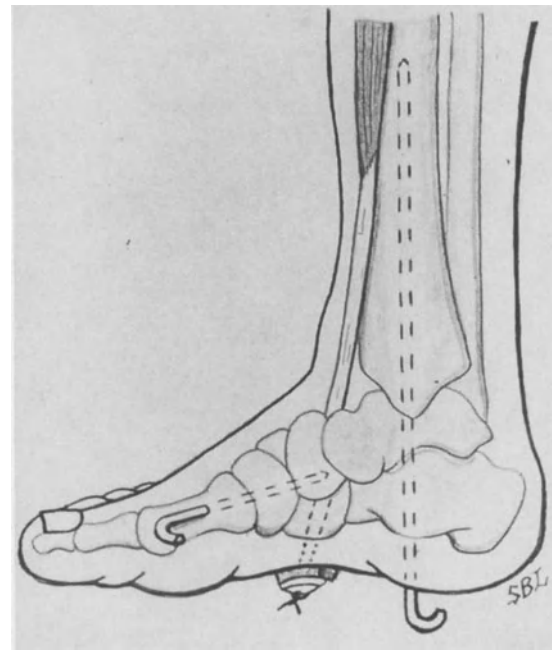


FIGURE 13.17. The wires are bent to prevent migration.

TABLE 13.2. Green/Lloyd-Roberts Classification.[17]

Excellent	Normal contour
	Plantar grade
	Dorsiplantar flexion 10° to 20°
	No pain with activity or athletics
	Midtarsal joints fully mobile
Good	Trace heel varus acceptable
	Full activity without discomfort
	Dorsiplantar flexion 0° to 10°
	Freedom at midtarsal joints
Poor	Heel varus
	Fixed adduction
	Restricted ankle motion
	Restricted activity

TABLE 13.3. Results.

	Number of feet	Percent
Excellent	0	0
Good	26	84
Poor	5	16

which the cast, pins, and sutures were removed. A Phelps-type brace attached to a reverse last shoe was used as a daytime postoperative walking orthotic.

The mean age at the time of the initial operation was 34 months (range 15 to 82 months). All patients were followed for a minimum of 2 and an average of 5 years.

Currently, there is no completely satisfactory classification in growing children with foot deformity; therefore, for the purpose of this study we selected the anatomical and functional criteria of the Green/Lloyd-Roberts classification (Table 13.2).[17] This classification emphasizes deformity, mobility, function, and pain, although with known inadequacies. All patient reviews adhered to the strict clinical criteria.

Based on these selectively exacting criteria, no patient was classified as excellent, which confirms Turco's statement that there are no completely normal feet resulting from surgery.[32] Twenty-six were classified as good, and five as failures (Table 13.3). The five patients classified as surgical failures had subsequent operations for recurrent hindfoot or forefoot deformities. There was one Achilles lengthening, one triple arthrodesis, one Verbelyi-Ogston cuboid decancellation, and two Akron midtarsal dome osteotomies.

In addition to these five surgical failures, we observed two superficial skin sloughs from the plantar button that healed uneventfully. In the group excluded for follow-up of less than 2 years, there was one incisional cellulitis that required IV antibiotics and one superficial abscess that was surgically drained. None of these complications adversely affected the final outcome.

Follow-up radiographs were examined to study the correlation between radiographic findings and clinical success. Based on the findings of Stark et al.[30] we examined the most recent radiographs to assess the incidence of TMT joint degeneration.

Radiographic assessments of 22 feet were carried out at last follow-up. Accepted normal values of 20° to 50° for the anteroposterior (AP) talocalcaneal angle and 25° to 50° for the lateral talocalcaneal angle were used. Only six feet (27%) were judged to be satisfactory by these radiographic standards. Four feet (18%) had mild-to-moderate subchondral sclerosis at the TMT joint. There was absolutely no correlation between radiographic assessment and clinical results.

Discussion

In this study the vast majority of our patients submitted to surgery were treated for a rigid adductovarus following treatment for clubfoot deformity.

The ATT was designed for the treatment of resistant or recurrent clubfoot in an effort to maintain correction of adductovarus deformity.[13,15] Garceau[13] stated, "Ideally, the operation should be performed on feet which have been fully corrected." Fripp and Shaw[8] thought that "In practice, the most satisfactory course is to combine the tendon transfer with the other operations." Our search of the literature did not reveal any published studies combining TMT mobilization and ATT.

Transfer of the anterior tibialis to the lateral part of the foot has been criticized for weakening an already weak foot dorsiflexor.[31] However, our experience with the cases in this study has shown that the dorsiflexor function of the foot is well preserved despite the transfer.

Overcorrection is presumably prevented by not transferring the tendon to the base of the 5th metatarsal as originally described by Garceau.

With the exception of two plantar button superficial skin sloughs, there were no problems encountered with the skin incisions in this series. Care was taken throughout surgery to preserve the dorsal neurovascular bundle and the superficial skin blood supply.

Radiographic evaluation of the skeletally immature foot is fraught with error. Variables such as the degree of ossification, line and angle reproduction, errors relative to the incident beam of radiation, and foot position relative to the plate all seriously affect radiographic data of the immature foot.

Degenerative changes of the tarsometatarsal joints were specifically examined in this study, but were not included in the Green/Lloyd-Roberts criteria. We found that only 27% of our sample population had acceptable radiographic hindfoot angles. Additionally, 18% had mild-to-moderate TMT subchondral sclerosis, the interpretation of which would be presumptive at best. Late degenerative change of the TMT joint is a potential contraindication to this procedure. We found previously that radiographic and clinical evaluations do not directly correlate in this patient population.[18] Follow-up of this patient population to maturity will be necessary to more properly evaluate degenerative changes.

Stark et al.[30] studied TMT capsulotomy for metatarsus adductus and found a 41% overall failure rate, and a 50% incidence of pain at late follow-up. He also examined radiographs of TMT joints and found 22 of 32 feet with changes, 4 of which were thought to be severe. In our study to date, no relationship was found between radiographic assessments and clinical results.

Our study differed from Stark et al.'s[30] in that our patient population was younger. It is postulated that results are generally better in younger patients, possibly because the younger patient has more time for remodeling. We have not, however, followed our patients to foot maturity and this may favorably affect our results. Stark et al.'s group III of eight patients most closely resembles our patient population; that group had 75% with good results.

Inconsistent grading scales among clubfoot series makes comparison difficult. The Green/Lloyd-Roberts classification used in this study has its limitations.[17] It uses stiffness as a criterion. Our patient population was preselected as being resistant, previously operated, and relatively stiff. The fact that we had no excellent results reflects both our strict adherence to the classification system and the fact that none of these children had a completely normal foot.

Using the Green/Lloyd-Roberts classification criteria, we classified five feet as failures. The majority of these failed because of residual hindfoot deformities. Only two needed further correction of the forefoot. We consider these two cases our true failures; that is, the correction of forefoot adductovarus was not obtained or maintained by the combination procedure. The TMT mobilization was initially described for the child 3 to 8 years of age.[22] Early correction allows adaptive change and early ambulation on a plantar grade foot. Although some have found age at surgery is not a factor,[30] it is generally thought that soft tissue procedures are most successful when done on younger patients. Transfer of the tibialis anterior tendon has been found to be most efficacious when performed between the 3rd and 6th years, but only after the basic deformity has been corrected.[2] The Akron midfoot dome osteotomy has been used successfully in the more mature foot, but results on patients younger that 8 years of age were satisfactory in only 70% of the patients. Therefore, we feel that the recommended age range for the combined procedures is $1\frac{1}{2}$ to 5 years of age.

We emphasize that this procedure has limited indication even in the previously treated idiopathic clubfoot. Other components of the failed clubfoot, particularly persistent hindfoot deformity, are not corrected by this surgery and are best addressed by other well-established operations. Based on our preliminary results, we have found that the ATT combined with the TMT mobilization is a reliable salvage procedure for the young patient with recurrent or residual forefoot adductovarus.

Summary

Based on an analysis of 31 idiopathic clubfeet, carefully scrutinized, the ATT and TMT mobilization is probably the most effective procedure for rigid metatarsus adductovarus in the walking child under 6 years of age.

Patients with idiopathic clubfeet with re-

sidual metatarsus adductovarus, following previous treatment, underwent tarsometatarsal mobilization combined with tibialis anterior tendon transfer at the average age of 34 months. The operation consisted of a tarsometatarsal soft tissue release (Heyman et al.[19]) combined with an osteotomy of the 2nd metatarsal base and transfer of the tibialis anterior tendon lateral to the midline axis of the foot.[9–15] This gave 84% satisfactory results.

This combination of surgical techniques proved to be a very acceptable way of managing recurrent or residual forefoot deformity in the clubfoot. However, this procedure should only be used to correct a forefoot deformity.

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Opening-Wedge First Cuneiform Osteotomy (Usually with 2nd Through 4th Metatarsal Osteotomies) for Resistant Metatarsus Adductus Following Clubfoot Release

T.F. Kling, Jr., M.J. Conklin, and T.L. Schmidt

Resistant adduction of the forefoot is one of the more frequent residual deformities following surgical treatment of a congenital clubfoot. Residual forefoot adduction usually presents in patients older than 3 years of age and parents often feel it is a recurrence of the deformity, even though the examination and radiograph show good hindfoot correction. If untreated, the fitting and wearing of shoes may be difficult and an in-toeing gait is evident. Some children with this deformity develop a callus on the base of the 5th metatarsal, especially if there is an overactive anterior tibial tendon with adduction and supination of the forefoot. As the child grows, they may develop pain over the lateral foot with strenuous activity.

Repeated manipulation and casting have been found to be ineffective in these older children. The most widely practiced surgical treatment for forefoot adductus in children 3 to 8 years of age is the mobilization of the tarsometatarsal and intermetatarsal joints described by Heyman and Strong[5,7] in 1958. In children older than 8 years of age, osteotomy of all five metatarsals has been recommended because it is believed that tarsometatarsal congruity after tarsometatarsal capsulotomies cannot be restored due to inadequate remodeling capabilities.[2]

We and other authors have found a high rate of recurrence of adduction deformity with tarsometatarsal capsulotomies.[3,6] Stark et al.[15] reported that 41% of feet had persistent adduction deformity and a 50% incidence of pain in a long-term follow-up of 48 patients who had had tarsometatarsal capsulotomies. They also found that 22 of 32 patients with a radiographic follow-up long enough to evaluate had degenerative changes of their tarsometatarsal joints. Metatarsal osteotomies are effective in older children but the possibility of injuring the proximal 1st metatarsal growth plate places this osteotomy distally (not in line with the other four), thereby giving the medial side of the foot a serpentine appearance.

When viewed roentgenographically, we observed a marked varus 1st metatarsal–medial cuneiform joint angle in feet with residual metatarsus adductus (Figures 13.18A and 13.19A). We also observed that the bases of the 2nd, 3rd, and 4th (but not the 5th) metatarsals were curved medially and that the medial side of the foot was short relative to the lateral side. We reasoned that, if the 1st metatarsal–medial cuneiform joint angle was abnormally angled medially and left uncorrected, then the adduction deformity would likely persist with growth despite procedures



A



B

FIGURE 13.18. A: Standing anteroposterior (AP) radiograph of a 4-year-old girl, 3 years after clubfoot release with metatarsus adductus. Note the marked medial obliquity of the medial cuneiform–1st metatarsal joint and straight 1st metatarsal. The bases of the 2nd, 3rd, and 4th metatarsals are curved medially, whereas the articulation with cuneiforms are aligned perpendicular to the long axis of the foot. The 5th metatarsal is less curved. B: Arthrogram of the medial cuneiform–1st metatarsal joint of the same patient shows the varus angulation of this joint. The cartilage model of the medial cuneiform articulates with the flat surface of the 1st metatarsal epiphysis and is not a gap, as the plain radiograph would indicate.

performed distal to the joint. Unfortunately, we could find no data describing the normal orientation of the medial cuneiform–1st metatarsal angle relative to the long axis of the foot. This search was made more difficult because the hindfoot had been previously released during the original clubfoot operation.

We propose that an opening-wedge osteotomy through the first cuneiform bone might correct the varus angulation of the medial cuneiform–1st metatarsal joint at its source. We reasoned that, if this joint angle was corrected, then the deformity would not be likely to recur with growth. This concept appeared viable since it had been used by Fowler, and later by Coleman, to treat adduction deformity in feet with poliomyelitis and congenital clubfoot, respectively.[4,6] In order to lengthen the medial column of the foot, we proposed to use a trapezoidal-shaped allograft that was narrower on its lateral side and wider on its medial side. We elected to use a freeze-dried, tricortical iliac crest allograft since it would lessen the morbidity of the surgical procedure for the child, would provide a rigid strut to keep the osteotomy open, and was known to be readily incorporated in children.

Since most feet also had medial angulation at the base of the 2nd, 3rd, and 4th metatarsal, we planned to perform closing-wedge osteotomies at the base of these metatarsal and to release the medial side of the fifth tarsometatar-



A



B

FIGURE 13.19. A: Standing AP radiograph of a 9-year-old boy, 8 years after posteromedial release with metatarsus varus. Note the medial angulation of the 1st metatarsal–medial cuneiform joint relative to the long axis of the foot and the 30° talar–1st metatarsal angle. The base of the 2nd through 4th metatarsals are also curved medially, whereas the 5th metatarsal is aligned with the long axis of the foot. B: Standing AP radiograph $2\frac{1}{2}$ years following opening-wedge medial cuneiform and 2nd through 4th metatarsal osteotomies of the same patient. The soft tissue shadows show excellent alignment of the forefoot with the hindfoot. The obliquity of the medial cuneiform–1st metatarsal angle is reduced. Note that the allograft has been completely incorporated and that the medial cuneiform has assumed its more normal rectangular shape. In addition, all the metatarsals are now aligned with the long axis of the foot. The talar–1st metatarsal angle is 5°, which would be rated as a good result.

sal joint if needed. We found in two cadaver feet that the wedge osteotomy of the medial cuneiform stayed open much more easily after closing wedge osteotomies of the 2nd, 3rd, and 4th metatarsals. From this observation, we incorporated the metatarsal osteotomies into the procedure.

In this report we describe our early experience with opening-wedge osteotomy of the first cuneiform combined with 2nd through 4th metatarsal closing-wedge osteotomies to treat residual adduction deformity of the forefoot following clubfoot surgery.

Materials and Methods

Sixteen patients (22 feet) underwent an open-wedge first cuneiform osteotomy usually combined with 2nd through 4th metatarsal osteotomies for severe metatarsus adductus at Children's Mercy Hospital in Kansas City or at

TABLE 13.4. Patient data and results of opening-wedge 1st cuneiform and 2nd through 4th metatarsal osteotomies.

Patient no.	Side	Age at operation (years)	Length of follow-up (years)	Talar–1st metatarsal angle			
				Pre-op (degrees)	Post-op (degrees)	Degrees correction	Result
1	R	6	2	20	5	15	G
	L			34	20	14	F
2	R	9	$2\frac{1}{2}$	14	2	12	G
3	R	7	$5\frac{1}{2}$	14	0	14	E
4	R	5	3	23	6	17	G
	L			18	5	13	G
5	L	7	4	18	−4	22	E
6	R	8	1	35	12	23	G
	L			44	19	25	G
7	R	8	$2\frac{1}{2}$	26	17	9	F
8	R	8	$1\frac{1}{2}$	28	11	17	G
	L			24	12	12	G
9	R	4	$1\frac{1}{2}$	38	24	14	F
	L			45	23	22	F
10	R	11	$1\frac{1}{2}$	14	−6	20	E
11	R	10	1	12	4	8	G
12	R	9	1	30	5	25	G
13	L	8	1	25	−6	31	E
14	R	5	1	22	−9	31	E
	L			36	24	12	F
15	R	7	$1\frac{1}{2}$	20	10	10	G
16	L	4	2	18	7	11	G

Result: E, excellent (less than 0°); G, good (1°–12°); F, fair (13°–24°); P, poor (greater than 24°).

Riley Children's Hospital in Indianapolis. The patients ranged in age from 4 to 11 years with a mean age of 7 years (Table 13.4). All patients had a forefoot adduction deformity after treatment of congenital clubfoot. Seventeen clubfeet in 12 patients had had a posteromedial release between 6 and 12 months of age as described by Turco.[16] Five feet in four patients had been treated with manipulation and serial casts and straight-last shoes. Two patients had had Heyman-Herndon capsulotomies to treat metatarsus adductus, one at the age of $1\frac{1}{2}$ years, and the other at 6 years. Thirteen of the involved feet were on the right and nine on the left. Six patients had bilateral deformities. The length of follow-up ranged from 1 to $5\frac{1}{2}$ years (mean 2 years). Additional procedures performed at the time of the medial cuneiform and 2nd through 4th osteotomies to balance the foot included an adductor hallucis release in seven feet, a plantar fasciotomy in five feet, and an anterior tibial tendon transfer to the second cuneiform in six feet. Early in the study, and in cases with mild deformity, seven patients underwent open-wedge medial cuneiform osteotomy only, without 2nd through 4th metatarsal osteotomies.

Preoperatively the patients complained of cosmetically displeasing deformity, difficulty fitting regular shoes, and many children had aching pain over the base of the 5th metatarsal with activity. All feet were examined for the correction of the hindfoot, the presence of cavus and supination, and flexibility of the forefoot. The feet were observed during gait to determine if the forefoot was supinated during swing and stance by the anterior tibial tendon. Standing anteroposterior and lateral x-rays

were evaluated to determine the correction of the hindfoot, obliquity of the medial cuneiform–1st metatarsal joint relative to the long axis of the foot and the deformity of the metatarsal. Adduction of the forefoot was quantitated by measuring the talar–1st metatarsal angle on the standing anteroposterior x-ray. The normal range for this angle is 0° to (−)20°.[14] A positive value measures the severity of the adducted forefoot. The presence or absence of cavus deformity of the forefoot was quantitated on the standing lateral x-ray by measuring the talar–1st metatarsal angle (Meary's angle). This value is normally 0°, with a positive value indicating the amount of cavus deformity.[11]

Patients were evaluated at the time of follow-up to determine the appearance of the foot, its flexibility, and to assess healing of the osteotomy and incorporation of the allograft. The children and parents were asked about cosmetic appearance of the foot, ease of shoe fitting, and the presence of foot ache or pain with activity. We asked the parents to rate the cosmetic appearance of the forefoot as (a) good or excellent, (b) better but not perfect, or (c) poor. The feet were examined with weight bearing to see if the lateral border of the foot was straight, and if there was persistent forefoot adduction, supination, or cavus deformity. Standing anteroposterior (AP) and lateral x-rays were evaluated to determine if the allograft was incorporated, and whether there had been collapse of the medial cuneiform osteotomy over time. The roentgenographic correction of the AP talar–1st metatarsal angle, 1st metatarsal–cuneiform foot angle, and Meary's angle were measured.

The feet were rated based on the radiographic correction of the talar–1st metatarsal angle. Since the normal talar–1st metatarsal angle is 0° to (−)20°, an excellent rating was given to those feet corrected to 0° or better. A good rating was given to those feet with an angle of 1° to 12°. The cosmetic appearance and ability of the foot to fit in regular shoes satisfied the parents and physician. Feet with angles of 13° to 24° were rated as fair and poor when measured with angles greater than 25°.

Procedure

The operation involves an opening-wedge osteotomy of the medial cuneiform with the wedge being thick enough to clinically correct the adduction deformity of the foot. Initially, we used the natural wedge shape of allograft bone from iliac crests to correct the angulation and to lengthen the medial side of the foot. We found the natural wedge shape or allograft iliac crest corrected some, but not all, of the angulation of the 1st metatarsal–cuneiform joint as measured by the talar–1st metatarsal angle. Later, we cut a triangular-shaped wedge to better correct the obliquity of the talar–1st metatarsal angle and, therefore, the 1st metatarsal–cuneiform angle. In three patients, the obliquity of the 1st cuneiform-metatarsal angle was documented with arthrograms of that joint (Figure 13.18). We found that the cartilage that makes up a significant portion of the medial cuneiform and 1st metatarsal base in children less than 6 years old mimicked the body model.

Under tourniquet control, a medial incision is made from the base of the 1st metatarsal to the naviculocuneiform joint. The incision is deepened to expose the abductor hallucis, which can be released or retracted plantarward. The medial cuneiform is exposed extraperiosteally on its anterior, medial, and plantar sides with the insertion of the anterior tibial tendon being carefully preserved. The 1st metatarsal–cuneiform and the naviculocuneiform joints are identified with a needle. The medial cuneiform is osteotomized at its midpoint, extending the osteotomy to, or just through, the lateral cortex, taking care not to cut the lateral periosteum. The first cuneiform is opened medially using a small laminar spreader while maintaining the lateral periosteal hinge. If the lateral periosteum is cut, then a lengthening of the cuneiform will be accomplished with less realignment of the medial cuneiform–1st metatarsal joint. If the medial cuneiform osteotomy opens with force and springs closed quickly, then the 2nd through 4th metatarsals are osteotomized.

The bases of the 2nd through 4th metatarsals are exposed subperiosteally through two longitudinal incisions on the dorsum of the foot. Proximal, laterally based closing-wedge osteotomies are cut with a microsaw large enough to correct the deformity noted on the preoperative standing x-ray. After the metatarsal osteotomies are cut, the first cuneiform osteotomy is filled with a wedge of allograft iliac crest bone. The allograft is cut in a triangle shape to correct the obliquity of the first

cuneiform–metatarsal joint angle so that the talar–1st metatarsal angle will be normal. The osteotomy of the first cuneiform is then fixed with a threaded Steinmann pin or screw to prevent collapse of the allograft during healing. The 2nd, 3rd, and 4th metatarsal osteotomies are then closed laterally and fixed with smooth Kirschner wires.

Postoperatively, the patient is treated in a well-padded short leg cast and remains non–weight-bearing for 8 weeks to allow the allograft to incorporate. The pins are removed at 8 weeks and the patient is placed back into a short leg walking cast for another 2 to 4 weeks when the allograft is seen radiographically to be incorporated. After the period of immobilization is complete, range of motion and strengthening exercises are begun, and the patient can generally begin wearing regular shoes.

Results

Clinically, each parent and patient rated the cosmetic appearance of the forefoot as good or excellent after a mean 2-year follow-up (range 1 to $5\frac{1}{2}$ years) (Figure 13.19). All patients wore regular shoes and none used braces. Fourteen of 16 patients had no pain with activity. Two patients complained of a mild ache in their foot, which improved postoperatively, and which did not restrict their activities. One of these patients had had Heyman-Herndon capsulotomies previously and the other's hindfoot was in 10° of valgus. Examination using a straight edge showed the lateral border of the foot was straight in each case. At follow-up there were no cases of significant cavus, and during gait the foot remained level without supination.

Roentgenographically, the preoperative adduction deformity averaged 25° with a range of 12° to 45° as measured by the talar–1st metatarsal angle (Table 13.4). At follow-up, the mean correction of the talar–1st metatarsal angle was 17° (range 8° to 31°) in these 22 feet. Based on the roentgenographic rating system, using the talar–1st metatarsal angle, there were 5 excellent results, 11 good, and 7 fair (Figure 13.20). No patient had a poor result or a talar–1st metatarsal angle of more than 24°.

The mean correction of the medial cuneiform–1st metatarsal angle was 10° or 71%, relative to the long axis of the foot. We had difficulty determining the long axis of the foot roentgenographically following clubfoot release because the talus and calcaneus landmarks were variable. In addition, we were unable to find normal values for this angle in children without foot deformity. For these reason, we did not think that roentgenographic measurement of this angle was useful.

Most of the feet did not have cavus deformities. In those feet that did, most were mild. The lateral talar–1st metatarsal angle (Meary's) had a mean of 10° (range 0° to 23°). The mean correction of the equinus deformity was 4°. Two feet had severe cavus deformities of 33° and 30°, which were corrected to 13° and 10°, respectively, with a biplane wedge allograft cut larger on the medial and plantar sides.

There were no operative or perioperative complications in this series. Specifically, there were no wound or pin tract infections, no cast sores, neurovascular injuries, or excessive scarring. The allograft bone incorporated into each cuneiform, including those with a relatively small ossific nucleus in younger children. There was no evidence of allergic or autoimmune reaction to the allograft bone. Based on review of the x-rays, the wedge of allograft bone did not appear to have collapsed during incorporation into the cuneiform.

Discussion

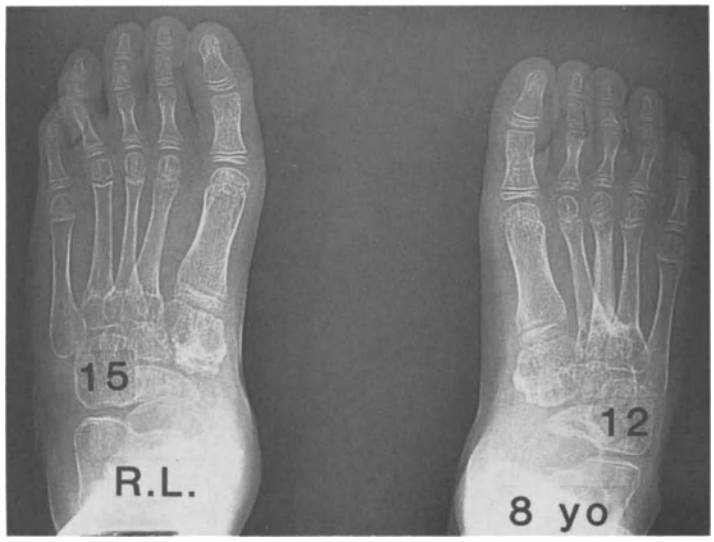
Osteotomy of the first cuneiform was described by Fowler et al.[4] for treatment of cavovarus deformity of the forefoot, usually as a residuum of poliomyelitis. Their procedure consisted of release of the plantar fascia and an opening-wedge osteotomy of the first cuneiform, based medially and plantarward, which corrected the adduction and cavus of the forefoot. Lincoln et al.[10] reported the results of an opening-wedge medial cuneiform osteotomy in patients with metatarsus varus alone and in clubfoot deformity. They reported excellent functional results in 18 of 19 feet and concluded that the procedure should be considered in the older patient with metatarsus varus. Hoffman et al.[6] reported their results with medial cuneiform osteotomies combined with Steindler stripping in 18 feet for residual metatarsus adductus and cavus deformity associated with clubfeet. Their average correction of forefoot adduction was 72% and of forefoot cavus was 47%. They believed that the operation was effective for



A



B



C

FIGURE 13.20. A and B: Standing AP radiographs in this 6-year-old, $5\frac{1}{2}$ years after bilateral posteromedial release, shows marked metatarsus adductus. The talar–lst metatarsal angle is 44° on the left and 35° on the right. C: Standing AP radiograph, 2 years following opening-wedge medial cuneiform and 2nd through 4th metatarsal osteotomies, shows good alignment of the soft tissue structures of the forefoot with the hindfoot and the metatarsals with the midfoot. However, there is still some residual obliquity of the medial cuneiform–lst metatarsal joint, and the talar–1st metatarsal angle measures 15° on the left and 12° on the right, respectively. These radiographic measurements place these feet in the fair category. This represents one of our worst radiographic results, although the clinical results were rated as good.

treatment of both adduction and cavus of the forefoot as a residuum of clubfoot. McKay (1990 personal communication) reported that approximately 20% to 25% of his patients had pain at the medial cuneiform–1st metatarsal joint 4 to 5 years following opening-wedge medial cuneiform osteotomy performed for metatarsus adductus. He reported that this operation was done as an isolated procedure and was not combined with plantar or abductor hallucis release or metatarsal osteotomies.

The etiology of metatarsus adductus is unknown. Muscle imbalance has been implicated by some authors. Kite[8] felt that the deformity was secondary to the anterior and posterior tibial muscles overpowering the peroneals. Peabody and Muro[12] recorded an abnormal attachment of the anterior tibial tendon distally and inferiorly on the 1st metatarsal shaft, providing it with an abnormal mechanical advantage. Reimann and Werner[13] produced the deformity by traction on the tibialis anterior when the tarsometatarsal joints were allowed to sublux by capsulotomy while simultaneously holding the heel in valgus.

Other authors have reviewed x-rays and noted bony changes in patients with metatarsus adductus. Bankart[1] thought that metatarsus adductus was the result of a deficiency of the medial cuneiform. Kite[8] noted considerable delay in the ossification of the first and second cuneiforms on x-rays of children with metatarsus adductus.[9] In addition, he observed that the first cuneiform may be small and the 1st metatarsal articulates with the medial side of the first cuneiform instead of being directly in front of it. Peabody reported that the 1st metatarsal is usually straight, but that the 5th, to a slight degree, and the 2nd, 3rd, and 4th metatarsals, to a marked degree, are curved medially in their diaphyses.[12]

Regardless of the etiology, the deformity roentgenographically lies in the area of the medial cuneiform–1st metatarsal joint and in the diaphyses of the other metatarsals. Since the 1st metatarsal is typically straight, and with the presence of the growth plate proximally on the 1st metatarsal, it would appear too distal and potentially dangerous to perform a corrective osteotomy in this area. Due to its location in the foot, it would seem more logical to perform a capsulotomy through the 1st metatarsal–cuneiform joint. However, with Stark et al.'s[15] report of a 50% incidence of pain, presence of dorsal prominence, and degenerative joint changes, a tarsometatarsal capsulotomy appears less than optimal. An opening-wedge osteotomy of the medial cuneiform appears to be a more logical approach since it corrects the deformity of the medial cuneiform–1st metatarsal joint. The efficiency of this procedure is supported by the good results reported by Hoffman et al.[6] and Lincoln et al.[10] McKay's report of late degenerative changes in the medial cuneiform–1st metatarsal joint is disturbing, although he opened the first cuneiform bone as an isolated procedure. We found both in the cadaver feet and in the patients in this series that 2nd through 4th metatarsal osteotomies greatly reduce the force required to hold open the first cuneiform osteotomy. We speculate that these metatarsal osteotomies and the plantar or adductor hallucis release done in some feet will decrease the pressure on the medial cuneiform–1st metatarsal joint, which will not subsequently become arthritic. In addition, the 2nd through 4th metatarsal osteotomies address the metatarsal deformity that Peabody and Muro[12] and others have observed. And, unlike tarsometatarsal capsulotomies, Berman and Gartland[2] have shown that metatarsal osteotomies are effective and reliable.

The 73% excellent and good results in this preliminary series supports the efficiency of an opening-wedge first cuneiform osteotomy combined with 2nd through 4th metatarsal osteotomies to treat resistant metatarsus adductus deformity in older children with clubfeet. We believe that the roentgenographic correction would have been better if a triangular wedge, cut to correct the talar–1st metatarsal angle, rather than a trapezoidal wedge, had been used in all cases. Based on this experience, we recommend cutting the graft into a triangular-shaped wedge that will completely correct the talar–1st metatarsal angle back to 0°, based on the preoperative x-rays. We no longer attempt to lengthen the medial side of the foot using a trapezoidal-shaped graft, although these grafts straightened the lateral border of the foot and provided good cosmetic correction. It is probably better to fully correct the talar–1st metatarsal angle in order to prevent recurrence with growth. The use of allograft bone to hold open the first cuneiform osteotomy lessens the surgical morbidity and appears to be both safe and effective in these preliminary results.

Summary

The medial cuneiform osteotomy combined with 2nd through 4th metatarsal osteotomies corrects the roentgenographic deformity observed in resistant metatarsus adductus in older children with treated clubfoot. In this short-term follow-up, the operation appears safe and effective. The procedure reduces the obliquity of the 1st metatarsal–medial cuneiform joint and of the metatarsals, which should prevent recurrent deformity with growth. Longer follow-up will be needed to determine if the forefoot will remain corrected and if the medial joints will develop arthritic changes.

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Combined Lateral Column Shortening and Medial Column Lengthening in the Treatment of Severe Forefoot Adductus

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Metatarsus adductus, either isolated or in association with deformities elsewhere in the foot, is a common problem in children. In most cases, nonoperative treatment is successful in correcting forefoot alignment. However, in particularly severe cases, a surgical solution is required. Various methods have been described; some have attacked the deformity at

the metatarsal level,[2,16] some at Lisfranc's joint,[5] some at the midtarsal level,[6–8,12] some at Chopart's joint,[4,9] and still others at the hindfoot.[15,17]

Since 1986, we have combined a medial opening wedge osteotomy with a lateral closing wedge osteotomy in the midfoot to treat severe forefoot adductus. We have used this technique on feet with isolated metatarsus adductus, on skewfeet (forefoot adductus with hindfoot valgus), and on clubfeet with residual or recurrent forefoot adductus after previous soft tissue releases. This report describes our experience with the procedure in 33 feet.

Materials and Methods

The records of all children requiring operative treatment for severe forefoot adductus from 1986 to 1989 were reviewed. A total of 29 patients were identified. Four had procedures other than the combined midfoot osteotomies. Three children were lost to follow-up. The remaining 22 patients were the subjects of this study. Eleven of them had the procedure performed on one foot (6 right, 5 left) and 11 had bilateral procedures, for a total of 33 feet. The average age at operation was 5 years 3 months (range 3 years 4 months to 9 years 6 months). Sixteen patients were male, 6 were female.

The indication for the procedure was marked forefoot adductus on clinical inspection that was deemed too severe to respond to bracing, corrective casting, or soft tissue release alone. The forefoot was typically noted to be fairly fixed in the adducted position. The presence of the ossific center of the medial cuneiform on an anteroposterior radiograph of the foot was a prerequisite. In the early part of the study period, there was no lower age limit for the procedure; however, we have since found that adequate bone stock for the osteotomies, particularly the cuneiform opening osteotomy, is rarely present prior to age 5.

Twenty-four of the 33 feet had the forefoot adductus as part of a clubfoot deformity. Eighteen of these had had a previous soft tissue release. Four had soft tissue releases concomitant with the midfoot osteotomies; no soft tissue release was performed at any time in two feet. Nine of the 33 feet in the study had either a skewfoot deformity or isolated, severe metatarsus adductus. None of these 9 feet had surgical treatment prior to the midfoot osteotomies. A limited medial soft tissue release centered on the 1st metatarsal–cuneiform joint was combined with the osteotomies in these nine feet.

The presence of hindfoot malalignment was not considered a contraindication to the procedure. Six feet demonstrated hindfoot varus preoperatively, as evidenced by a Kite's angle less than 20°. Although no foot had a Kite's angle greater than 40°, excessive hindfoot valgus was noted clinically in three of the feet as well.

The average length of follow-up was 2 years (range 3 to 43 months). Preoperative and postoperative radiographs were assessed. Specific parameters measured included the anteroposterior talocalcaneal angle (Kite's angle), the calcaneo–2nd metatarsal angle,[15] the talar–1st metatarsal angle, and the medial/lateral column ratio. This ratio was calculated by dividing the distance from the proximal midpoint of the navicular to the most distal extent of the first cuneiform, by the maximum measured length of the cuboid on an AP radiograph. In addition to these quantitative evaluations, each final follow-up radiograph was subjectively rated either improved, unchanged, or worse in comparison to the preoperative film.

Operative Technique

The procedure was performed under pneumatic tourniquet control. First, the medial cuneiform was exposed through an oblique incision in the skin lines. If a surgical scar from a prior soft tissue release was present over the cuneiform, the bone was approached through it. When the osteotomies were performed in conjunction with a soft tissue release, the medial cuneiform was easily accessible through the anterior limb of the transverse skin incision, whereas the cuboid was approached separately. It was usually necessary to release the most proximal attachment of the tibialis anterior tendon to visualize the naviculocuneiform and the cuneiform-metatarsal joints. Distally, a soft tissue release was performed, which included the medial and plantar 1st metatarsal–cuneiform capsule and a fractional lengthening of the great toe abductor. A vertical osteotomy was then made across the medial cuneiform at its midpoint with an oscil-

lating saw. Care was taken not to extend the cut into the middle cuneiform.

The cuboid was then exposed through a separate oblique incision. The proximal and distal articulations of the cuboid were defined. A laterally based corticocancellous wedge was then removed, which was as large as possible while still leaving adequate bone for staple fixation. This typically measured 7 to 10 mm at its base.

After removal of the wedge from the cuboid, the osteotomy of the medial cuneiform was opened with a lamina spreader. If the wedge from the cuboid was of suitable size, it was placed into the medial opening wedge; in instances where it was inadequate, a corticocancellous wedge was harvested from the iliac crest or the ipsilateral tibia. The bone graft was gently seated in position with an impactor. Fixation of the osteotomies has included transfixing Kirschner wires, two-pronged bone staples, and custom-made staples fashioned from smooth Kirschner wires. In the most recent cases, both osteotomies have been fixed with the pneumatic power stapler (3M Corp.). All feet were immobilized in below-knee non–weight-bearing casts for 6 weeks postoperatively.

Results

The average calcaneal–2nd metatarsal angle changed from 37° preoperatively to 18° postoperatively (normal: 15° to 20°). The average talar–1st metatarsal angle decreased from 15° preoperatively to −2° (valgus) postoperatively (normal: 0° to −20°). The changes in each of these angles represent virtually complete correction of the adductus deformity. The AP talocalcaneal angle was not significantly changed for the group as a whole. However, in patients treated for metatarsus adductus combined with hindfoot valgus, an average decrease in Kite's angle of 9° was seen. This improvement was not usually seen on the immediate postoperative film, but developed after several months postoperatively. The ratio of medial/lateral column length was increased postoperatively an average of 34%. Staple fixation was generally superior to Kirschner wire or no internal fixation in holding the osteotomies in the desired positions, and thereby maintaining improvement in the medial/lateral column ratio.

On quantitative comparison of the pre- and postoperative radiographs, 27 of the 33 feet (82%) were noticeably improved by the procedure. Two feet (6%) were rated as failures. One patient, a 4-year-old girl treated for isolated severe metatarsus adductus, exhibited marked abduction of the forefoot and an overcorrected appearance postoperatively. Her other foot was treated with the same procedure at the same sitting for residual adductus from clubfoot and the result was satisfactory. The other failure was in a 5-year-old child treated for residual clubfoot deformity; Kirschner wire fixation failed to hold the cuboid osteotomy closed and no correction was achieved.

Although not quantifiable by conventional means, a marked change in the orientation of the cuneiform–1st metatarsal joint was effected by the procedure. This joint was typically oblique relative to the transverse when viewed on the AP preoperative radiograph. Postoperatively, a change in orientation toward the transverse was generally seen.

The improvement in forefoot position seen postoperatively after osteotomies was maintained during follow-up. In some instances, the correction was noted to increase with time. One patient exhibited radiographic changes typical of aseptic necrosis of the navicular (Kohler's disease) on follow-up at 3 months. There were no deep infections, wound problems, or delays in bony union in the series. Staple removal has been required for local discomfort in a few cases. There have been no instances of subsequent degenerative arthritis or joint pain in these children.

Discussion

We developed this combination of medial and lateral column osteotomies out of dissatisfaction with other existing procedures to correct severe forefoot adductus. In our experience, the two major drawbacks typically encountered were either recurrence following soft tissue releases at the tarsometatarsal joints or morbidity associated with metatarsal osteotomies. Furthermore, we feel that the combination of medial and lateral column osteotomies addresses the problem at its anatomic locus, namely the midfoot.

In the normal foot, the navicular is centered on the talar head, and the 1st metatarsal is

aligned with the long axis of the talus or is slightly lateral to it.[1,14] The 1st metatarsal–cuneiform joint is relatively transverse. However, although many angles in the foot have been described and quantitated, no normal values have been established for inclination of this joint. The ossification center of the cuboid should be present at or near birth, whereas that of the medial cuneiform does not appear until about 2 years of age.[16] In the foot with severe forefoot adductus, there is typically a marked inclination or obliquity of the 1st metatarsal–cuneiform joint, which is seen on the AP radiograph.[6,7] Although the deformity could theoretically be centered at either the naviculocuneiform joint or the metatarsal-cuneiform joint, it is the angulation at the distal articulation that is more severe.[11] In their series of treated clubfeet with residual forefoot adductus, Lowe and Hannon[10] noted abnormal obliquity in the midfoot in 73%.

The length disproportion between the medial and lateral columns of the midfoot have been cited as the "essential deformity" in clubfoot.[4] In the infant's foot, this discrepancy can usually be overcome with soft tissue releases alone, including reduction of both talonavicular subluxation and calcaneocuboid subluxation.[3,15] However, after adaptive bony deformity is present, more definitive treatment is required. Johanning[7] described wedge resection and enucleation of the cuboid followed by manipulation and casting as treatment for resistant clubfeet. Other lateral column-shortening procedures such as resection of the distal end of the calcaneus[9] and resection-arthrodesis of the calcaneocuboid joint[4] have also been described. Although results with these procedures have been inconsistent, the concept of lateral column excess remains valid.

Procedures to lengthen the deficient medial column have also been described. Hoffman et al.[6] recently reported results with Fowler's technique of a medial opening wedge in the first cuneiform. They used the procedure to correct residual forefoot adductus and cavus in treated clubfeet of children 4 to 15 years old. The adductus was corrected by an average of 72%. A normally aligned hindfoot was a prerequisite in their series. More recently, Kling et al.[8] described a similar procedure combined with osteotomies of the 2nd through 4th metatarsals.

It would seem, therefore, that maximum correction could be achieved by combining a lateral column–shortening procedure with medial column lengthening. McCormick and Blount[11] reported a case of skewfoot that they treated with a cuboid wedge resection combined with a medial opening wedge at the base of the 1st metatarsal. McHale and Lenhart[12] reported a series of seven clubfeet in which they transferred a wedge from the cuboid to the cuneiform. In a cadaver study, they demonstrated that combining the osteotomies provided more correction than either one alone. Using such a combination, we have shown that severe forefoot-midfoot adductus can be virtually completely corrected.

In addition to the theoretical advantages of this procedure, complications such as stiffness and pain at Lisfranc's joint, painful bony prominences, and possible growth disturbance of the 1st metatarsal are avoided.[5,16] Certain technical points are of importance. Although the medial cuneiform begins to ossify at age 2, we have found that the first cuneiform typically has not ossified sufficiently to ensure healing of the osteotomies until age 5 or 6. If the bone resected from the cuboid does not have sufficient cortical rigidity, tibial or iliac crest graft should be obtained. Fixation is best obtained with two staples, each securely fixing both the bone fragments of the cuneiform and spanning the interposed bone wedge.

It has been stated that surgical correction of the forefoot adductus in skewfoot necessitates bony stabilization of the hindfoot to avoid potentiating the severe valgus deformity.[13,16] However, we have found that, in such feet, this procedure made the hindfoot valgus no worse, and in some cases may have improved it, as evidenced by the decrease in Kite's angle. Evans[4] found that midfoot column disproportion can influence hindfoot position. McCormick and Blount[11] identified angulation of the medial cuneiform as the site of maximum deformity in skewfoot. It is presently our policy not to perform subtalar stabilization in conjunction with the midfoot osteotomies. Furthermore, we do not consider the presence of hindfoot varus or valgus a contraindication to this procedure.

We feel this procedure is indicated in feet with severe forefoot adductus in children age 5 and above. The etiology of the deformity and the presence of hindfoot involvement have not had a bearing on its efficacy. Although these feet tend to be more rigid in adolescents, we have found the correction obtained, albeit in-

complete, made the procedure worthwhile. We have not performed the transfer in a skeletally mature patient.

The roentgenographic analysis of these feet is challenging, as various authors use different parameters to assess forefoot deformity.[6,8,12,14,15] Although the average talar–1st metatarsal angle for the group reflected the correction noted clinically and qualitatively on radiographs, we found the calcaneal–2nd metatarsal angle, as reported by Simons,[15] to be more consistent and reproducible. The assessment of the pre- and postoperative medial/lateral column ratio also confirmed that the procedure normalized the length of the columns.

This combination of medial and lateral column osteotomies has reliably corrected severe forefoot adductus from a variety of causes. The obliquity of the 1st metatarsal–cuneiform joint often seen in these deformities is eliminated. This highly effective and versatile procedure has corrected difficult feet without creating morbidity elsewhere in the foot.

Summary

A one-stage procedure combining a closing-wedge osteotomy of the cuboid with an opening-wedge osteotomy of the medial cuneiform was used for the treatment of metatarsus adductus. Twenty-four of the 33 feet had forefoot adductus associated with clubfoot; the others had either skewfoot or severe isolated metatarsus adductus.

Clinical and radiographic improvement in forefoot position was achieved in 82% of cases. The mean calcaneal–2nd metatarsal angle improved from 37° to 18°. The ratio of medial/lateral column length increased an average of 34%. The initial postoperative correction was well maintained over time and often continued to improve with subsequent growth. Residual hindfoot varus in patients with a history of clubfoot did not limit the efficacy of this procedure in aligning the forefoot. Two feet (6%) were rated as failures, one for lack of correction and the other for gross overcorrection.

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Treatment of Residual Clubfoot Deformity—The "Bean-Shaped" Foot—By Opening-Wedge Cuneiform Osteotomy and Closing-Wedge Cuboid Osteotomy: Clinical Review and Cadaver Correlations

K.A. McHale and M. Lenhart

Despite educated and conscientious treatment of clubfoot deformity, residual problems after surgical intervention are quite common. Certain clinical patterns can be manifestations of residua at the various sites that are involved in the original deformity, i.e., the leg, the ankle, the subtalar complex, and the forefoot. An internally rotated gait, because of uncorrected or recurring rotation at the talocalcaneal joint, is perhaps the problem most frequently addressed in the literature. Another common clinical pattern, the sagittally breached or "bean-shaped" foot, is the result of a combination of forefoot adductus, midfoot supination, and mild hindfoot varus, which produces an elongated lateral column of the foot with an internally rotated gait, but a plantar grade foot (Figure 13.21). Functionally, these patients "walk" on the lateral border of the foot, and thus can have difficulty fitting shoes and tend to wear out shoes on the lateral side. They complain of frequent tripping and occasionally of lateral knee and ankle pain. Roentgenographically, these patients have persistently abnormal rotation of the talus and calcaneus (lateral and anterior talocalcaneal angles $<20°$), superior and/or medial displacement of the tarsal navicular, and forefoot adductus (abnormal talar–1st metatarsal angles and abnormal tarsal–1st metatarsal angles) (Figure 13.22).

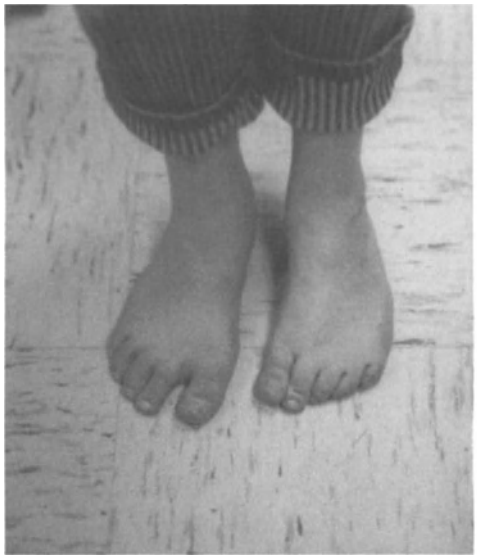
Unfortunately, structural appearance of this pattern of deformity may not become evident until the foot is at the stage where soft tissue release by itself will not accomplish correction because of bone deformation that has occurred with time. After age 4 to 6, hindfoot derotation is not prudent because of the limited ability of the subtalar joint to remodel. The resultant hindfoot cavus can be addressed by surgery on the osseous components, but this will not accomplish derotation. The forefoot directional problems can be changed with either extensive soft tissue release or bony procedures. This is also the case with midfoot directional problems, although not as much attention has been paid to this problem in the literature.

Since the children who present with the "bean-shaped" foot are usually in the 4 to 11 year age range, they are too old for a soft tissue release by itself, too young for a triple arthrodesis, and have too much dysfunction to be temporized with orthotic management. Previously described bony salvage procedures often address only the pathology in one area and must be combined with extensive soft tissue releases, which can be potentially dangerous in the reoperated foot.

The combination of two commonly used procedures, the opening-wedge medial cuneiform osteotomy and the closing-wedge cuboid osteotomy, addresses the pathology in two planes to effect the desired functional clinical improvement. Derotation of the hindfoot is not a goal of this surgery, as these patients are too old to expect remodeling of the subtalar joint. To quantitate the amount of dissection and to further determine how the alteration at each surgical site translates into clinical correction, the procedure was repeated on fresh cadaver specimens. Clinical and roentgenographic evaluation was made in order to direct reproducible results from the combination of procedures.

Materials and Methods

Over a 2-year period at Walter Reed Army Medical Center, 21 patients aged 2 to 12 who previously had surgery for clubfoot were determined to need further surgery for residual deformity. Of these children, six patients with seven involved feet were 4 to 10 years of age



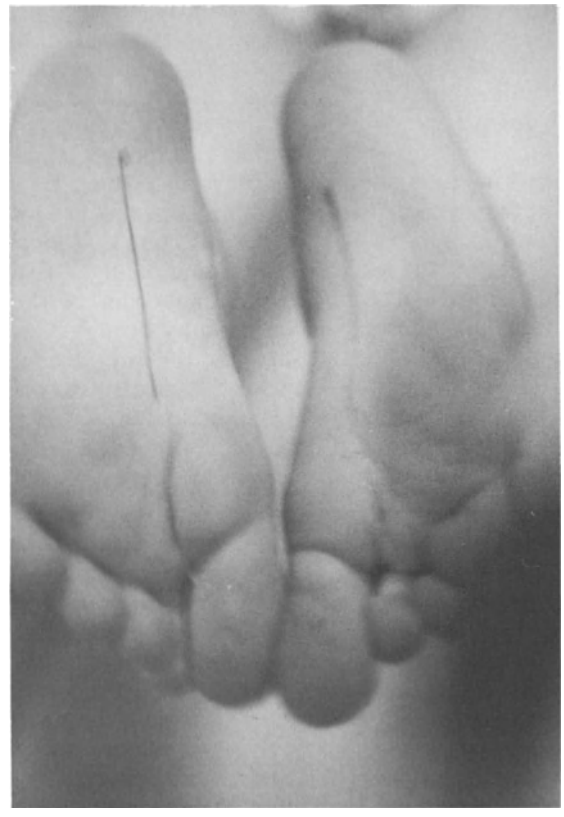
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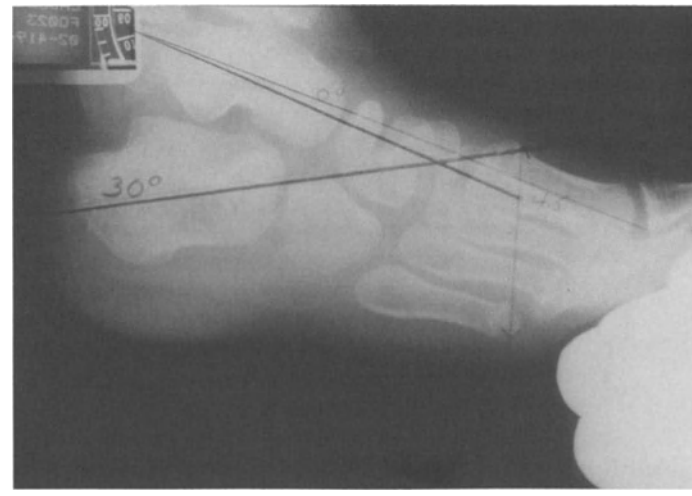


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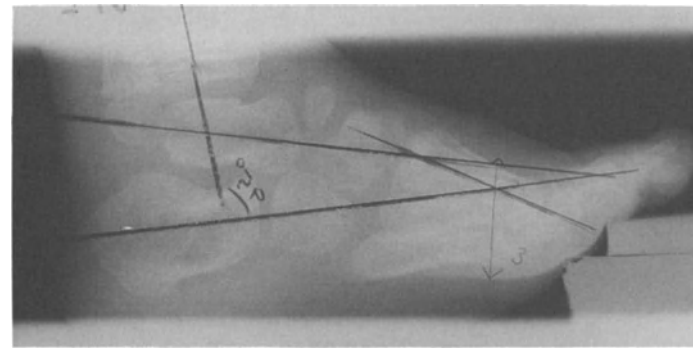


D

FIGURE 13.21. The clinical picture of the "bean-shaped" foot is a plantar grade foot with (A) forefoot adductus, (B) midfoot supination, and (C) hindfoot varus. (D) An abnormally low bimalleolar angle indicates lack of correction of hindfoot rotation, not well demonstrated in this photograph.



A



B



C

FIGURE 13.22. Roentgenograms preoperatively show (A) decreased talocalcaneal angles indicating heel varus, (B) superior and/or medial placement of the tarsal navicular, and (C) abnormal talar–1st metatarsal angles and abnormal tarsal–1st metatarsal angles indicating adductus.

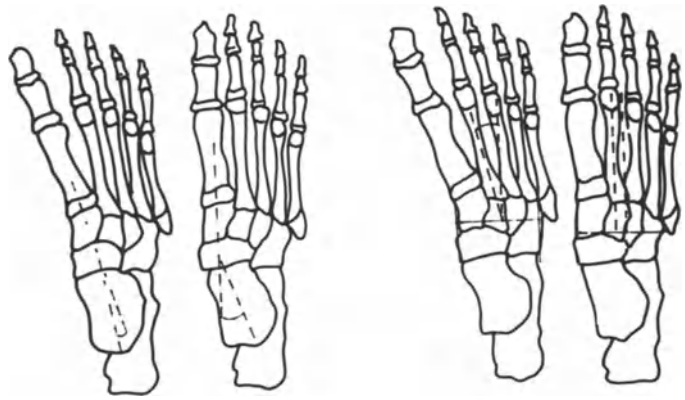


FIGURE 13.23. An abnormally high talar–1st metatarsal angle should decrease with correction (left). However, because of the abnormal medial deviation of the talus, the 2nd metatarsal–tarsal angle might be a more accurate measurement (right).

and had a sagittally breached or "bean-shaped" foot. The chief complaint of these patients was difficulty fitting shoes and wearing out the shoes on the lateral side. The parents of all the children were concerned about their child's gait and related excessive tripping. Two patients complained of lateral ankle and knee pain.

All patients had undergone serial casting and a posterior medial release through a standard medial "hockey-stick" incision in infancy. Clinically, each child walked on the lateral border of the foot and appeared to rotate the lower extremity internally. There was universal smallness of the calf and a mild limb length discrepancy in all cases. The patients had a plantar grade foot, but demonstrated forefoot adductus, elongation of the lateral column of the foot with calluses on the lateral plantar surface of the foot, and a mild hindfoot varus. Ankle motion was limited as compared to the uninvolved side, with an average of only 5° of dorsiflexion and 15° of plantar flexion. The bimalleolar angle, a measure of hindfoot derotation, averaged 68° (normally 84° to 90°).

Roentgenographically, the patients all had a talocalcaneal angle of less than 20° both on the AP and the lateral view, demonstrating lack of hindfoot derotation. Talar–1st metatarsal angles were measured as an indicator of forefoot adductus. Although the measurements were generally abnormal (normal is 0° to −20°), measurements were varied, probably because of the persistent medial direction of the head of the talus. Therefore, the 2nd metatarsal–tarsal angle (the intersection of a line drawn through the 2nd metatarsal shaft and a line that bisects the width of the tarsus at its midpoint on an anteroposterior weight-bearing roentgenogram) was also measured. There was an increase in this angle in all cases (Figure 13.23). Measurement of the supination of the midfoot was even more difficult. However, persistent midfoot supination in a plantar grade foot assumes equinus deformity of the forefoot or at least the first ray. Meary's angle (the talar–1st metatarsal angle on a weight-bearing lateral roentgenogram) was recorded preoperatively. A weight-bearing lateral in some cases gave the appearance of an oblique roentgenogram when evaluating the foot, probably due to the severe degree of residual midfoot supination in these cases. Therefore, yet another measurement was assessed on the preoperative lateral roentgenogram. The width of all the forefoot was measured at the midpoint of the 1st metatarsal. With correction of the supination, this width was expected to decrease (Figure 13.24).

The procedure was performed with the patient in a supine position. A small longitudinal incision was made over the cuboid. A 1- to 7-mm wedge with its base in a dorsolateral position was created with an osteotome and removed. The medial cuneiform was approached using part of the distal extension of the previous medial incision. The bone was osteotomized, making sure that the anterior tibialis was still attached to the distal piece of bone. The medial cuneiform osteotomy site was then spread with a lamina spreader, and the wedge removed from the cuboid was plugged into the medial cuneiform at the base of the wedge straight medially. Clinical correction was then

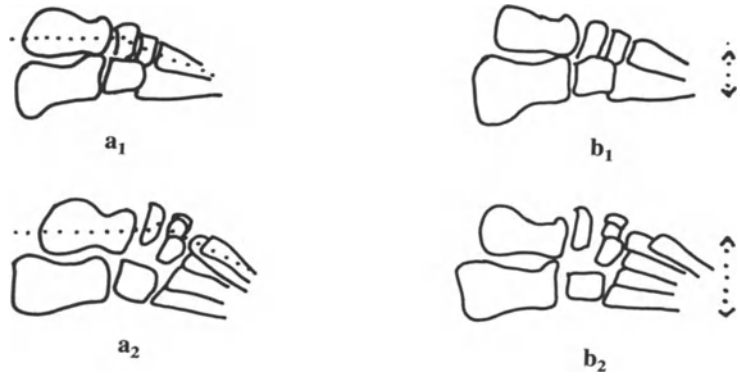


FIGURE 13.24. Meary's angle (a_1) should decrease with correction of midfoot supination (a_2) (left). Since an oblique position of the forefoot on the lateral roentgenogram can be caused by the midfoot supination (b_1), a decrease in the height of the forefoot can be expected with correction (b_2) (right).

checked. If the lateral border of the foot still appeared prominent, i.e., the midfoot supination was not corrected, a larger wedge was removed from the cuboid. Smooth Kirschner wires were used to fix the foot in the corrected position (Figure 13.25). One pin was placed through the cuboid by starting in the calcaneus and exiting through the base of the 5th metatarsal. The other pin was inserted through the first web space, skewered the medial cuneiform, and traversed the tarsal navicular to end in the talus. Intraoperative roentgenograms were taken to confirm the location of the pins and to check the position of the bones. After the positioning of the forefoot, the lateral three toes were often in flexion, which was passively correctable. Simple flexor tenotomy was used to correct this.

A short leg plaster cast with thick cotton padding was applied to allow for swelling postoperatively. A wound check was performed at 2 weeks and a more form-fitting, non–weight-bearing cast was applied. The pins were removed at 6 weeks. Another weight-bearing cast was applied until bone unity was demonstrated roentgenographically: this was generally at 8 to 12 weeks. The child was fitted with a University of California–Berkeley (UCBL) insert, which was worn for 6 months or until the child outgrew it.

Clinical Results

The average follow-up was over 2 years for all patients, except for one patient who had surgery 18 months prior to the follow-up evaluation. All patients and parents feel that the feet are markedly improved. All patients have improved ability to fit into commercially available shoes and the "life" of the shoe has been prolonged. There were no further complaints of ankle and knee pain from those patients who had complained of these symptoms preoperatively.

The gait appeared to be improved in that the patients no longer walked on the lateral border of the foot and there was less apparent internal rotation. Since there was no improvement in ankle motion, there was still some "foot dragging" in the swing phase.

The clinical examination of the foot showed improvement in general. Parameters such as ankle motion and bimalleolar angle did not change since the ankle and hindfoot had not been approached surgically. The prominence of the lateral border of the foot, i.e., the midfoot supination, had been eradicated in all cases. Forefoot adductus was corrected in all but one case. In this foot, the forefoot was improved, but maximal correction was not attained. In essence, the feet no longer appeared "bean-shaped" (Figure 13.26).

Roentgenographically, there was an average improvement of 9° in the talar–1st metatarsal angle. This reflects changes in five feet only; there was no change in the talar–1st metatarsal angle in two feet. Measurement of the 2nd metatarsal–tarsal angle, however, showed an improvement in all feet with a range of 8° to 20° and an average of 14°. The one foot that demonstrated residual clinical forefoot adductus still had an improvement of this angle, but only of a few degrees. Adductus of the forefoot, therefore, was considered significantly roentgenographically improved in all cases

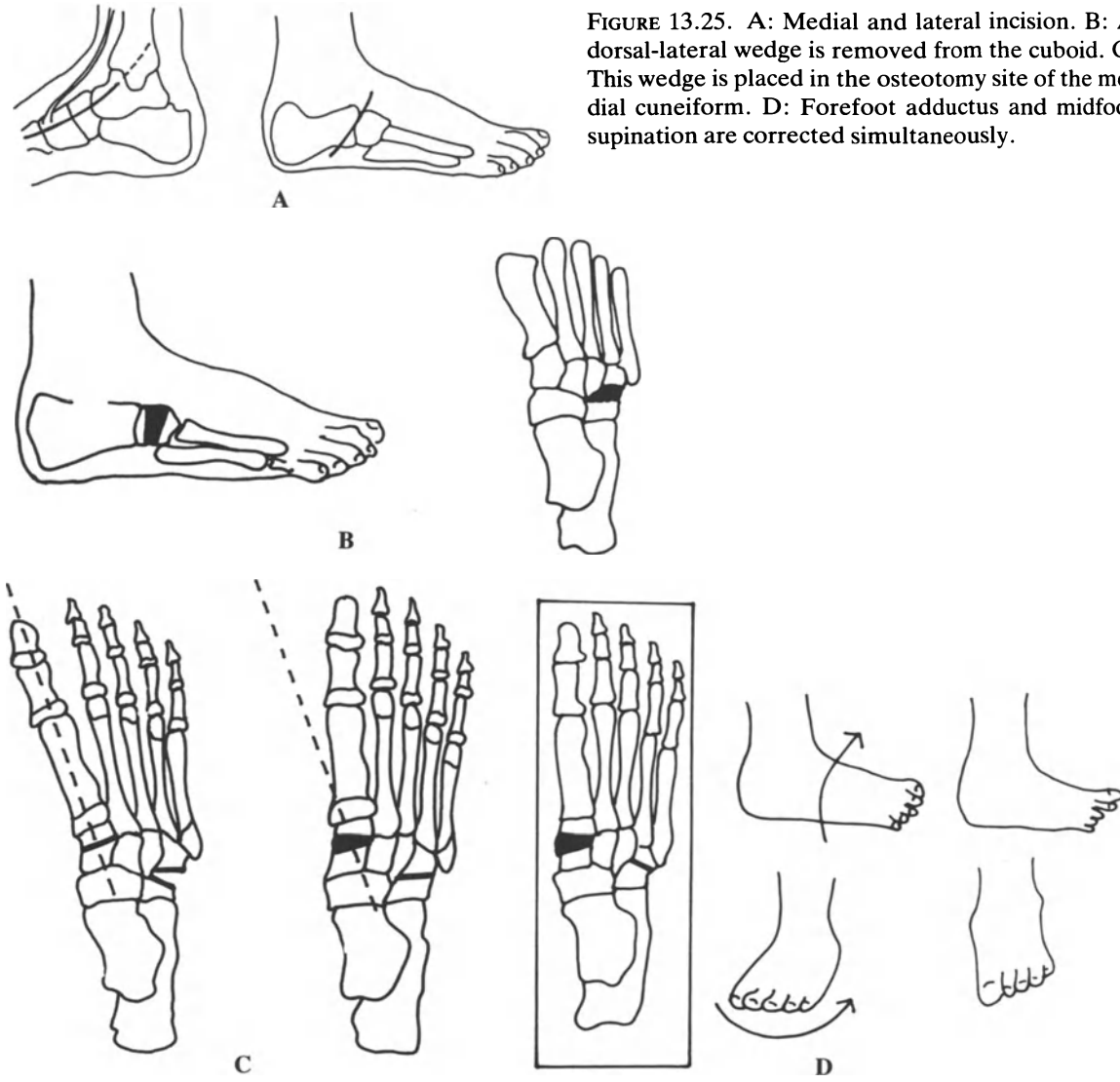
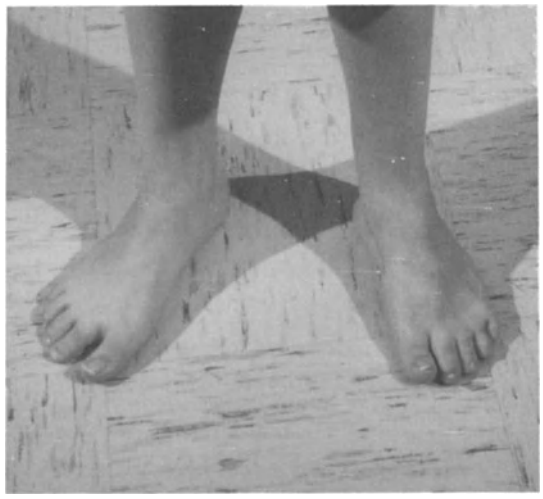


FIGURE 13.25. A: Medial and lateral incision. B: A dorsal-lateral wedge is removed from the cuboid. C: This wedge is placed in the osteotomy site of the medial cuneiform. D: Forefoot adductus and midfoot supination are corrected simultaneously.

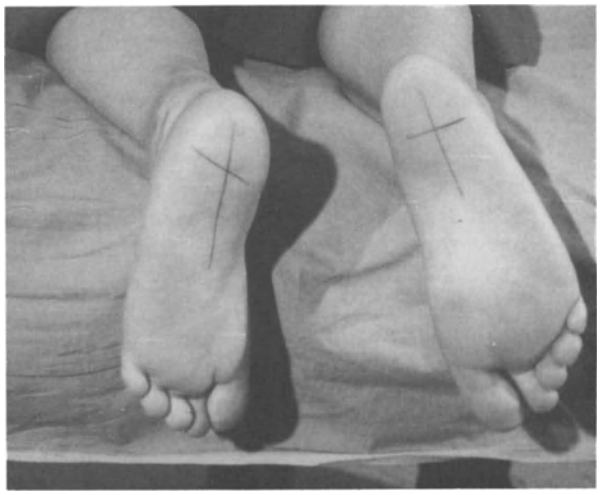
except one. The roentgenographic measurement of the changes in the midfoot was done both with Meary's angle and the width of the forefoot (height of the metatarsals) on a lateral film. There was a change in Meary's angle in all cases, but this averaged only 3°. The change in the metatarsal height was impressive. Each foot had a decrease of at least 10 mm with an average of 13 mm. Preoperative standing lateral roentgenograms often captured the forefoot in an apparent obliquity; postoperative laterals now gave the appearance of a normal foot in the lateral projection.

Cadaver Reproduction of the Procedure

In reviewing the clinical results, there were two unknowns that needed to be investigated. The first of these was the amount and type (abduction vs. pronation) of deformity at the two osteotomy sites. The second problem was the difficulty in standardizing roentgenographic analysis of results with the various deviations from normal foot anatomy in these residual clubfeet, especially roentgenographic docu-



A



B



C

FIGURE 13.26. The postoperative appearance. A: The forefoot adductus is corrected. B: The heel remains in mild varus; however, because of correction of midfoot supination, the patient no longer has excessive wear on the lateral border of the foot. C: Roentgenographic healing of the cuboid is present at 6 weeks.

mentation of the improvement in the midfoot rotation (supination vs. pronation).

Therefore, reproduction of the surgical procedure was performed on normal fresh cadaver feet. There were two phases to this laboratory exercise.

Phase One

The combined procedure was done on eight feet to test the reproducibility of the procedure. Both the adductus angle (2nd metatarsal–tarsal angle) and the talar–1st metatarsal angle (AP) were measured to assess change in forefoot adductus. The talar–1st metatarsal angle (Meary's angle) and the metatarsal height (forefoot width) on a lateral roentgenogram were measured to look at the change in midfoot rotation. With these eight feet, the procedure was done in a similar fashion as with the patients. The wedge of bone removed from the cuboid was used to keep open the osteotomy of the medial cuneiform. This piece of bone is of random size essentially because, although a 0.75- to 1-cm wedge is to be taken, the compressibility of the cancellous bone of the cuboid may cause the wedge to vary in size by several millimeters during removal and reinsertion. The feet were pinned in the corrected position. Anteroposterior and lateral roentgenograms were taken before and after the procedure.

All of the cadaver feet had a clinically and roentgenographically normal foot before the procedure. There were changes made on the anteroposterior view in all cases despite the wedge size. Both the talar–1st metatarsal angle and the 2nd metatarsal–tarsal angle moved from 4° to 10° (average 5°) away from adductus. There was approximately the same amount of change in the parameters measured on the lateral projection.

This part of the laboratory study showed that (a) the procedure is reproducible, (b) both the forefoot and midfoot positions will be altered, and (c) these changes can be made without any soft tissue dissection or release. However, we were unable to quantitate the amount of correction because of the collapsibility of the wedge section. Also, since these feet had both sites modified during the same procedure, the independent contributions from each site could not be determined.

Phase Two

The cadaver feet were radiographed and then approached medially first. An osteotomy was made of the medial cuneiform, and metallic coated wooden wedges with a 0.5-, 0.75-, and 1.0-cm base were fitted into the osteotomy sites. We attempted to insert a 1.5-cm wedge, but the soft tissue compliance did not appear to be sufficient to allow this much change. Roentgenograms in the anteroposterior and lateral planes were taken after each insertion. It was found that maximum change in the talar–1st metatarsal angle and the 2nd metatarsal–tarsal angle occurred with the largest wedge size, i.e., the forefoot adductus changes in direct proportion to the wedge size with the maximum wedge being 1.0 cm in width. However, no change in Meary's angle or the height of the metatarsals (forefoot width) was found on the lateral roentgenograph.

The metallic wedges were then extracted from the cuneiforms, and a 1.0-cm wedge was removed from the cuboid. Roentgenograms were taken. After removal of the cuboid wedge and closing of the osteotomy site, there was a change in the midfoot position, as evidence by a decrease in Meary's angle and in the metatarsal height (forefoot width) on a lateral roentgenogram. There was also a mild change of 2° to 3° in the forefoot adductus on the anteroposterior film despite the wedges in medial column being absent.

The metallic wedges then were reinserted individually into the medial cuneiform. There was no more change in the parameters measured on the lateral film. There was a larger change on the anteroposterior film in the forefoot than before the cuboid wedge had been removed.

It appears from the laboratory study that the proposed questions have been answered:

1. *Site of correction*. Changes in the midfoot are due to the cuboid wedge resection. The cuboid wedge removal will allow changes in the forefoot but not to the extent that is effected by an opening-wedge medial cuneiform osteotomy.
2. *Quantity of correction*. Changes in the forefoot are directly proportional to the size of the wedge inserted into the medial cuneiform, with 1 cm being the largest size that can be feasibly used in a normal adult foot. The combination of cuboid and medial cuneiform osteotomies gives the greatest allowable change in the forefoot adductus.
3. *Reproducibility*. This procedure can consistently reproduce changes in the forefoot and midfoot.
4. *Necessity for soft tissue surgery*. Changes in the desired locations can be accomplished without significant soft tissue dissection or release.

Discussion

The procedure described in this paper is a combination of procedures that have been used in the past to address residual deformities in clubfoot. Ankle and hindfoot rotational abnormalities are not the target of this study. Only the very common "bean-shaped" foot, which is the result of forefoot adductus and midfoot supination, is a candidate for this procedure. A review of the literature shows that various authors have approached this pattern of clubfoot residua with other procedures or even similar procedures that have been aimed only at one site of the problem.

There are a few classic procedures that are used often to correct forefoot residua. A tarsometatarsal mobilization (Heyman-Herndon

procedure) or multiple metatarsal osteotomies can be used to address forefoot adductus only and require at least moderate dissection of the soft tissue.[7] Hoffman et al.[8] described the use of the opening-wedge medial cuneiform osteotomy (Fowler's procedure) to correct residual forefoot adductus in clubfeet. They showed this simple procedure to be reproducible in giving a good clinical result with the forefoot. However, roentgenographic changes were only consistently present on the anteroposterior view. Indicators of rotation in the midfoot on the lateral view showed no change.

Similarly, there are well-described procedures for correction of the lateral border of the foot that will affect the midfoot.[1,2,6,9,10] The best example of this is the calcaneocuboid joint resection and fusion with soft tissue releases (Dillwyn Evans' procedure).[7] A cuboid decancellation or wedge resection can possibly accomplish the same goals on the lateral side without permanence. Evans' basic tenets were that (a) the deformity in clubfoot was in the midtarsal joints, (b) other deformities in the clubfoot (including hindfoot varus) were adaptive, and (c) the correction of the primary cause plus soft tissue release would give a good result.[1] Although more light has been shed on the pathologic anatomy of the clubfoot and the reasons for residual deformity, Evans' ideas have merit, and his procedure can give a clinically fine result in the older child (4 to 8 years old). In Abrams'[1] review of this procedure, there are several interesting items that are also our observations. In that series, as in ours, there was residual displacement of the tarsal navicular, which probably contributed to the persistent midfoot supination. Those feet that had been operated upon previously tended to be stiff, and soft tissue release could not always give satisfactory correction in that situation. He also mentioned that the procedure (even considering the soft tissue release) would not correct forefoot adductus.

It makes sense, then, that the combination of the opening-wedge cuneiform and closing-wedge cuboid osteotomies will address the problem of the residual clubfoot in two sites and change the rotation in two planes. Using direct approaches to the bone can eliminate extensive and dangerous dissection, which may not accomplish its goal anyway in a stiff, previously operated foot. All cases must be individualized. The one foot in our series that did not gain satisfactory correction of the adductus is the one case in which a planned overcorrection in the opening medial or closing cuboid wedge may have been in order. This foot may have benefited from an abductor hallucis release or flexor hallucis longus release/lengthening.

Valuable information was learned on an additional issue. This is the problem of assessing the preoperative situation and the postoperative results roentgenographically. We found that the classically used talar–1st metatarsal angle drawn on an anteroposterior film was less useful that the 2nd metatarsal–tarsal angle in assessing the forefoot change with this procedure. This may be due to the fact that this procedure rotates the midfoot. Therefore, the postoperative anteroposterior film actually may be more of an oblique roentgenogram because of the position of the midfoot. The relationship of the 2nd metatarsal to the entire midfoot may register more of a measurable change than that of the 1st metatarsal to the talus in this situation. Similarly, the talar–1st metatarsal angle of the lateral film was less useful than the metatarsal height (forefoot width).

Conclusion

Combining opening-wedge medial cuneiform osteotomy with closing-wedge cuboid osteotomy is a simple, direct, and reproducible procedure that will address both residual forefoot adductus and midfoot supination in the sagittally breached, "bean-shaped" foot. This procedure can be used in the older child who is too old for a soft tissue release by itself and too young for the definitive triple arthrodesis. Another advantage of this feature is that it can eliminate the necessity for dangerous, extensive dissection in previously operated feet.

Summary

Patients with a "bean-shaped" (sagittally breached) foot following previous surgery were treated with opening-wedge medial cuneiform and closing-wedge cuboid osteotomies with good resolution of the prominent midfoot

supination and forefoot adductus. Significant soft tissue dissection and invasion of growing areas of the foot were avoided. Cadaver reproductions show that the cuboid closing wedge is responsible for the change in the midfoot, whereas the cuboid and cuneiform osteotomies both contribute to the change in the forefoot.

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Discussion

Simons (Milwaukee): When a child comes into your office with a toeing-in gait, he must be evaluated obviously from one end of the lower extremity to the other. Dr. Weiner, would you tell us where the various causes of the toeing-in may originate.

Weiner (Akron): It's either from the hip, from the knee down, from internal tibial torsion, or from the foot. I don't think it's in the tibia. I think it's mostly talocalcaneal or forefoot, and in various stages you may have deformities coming from any or all of these areas. When I have this problem, I try to separate the hindfoot from the midfoot deformities. Generally one can separate the hindfoot deformities and the forefoot deformities without too much difficulty. But one can't expect forefoot operations or midfoot operations to correct hindfoot deformities.

Simons: Exactly. I think of these deformities as existing in the hindfoot, midfoot, or forefoot also. If they exist in the hindfoot, one has an uncorrected calcaneal rotation that McKay has talked about, which may cause the foot to deviate medially. Secondly, the talonavicular joint may be subluxated medially without subluxa-

tion at the calcaneocuboid joint. Alternately, one may have calcaneocuboid subluxation without talonavicular subluxation or they may both occur together. One may also have a sharply angulated first cuneiform bone causing the 1st metatarsal to deviate medially. Finally, the child may have deformity in the forefoot. So, I think there are a number of areas where the medial deviation may arise. If we correct only one of these, we can't expect full correction of the foot when more than one area is involved.

Ward (Pittsburgh): Dr. Abberton, I'm a proponent of Goldner's four-quadrant release, which includes lengthening of the anterior tibial tendon. I find that about 8% of my feet have persisting internal rotation of the foot. If one looks at the foot itself, it looks straight but it's twisted and I believe it's probably twisted at the ankle. Is the internal rotation you are talking about a dynamic thing or is it a fixed adduction? If it is fixed adduction, it seems more reasonable to me to do one of the bony procedures that we've just heard of. If it's a dynamic deformity, it seems to me to be a much better idea to do an external rotational osteotomy of the tibia. I don't understand how releasing the medial joint solves the dynamic internal rotation problem because I've done that routinely with Goldner's procedure initially and it's not quite enough all the time.

Abberton (Leeds, England): I don't perform the transposition of the anterior tibial tendon to the dorsum of the 1st metatarsal as a part of my standard procedure. What I was addressing in this paper were a number of revision procedures that I had to do for the residual deformities of other surgeons' cases, as well as for several of my own, which had been less successful than they should have been. This is a revision procedure that I am describing and it is indicated only for dynamic supination. I'm not saying that the anterior tibial tendon is the entire cause of the internally rotated foot following clubfoot surgery. Certain children have an internally rotated gait in which the whole foot looks well corrected but is spun inward. These children have deformity of the hindfoot and require releases of the posterior lateral aspect of the foot. The deformity I mention in my paper is a dynamic one. Most of the other papers in this session have dealt with fixed deformity.

Goldner (Durham): There's one other area to consider besides the foot and that is the knee joint. Look at the knee of a normal newborn child. If you turn the foot inward with the knee bent to a right angle, the foot turns inward 90° in some children. If you try to turn it outward, it may not reach neutral. If that child has a clubfoot that remains incompletely corrected for a couple of years, it improves spontaneously but it does not correct to neutral and when it doesn't, the child swings his foot inward, he toes-in. I now have over 30 patients in 20 years on whom I have performed a supramalleolar external tibial rotation osteotomy (but not the fibula) for this deformity. I agree there may be a problem with the talocalcaneal angle, which isn't perfect, since I'm not opening the subtalar joint, but it isn't that bad. I can turn the tibia outward 30°.

Simons: If your anteroposterior talocalcaneal (APTC) angle is abnormally low, you have identified the source of your problem. It is incomplete correction of the calcaneal rotation, which, like persistent varus of the hindfoot, requires extensive subtalar release in the young child. In the older child, I prefer to perform corrective surgery at the site of the problem, specifically, by osteotomy of the hindfoot rather than tibial osteotomy.

Kuo (Chicago): I very seldom do surgery for forefoot adduction in the clubfoot as I think that many are really supination deformities. I did a complete anterior tibial tendon transfer to the middle of the forefoot but have subsequently changed to the split anterior tibial tendon transfer.

Abberton: I have limited experience with the total anterior tibial tendon transfer and the split transfer but generally I have not found them to be very satisfactory.

Kling (Indianapolis): I've had the opportunity to see some of Garceau's own anterior tibial transfers in follow-up of patients who are now adults. These were often done for supination deformity without correcting the hindfoot. He did this tendon transfer and then he frequently did a midfoot osteotomy later because the deformity came back. He performed a Cole dorsal wedge osteotomy for many of them. So, it seems that some of these feet need more than

just an anterior tibial tendon transfer unless the foot is extremely supple.

Anderson (St. Louis): Our feet are mostly fairly rigid. They weren't supple enough to be reduced back to the neutral position by a tendon transfer.

Weiner: The comment on supination is the principal reason we presented out material. This forefoot release will not be enough to control the foot. One has to take the anterior tibial tendon and get rid of its supination power by moving it to a site where it won't continue to supinate anymore.

Simons: Do you believe that the foot that has associated supination in addition to forefoot adduction will require a balancing procedure?

Weiner: If you don't do the transfer along with the tarsometatarsal release (even with the 2nd metatarsal osteotomy), you won't correct the supination.

Goldner: Dr. Weiner's paper is certainly a contribution. However, after 15 years follow-up of our Heyman-Herndon procedures, 40% had traumatic arthritis when all five joints were released. We stopped doing that and only did the 1st, 3rd, 4th, and 5th and did an osteotomy of the 2nd. I think that that's extremely important.

We move the anterior tibial tendon only to the 2nd metatarsal. Sometimes I'd place it in the cuneiform because if you do an osteotomy of the 2nd metatarsal base, it is difficult to insert the tendon into the proximal portion of the metatarsal.

Griffin (Charleston): In performing the combined calcaneocuboid osteotomy, one has to be careful not to overcorrect the medial side of the foot as the patient will be unhappy with the prominence of the cuneiform.

Some supination deformities are flexible and will be corrected if you move the anterior tibial tendon to the 2nd metatarsal but if the supination is fixed, this operation will not work. The cause for the fixed supination of the metatarsals must be treated before the adduction is corrected.

Catterall (London): The Europeans have a fairly extensive experience with tibialis anterior transfer. They feel it's a good operation for this type of foot, that the anterior tibial can be put over to the lateral side, and that if you put it over to the lateral side, you must bring it back in about 25% because of overcorrection. Those feet in which the anterior tibial tendons needs to be brought back have marked ligamentous laxity.

Lehman (New York City): I've had trouble with tarsometatarsal capsulotomies. The reason was that I couldn't seem to move the metatarsals much after I released them. They eventually developed chronic swellings over the metatarsal joints that were hard and looked and felt like bunions. They were very uncomfortable with shoes. Now I'm delaying surgery. I'm not doing metatarsal capsulotomies but rather waiting to do metatarsal osteotomies later when the children are a little more mature.

Weiner: I was disappointed with metatarsal capsulotomies until I added the 2nd metatarsal osteotomy to the other capsulotomies. The 2nd metatarsal osteotomy in addition to the joint release mobilizes the foot almost completely, and we haven't had a problem with a prominent dorsal bump in this group that has had the osteotomy.

Handelsman (New Hyde Park, New York): We've discussed two interesting ways of correcting forefoot adduction but often there is a persistent supination deformity associated with the adduction. I perform metatarsal osteotomies. I think the trick here is to incise a small portion of the base of the 4th and of the 5th metatarsal to improve the mobilization of the forefoot. Then you can correct both the supination and the adduction.

Dias (Chicago): We have been using the combined cuneiform and cuboid osteotomies at Children's Hospital in Chicago for the last three years. We just recently reviewed our results in 23 feet. We have 22 out of 23 feet with very nice correction. I also agree with Dr. Kling that frequently additional surgery needs to be done at the same time: a plantar release for a cavus component, or a split anterior tibial tendon transfer for an inversion deformity, or even a total transfer of the anterior tibial tendon.

Goldner: With the first cuneiform and cuboid osteotomies the surprising thing is that as you correct the foot, the curve of the metatarsals

suddenly seems to straighten out. A lot of it is apparent because they're rotated. So we seldom have to do the metatarsals if we do the first cuneiform and cuboid osteotomy.

Editor's Comments

Abberton describes the release of the medial half of the insertion of the tibialis anterior from the medial and plantar aspect of the cuneiform and 1st metatarsal base. This is used for the treatment of mild adduction and supination deformity, and is mostly used in small children.

Smith and **Weiner** describe the use of tarsal-metatarsal mobilization (metatarsal capsulotomies) combined with an anterior tibial tendon transfer to the lateral side of the foot. They use this for the treatment of residual forefoot adduction following previous treatment, either conservative or surgical. The authors correctly point out that tarsal-metatarsal (TMT) mobilization has been shown to have a significant rate of late degenerative changes in a recent long-term study.[1] As a result of this report, TMT mobilization is currently avoided by many surgeons. However, the authors believe that their younger population should have better results than those demonstrated by Stark et al.[1] Furthermore, the authors describe an interesting addition to the conventional metatarsal capsulotomies in that they osteotomize the base of the 2nd metatarsal rather than performing a capsulotomy. This is performed to improve the mobilization of the metatarsals as the base of the 2nd metatarsal is positioned in a "tarsal mortise."

They also pass a Kirschner wire through the plantar surface of the foot, across the distal tibial epiphysis, into the lower tibia. This is necessary to decrease the tension on the tendon transfer. Once the capsulotomies have been made, it is then no longer possible to use the forefoot as a lever to decrease the tension on the transfer. Therefore, the Kirschner wire is inserted into the tibia. In addition, a second Kirschner wire is passed across the base of the 1st metatarsal distal to the physis, then across the osteotomy of the 2nd metatarsal into the tarsus. Some surgeons would have difficulty accepting the use of Kirschner wires passing through the physes for fear of growth arrest.

The paper by **Kling et al.** describes their use of an opening-wedge first cuneiform osteotomy associated with 2nd, 3rd, and 4th metatarsal osteotomies. This has the advantage of approaching the deformity at the primary sites, i.e., the first cuneiform appears to be wedge-shaped in many cases of significant forefoot adduction. In addition, the proximal diaphyses of the 2nd through 4th metatarsals are often markedly curved at this level. Therefore, correction of both the metatarsals, as well as the first cuneiform, strives for perfection in the correction of the residual deformities of the clubfoot. However, as pointed out by the authors, McKay (personal communication) experienced early degenerative changes at the 1st metatarsal cuneiform joint in 25% of his patients undergoing first cuneiform opening-wedge osteotomy alone (i.e., McKay's patients did not have associated osteotomies of the metatarsals). The metatarsal osteotomies no doubt have an unloading effect on the medial column, which thereby might tend to counter the tendency to develop early degenerative changes.

Both **McHale et al.** and **Schoenecker, Anderson, et al.** described double tarsal osteotomies with the removal of a lateral-based wedge from the cuboid and the insertion of the wedge into an osteotomy in the medial cuneiform.

Effect of the Procedures on Supination

Abberton's procedure (release of the medial half of the insertion of the anterior tibial tendon) is designed for the correction of both

metatarsus adductus and supination. **Smith** and **Weiner's** procedure (TMT mobilization with anterior tibial tendon transfer) and **Kling's et al.'s** procedure (opening cuneiform osteotomy with osteotomies of the base of the 2nd through 4th metatarsals) probably also have a corrective effect on supination, although the authors do not specifically state this. The reason is that the anterior tibial tendon transfer is a part of both of these procedures. **Schoenecker**, **Anderson**, **et al.** do not state that their procedure of combined cuboid and calcaneal osteotomies is helpful for supination; however, it would follow that it does have a corrective effect on supination, because **McHale** and **Lenhart's** procedure (essentially the same procedure) specifically improves supination.

As the combined osteotomies of the cuboid and cuneiform virtually create a complete transection of the midtarsus, it is probable that, following osteotomy, the whole distal fragment can be rotated into pronation rather easily.

Indications for the Various Procedures

Abberton's procedure is indicated for the child under 5 years of age who does not have fixed deformity, i.e., a very mild CTEV.

Smith and **Weiner's** procedure is probably indicated also for the child under 5 years of age who has moderate to severe deformity.

The procedures of **Kling et al.**, **Schoenecker**, **Anderson et al.**, **McHale and Lenhart** are all indicated in children over 5 years of age. **Kling et al.'s** would be indicated for the milder degree of deformity (particularly with a calcaneal–2nd metatarsal angle of less than 30°). **Schoenecker**, **Anderson**, **et al.'s** and **McHale** and **Lenhart's** procedures would be indicated for moderate and severe deformities over 5 years of age.

Regarding the Combined Cuboid-Cuneiform Osteotomies

It would seem that the following observations are worth reiterating:

TABLE 13.5. Indications for this chapter's procedures.

Procedure	Indications
Medial one-half ATT release and midtarsal capsulotomies (Abberton)	<5 years old with mild-to-moderate deformity, with no fixed deformity
TMT mobilization with ATT transfer (Smith and Weiner)	<5 years old with moderate-to-severe fixed deformity
Cuneiform osteotomy and 2nd through 4th MT osteotomies (Kling et al.)	>5 years old with mild-to-moderate deformity
Cuneiform and cuboid osteotomies (McHale and Lenhart, and Schoenecker, Anderson et al.)	>5 years old with moderate-to-marked deformity and supination (fixed)

ATT, anterior tibial transfer; MT, metatarsal; TMT, tarsometatarsal.

1. A disadvantage of these combined osteotomies is that they should not be performed in children under 5 years of age because the ossification center, particularly of the cuneiform, is not developed well enough to allow good incorporation of the bone graft prior to that time. The same principle possibly can be applied to the cuboid as well, although the cuboid is more advanced in its ossification than the cuneiform.
2. The combined osteotomies give correction of supination as well as adduction. This is a significant advantage in that this procedure and Abberton's are the only procedures (of the four described) in which correction of supination has been definitely documented.
3. The improved midfoot radiographic findings resulting from surgery were due to the cuboid resection, whereas the improved forefoot findings were due to both the cuboid and cuneiform osteotomies (**McHale** and **Lenhart**).
4. Hindfoot deformity was not a contraindication to combined osteotomies in the midfoot; in fact, hindfoot valgus may be improved by these osteotomies (**Schoenecker**, **Anderson, et al.**).
5. The question remains as to why **McHale** and **Lenhart** achieved only 9° of correction with the combined osteotomies, whereas **Schoenecker**, **Anderson**, **et al.** achieved 17°

on the average—almost double the correction.

6. These various procedures were difficult to cross-evaluate because a standard method of measurement was not used.

Regarding Radiographic Measurements of the Forefoot

The calcaneal–2nd metatarsal angle is the best measurement for measuring metatarsus adductus, according to **Schoenecker**, **Anderson, et al.**, whereas **McHale** and **Lenhart** believe that the tarsal–2nd metatarsal angle is the best measurement for this purpose. Although I have not had personal experience with **Barriolhet's** first ray angle for metatarsus adductus (Chapter 4), theoretically it may be more accurate and easier to obtain than either of the above. There does not appear to be a good radiographic measurement for the deformity of supination.

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14
Surgical Complications: Ischemia/ Necrosis/Effects of Surgery/Analysis of Failures

Introduction

Simons reports a case of compartment syndrome occurring in a child with a previously operated clubfoot. The course of the syndrome is described, as are the probable reasons for the complication and suggestions for its prevention.

Hootnick and **colleagues** present three cases of necrosis of the foot following clubfoot surgery that eventually led to amputation. One of these feet had an absent posterior tibial artery. The authors describe the possible contributing factors.

Szabo, **Kranicz**, **et al.** report on the anatomical variations and accessory bones in normal feet and the alterations in anatomy seen in congenital talipes equinovarus (CTEV). Among the latter are a generalized delay in ossification, multiple ossification centers in some bones, and various iatrogenic abnormalities. In a second paper, they analyze their unfavorable results following posteromedial release and divide their failed cases into two major groups—the undercorrected and the overcorrected clubfeet.

Turco also presents reasons for failure with the posteromedial release, dividing his failed cases into three groups—those in which correction was never obtained, those in which correction was not maintained, and those that were due to failure to identify an unusual type of clubfoot—the "atypical" type, which has a high propensity for recurrence.

Compartment Syndrome in the Clubfoot

George W. Simons

Compartment syndrome has been described in the arm, forearm, thigh, leg, and foot. It has also been described in the deltoid, gluteal, and iliacus muscles.[6] The first case of compartment syndrome of the foot was described in 1986.[1] Since then, many causes have been cited for compartment syndromes in the foot. These include fractures of the forefoot,[2,5,11] mid-

foot, and hindfoot[2,5]; dislocations of the foot[2,3,5,7,8,11]; and crush injuries to the foot.[1,2,7,8,11] However, compartment syndrome of the foot secondary to clubfoot surgery has not been reported.

The foot does not provide physical findings of compartment syndrome as readily as other sites. For example, passive stretching frequently fails to elicit severe pain. Pulses may be present late in the course of the complication and paresthesia may not appear until late. Tense swelling is a reliable sign, but the most valuable finding is that of increased compartment pressures.[5]

Until recently, only eight compartments had been recognized within the foot, four of these involving the interosseous muscles. However, in a recent study of foot compartments using dye injections in cadaver specimens, Manoli and Weber[4] have described a new ninth compartment, the calcaneal compartment, which contains the quadratus plantae muscle. They have also suggested a name change for the central compartment, as this involves the superficial and the adductor compartments as well as the new calcaneal compartment. Thus, the new terminology would be medial compartment, superficial compartment, calcaneal compartment, lateral compartment, four interosseous compartments, and adductor compartment (Table 14.1). A tenth "dorsal" compartment may exist, but injection studies of the dorsum of the foot have not yet been performed.

Manoli and Weber[4] also verified that the new calcaneal compartment communicates through the retinaculum behind the medial malleolus with the deep posterior compartment of the leg, following the neurovascular and tendinous structures. Claw toe deformity following calcaneal fractures appears to be due to late contracture of the quadratus plantae muscle in the calcaneal compartment, resulting from preexisting compartment syndromes.

The purpose of this paper is to present a case report of a child who developed a compartment syndrome following clubfoot surgery.

TABLE 14.1. Location of muscles by compartment.

Compartment	Component muscles/tendons
Medial	Abductor hallucis
	Flexor hallucis brevis (two heads)
Superficial	Flexor digitorum brevis
	Lumbricals (four)
	Flexor digitorum longus tendons (four)
Calcaneal	Quadratus plantae
Lateral	Abductor digiti quinti
	Flexor digiti minimi brevis
Interosseous	Interossei (four dorsal and four plantar)
Adductor	Hallucis
Dorsal (possible ninth)*	Extensor digitorum brevis

*Hypothesized by Manoli and Weber,[11] but not yet proven.

Case Report

A 2-year, 9-month-old white male was born with bilateral talipes equinovarus deformities. At the age of 2 years, he had posteromedial releases performed at another hospital.

At the age of 2 years 9 months, he presented at our clinic at which time he was treated by the application of bilateral long leg casts. Three months later at the age of 3 years, he had a right complete subtalar release without complications. One week later he had a left complete subtalar release.

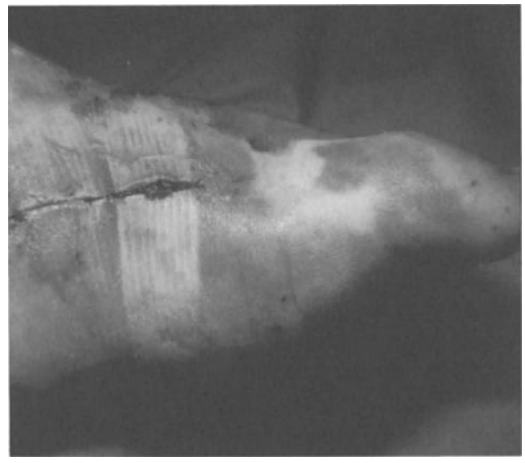
An unusual aspect of this child's anesthesia was that he was not only given a general anesthetic, but also had an epidural block, which the anesthesiologists currently use simultaneously with general anesthesia for improved control of postoperative pain. However, in our case this acted as a sympathetic block obscuring the signs of ischemia in the foot.

On the day following surgery, the patient was given another sympathetic block for his pain. Two days following surgery, the third and fourth toes were noted to be cyanotic. Therefore, the cast was split with relief of the cyanotic appearance of the toes. (In retrospect, I believe the cast should have been removed and the foot inspected. However, at that time the cast was not removed.) Four days following surgery, the second and third toes again became cyanotic and once again the cast was spread.

However, on the fifth day following surgery (Figure 14.1), the patient was having increasing pain despite analgesics and the toes were again cyanotic. The cast was removed, the foot was inspected, and it was thought that adequate blood supply was present but border-



A



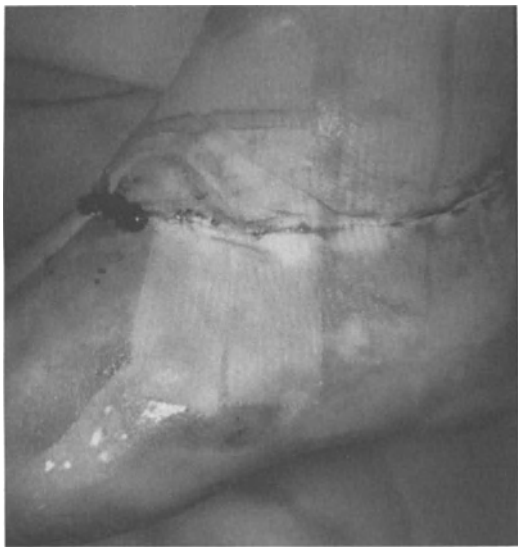
B



C



D



E

FIGURE 14.1. Five days after surgery. A: Cyanosis of third and fourth toes. B–E: Areas of blistering alternating with erythema and blanching.



FIGURE 14.2. Six days after surgery. The patient's compartment pressures were elevated in the foot. The wound has been opened and the abductor hallucis appears hyperemic, although muscle contractions did not occur when the muscle was pinched with forceps.

line. Therefore, hyperbaric oxygen treatments were given twice a day.[9]

In addition to the cyanosis of the third and fourth toes, (Figure 14.1A), there was diffuse blanching of the foot mixed with areas of erythema, which was particularly apparent on the medial side of the foot (Figure 14.1B). On the plantar aspect of the foot (Figure 14.1C), the heel blisters were obvious. On the posterior aspect of the foot over the proximal wound (Figure 14.1D), a large area of erythema with multiple small blisters was present, and on the lateral side of the foot (Figure 14.1E) there was an area of mottled blanching and erythema.

At six days following surgery, the patient's pain continued. His foot was felt to be very tense when the cast was removed. Therefore, the compartments in the lower leg as well as in the foot were monitored. The pressures in the leg were normal but the pressures in his foot ranged from 70 to 90 mm of water. This was thought to represent a compartment syndrome and therefore, compartment releases were performed. In Figure 14.2, the abductor hallucis appeared hyperemic. However, at the time that the wound was opened, the abductor hallucis was initially a pale gray color; 1 minute later following profusion, it looked pink. The muscle, however, did not contract when pinched with forceps. Compartment decompressions were performed. The wound was packed open and the dressings were changed at biweekly intervals.

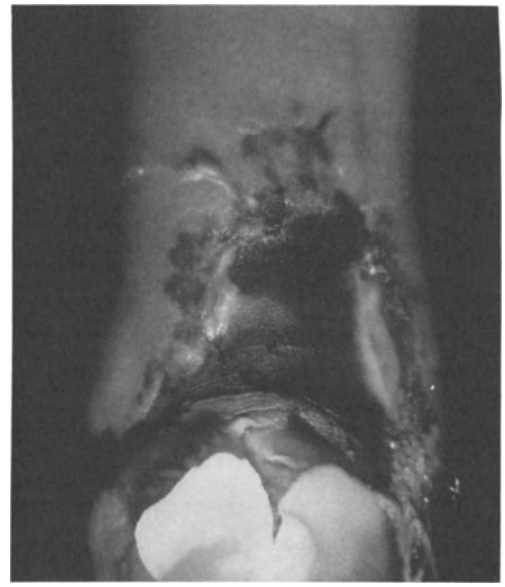
Ten days following surgery (Figure 14.3), the foot had developed an area of necrosis over the middorsum (Figure 14.3A), as well as an extensive eschar over the heel (Figure 14.3B). Gauze packing remained in the depth of the incision on the medial side of the foot (Figure 14.3A).

At five weeks following surgery (Figure 14.4), the medial wound was just beginning to granulate (Figure 14.4A). The third and fourth toes had a necrotic appearance with the skin being black and well demarcated across the midtoes (Figure 14.4B). The skin of the heel looked very dark and the plantar surface had become thick, leathery, and unpliable (Figure 14.4C). The eschar on the heel had become well demarcated (Figure 14.4D).

At seven weeks following surgery (Figure 14.5), the medial wound of the foot had developed good granulation tissue (Figure 14.5A). The necrotic skin on the distal ends of the third and fourth toes had fallen off and normal skin with normal nail beds was present (Figure 14.5B). The plantar surface of the



A



B

FIGURE 14.3. Ten days after surgery. A and B: The patient has developed necrotic areas on the dorsum of the foot and extensive eschar over the heel.

foot had lost its thick, leather-like layers of skin with new skin present (Figure 14.5C). Granulation tissue was starting to grow within the heel wound and the eschar was starting to detach (Figure 14.5D).

Three months following surgery (Figure 14.6), the medial wound had almost entirely healed except for one small area (Figure 14.6A). The dorsum of the foot (not shown) and the plantar surface of the foot (Figure 14.6B) looked excellent. Several small areas over the heel were still granulating (Figure 14.6C).

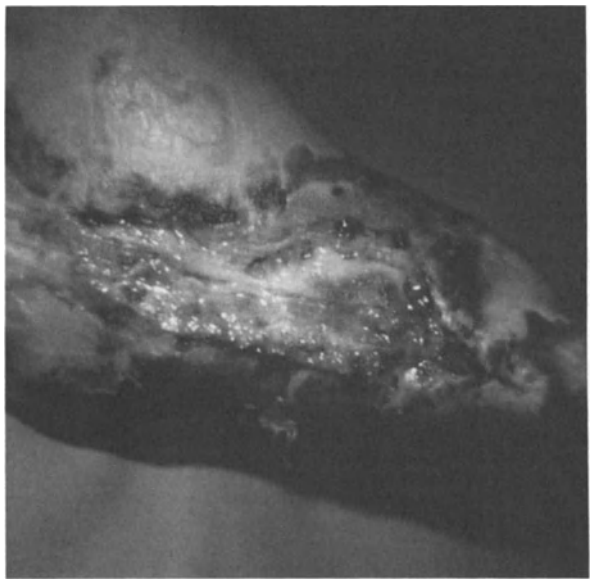
Four months following surgery (Figure 14.7), the medial wound had healed (Figure 14.7A). The dorsum of the foot looked excellent (Figure 14.7B), as did the plantar surface of the foot (Figure 14.7C) and the heel had almost entirely granulated except for one small area about 1 cm in diameter, which healed completely within the following few weeks (Figure 14.7D). Skin breakdown over the heel did not occur as a result of subsequent shoe wear.

Discussion

This is the first reported case of a compartment syndrome complicating clubfoot surgery. The exact sequence of events that led to this complication is not entirely clear. However, as the patient had previous surgery, there was considerable fibrosis around the neurovascular bundle. With repositioning of the foot following an extensive release, it is possible, if not probable, that the neurovascular bundle was placed under tension, causing borderline ischemia of the foot. When the epidural blocks wore off, the cyanotic changes became apparent and the eventual changes of compartment syndrome occurred.

Signs of toe ischemia require inspection of the whole foot. The cast should have been removed and the foot carefully inspected when the toes were initially found to be cyanotic. If upon removal of the cast, the foot appears to be ischemic, the pins should be partially removed and the foot placed back into a position of partial deformity. If the foot is still ischemic, the pins should be entirely removed and the foot allowed to return to the full position of deformity. If ischemia is still present, the compartment pressures should be measured and, if elevated, decompression of the compartments of the foot should be carried out.

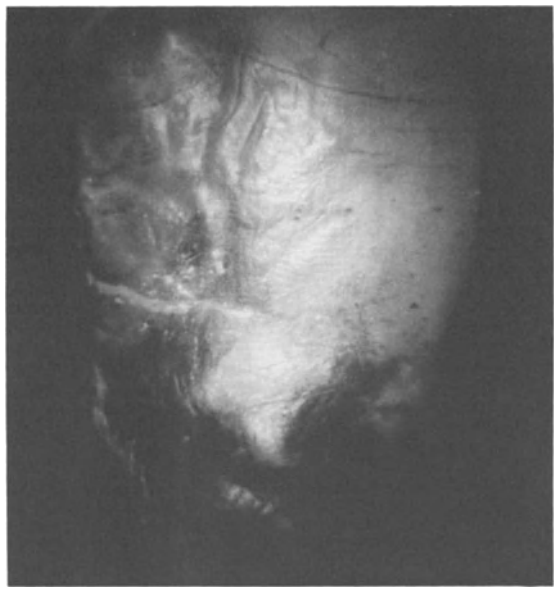
Manoli[5] has recommended multiple-stick compartment pressure testing and fasciotomy when pressures over 30 mm Hg are present or when pressures reach 10 to 30 mm below the



A



B

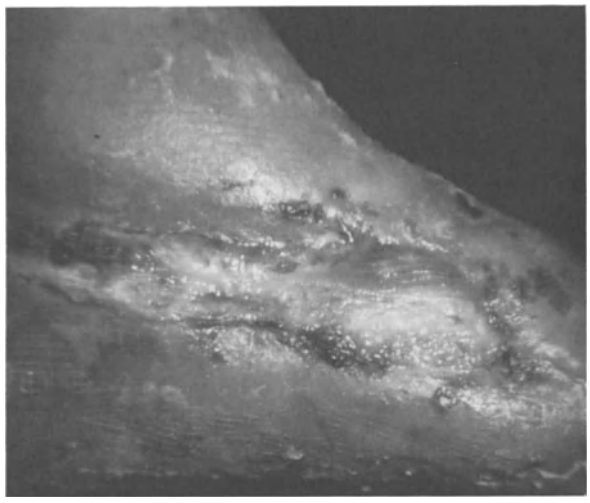


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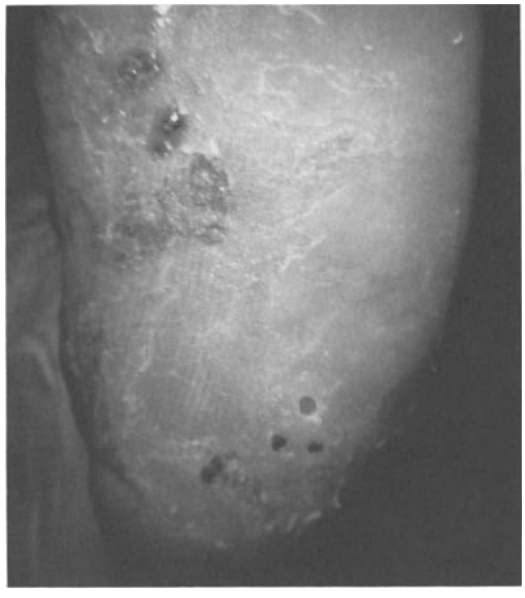
FIGURE 14.4. Five weeks after surgery. A–D: third and fourth toes now appear necrotic. The medial wound is beginning to granulate and the skin on the heel looks very dark, has become thick and unpliable. The heel eschar has become well demarcated.



A



B



C



D

FIGURE 14.5. Seven weeks after surgery. A–D: There is good granulation tissue in the medial wound. The necrotic skin on the third and fourth toes has fallen off and there is normal skin and nail beds beneath. The plantar surface has lost its thick, leathery skin. The eschar is starting to detach.



A

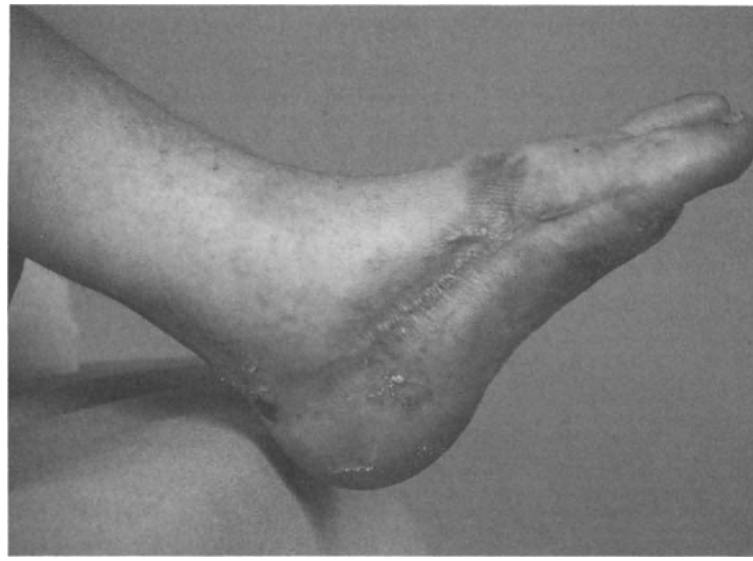


B



C

FIGURE 14.6. Three months after surgery. A and B: The medial and plantar surfaces have healed. C: One small area of granulation remains.



A



B



C

FIGURE 14.7. Four months after surgery. A–D: The medial wound has healed, the dorsum of the foot looks excellent, as does the foot from all other views. Only one small area over the heel remains to granulate.



D

FIGURE 14.7 (cont.)

diastolic pressure. He has also recommended a three-incision fasciotomy technique to decompress the various compartments: a longitudinal incision over the medial side of the heel about 3 cm above the plantar surface; and two longitudinal incisions over the dorsum of the foot, extending approximately 4 to 5 cm in length—one into the first and second interspaces and the other into the fourth and fifth interspaces.

Despite marked skin necrosis, healing in this child was phenomenal. A conservative approach is recommended for healing of open granulating wounds in children before performing skin grafting, which is very seldom necessary in clubfeet, in the author's experience.

The use of hyperbaric oxygen has not achieved universal acceptance as a means of treatment of acute ischemia in orthopedic surgery. However, Strauss[9] has described its use in acute ischemia in crush injuries. In this patient, hyperbaric oxygen was used because there was a persisting cyanosis in the child's foot following repeated examinations and opening of the cast. The effects of hyperbaric oxygen in this case were unclear because several other factors were involved, particularly the use of epidural anesthesia, which was administered to prevent pain postoperatively.

Strecker et al.[10] have reported the occurrence of compartment syndrome in the leg of a patient whose symptoms and signs were masked by epidural anesthesia. They recommend that epidural anesthesia be used cautiously in patients who are at risk for the development of a compartment syndrome. I believe that patients having clubfoot surgery are at risk for compartment syndrome, especially patients with previous extensive soft tissue releases. Since all of these children have abnormal vasculature of the foot as described in Chapter 1, CTEV patients with previous extensive soft tissue surgeries are especially at risk for compartment syndrome; therefore, it is my opinion that *epidural anesthesia is contraindicated in these patients*.

Summary

A case of compartment syndrome is presented along with a short review of the difficulties in detecting this complication. Manoli and Weber's[4] dye injection study in which they demonstrate the existence of a new ninth compartment is reviewed. Recommendations are made regarding measurement of compartment pressures and the treatment of wounds of the foot when compartment pressures are elevated. The author cautions against the use of epidural anesthesia in patients undergoing surgery for CTEV.

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Three Cases of Necrosis Following Clubfoot Surgery: A Proposed Vascular Etiology

D.R. Hootnick, D.S. Packard, Jr., E.M. Levinsohn, and A.R. Wladis

Arteriography of the clubfoot has shown that 90% of limbs with talipes equinovarus (TEV) clubfoot demonstrate deficiency of the anterior tibial artery (Figure 14.8).[5] Since that artery and its derivatives contribute a major part of the blood supply to the medial and dorsal portions of the foot, it seems reasonable to anticipate an increased likelihood of postsurgical complications in these regions in patients with diminished vascular reserve.[1] The tissues provided by the most tenuous blood supply (in this situation, the dorsomedial part of the foot) are the most at risk after surgery for resistant clubfoot repair. A single previous case report failed to clarify the origin of the necrosis.[7]

The dorsalis pedis artery, which derives from the anterior tibial artery, provides the majority of the blood supply to the medial part of the plantar arch via a deep communicating branch near the base of the 1st metatarsal[4] before it runs distally as the first dorsal interosseous artery.[3] Except for the dorsalis pedis and first dorsal interosseous arteries, the dorsal skin is supplied only by a subdermal plexus derived from the posterior tibial artery (Figure 14.9). Incisions that parallel the posterior tibial tendon below the ankle interrupt the blood supply to the skin of the dorsomedial foot.[2] Any remaining blood supply is circuitous.

Aware of several anecdotal cases of postoperative necrosis after clubfoot surgery, we sought to investigate as many instances of these occurrences as possible in order to understand the etiologic processes. The following three cases document the occurrence of attempted repair of resistant clubfoot complicated by postoperative necrosis. The first case, reported separately,[1] will be outlined in this study in order to compare and contrast this case with two other cases recently brought to our attention. All patients had other defects including clubbed feet, which were noted at birth (Table 14.2), and all had been treated unsuccessfully with casts prior to surgery.

Case Reports

Case One

The first attempt at surgical correction of the clubfoot, a posteromedial release with pin fixa-



FIGURE 14.8. Anteroposterior radiograph of a clubfoot angiogram reveals tibialis posterior (TP) arterial filling. The lateral plantar artery supplies the plantar metatarsal and common digital arteries. The hallux and the little toe each receive only one plantar digital artery. The other central toes all receive two plantar digital arteries. Arteriography has not been performed on any patient in this study. (Reprinted by permission from Sodre et al.[6])

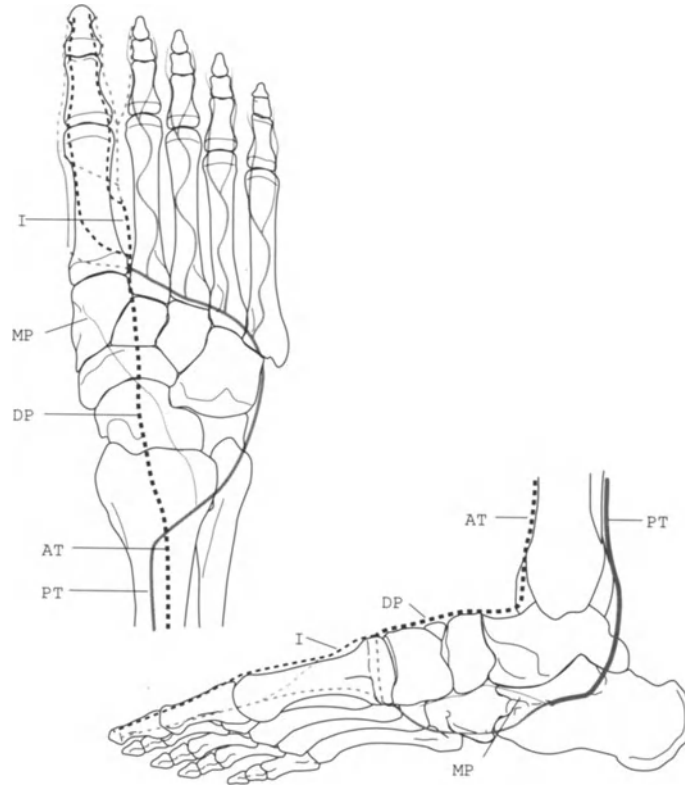


FIGURE 14.9. Anteroposterior and lateral diagrams of the normal skeletal structure of the foot. The derivatives of the anterior tibial artery are represented by the dotted lines. The dark dotted lines change to gray when entering a deeper or remote plane of tissue. The derivatives of the posterior tibial artery are represented by the solid gray lines. Arteries: PT, posterior tibialis; AT, anterior tibialis; DP, dorsalis pedis; I, interosseous; MP, medial plantar.

TABLE 14.2. Anomalies associated with clubfoot.

Case one
Right clubfoot
Syndactyly fingers both hands
Syndactyly toes two through five left foot
Case two
Left clubfoot
Constriction band left calf
Syndactyly left hand fingers three through five
Case three
Bilateral clubfoot
Caudal regression syndrome
Bilateral dislocated hips
Vertebral anomalies
Paralysis limbs
Imperforate anus
Undescended testicles
Rectourinary fistula

tion, occurred at 6 months of age. Incomplete reversal of the deformity led to multiple metatarsophalangeal capsulotomies at age 20 months. Again, the foot remained in equinovarus. At age 32 months, the patient again underwent a posteromedial release for his residual right foot deformity. The operative notes revealed that the surgeons used the previous posteromedial incision once again. They closed the skin without tension and applied a long leg cast. Following deflation of the tourniquet, the patient's toes were noted to be pink.

The patient's postoperative course progressed uneventfully for 2 days, after which he left the hospital. One week postoperatively, the patient complained of severe foot pain unrelieved by medication. Upon his return to the hospital, doctors split the cast and noted that the foot became "pink" following this procedure. The viability of the hallux remained in doubt (Figure 14.10). The hallux eventually necrosed.

Seven weeks postoperatively, the right foot became swollen and gave off a necrotic odor. The fourth and fifth digits blackened with eschar, and necrotic soft tissue covered a large medial plantar wound. At that time, many of the plantar digital joints were exposed. One week later, a split thickness skin graft was applied. The skin graft healed completely, complicated by some protruding bone, which was removed. Despite bracing, the patient's forefoot became supinated, and significant inversion again developed (Figure 14.11).

At a third referral center, the patient underwent his fifth and final foot operation, 9



FIGURE 14.10. This photograph of the medial aspect of the foot of case one was taken approximately 2 weeks postoperatively and shows the extent of the necrotic tissue. (Reprinted by permission from Hootnick et al.[1])



FIGURE 14.11. This photograph of the foot of case one after multiple debridements and skin grafting reveals recurrence of the deformity and loss of the hallux.

months after the second posteromedial release. Good function resulted from a Syme's amputation.

Case Two

At age seven months, surgeons performed a posterior ankle capsulotomy, heel cord lengthening, and release of a constriction band. Further casting failed to impede a rapid return to the preoperative deformity. A more extensive posteromedial release and cuboid decancellation were carried out at age 15 months. The correction remained incomplete and the deformity recurred. Further casting proved futile in correcting the deformity.

The patient returned at age 30 months for a radical repeat of the posteromedial release, after which he was fitted with a long leg plaster cast. The neurovascular supply to all the toes appeared to be normal and capillary refill remained intact. Four days postoperatively, an examination by the attending surgeon at the time of discharge revealed no circulatory embarrassment. Ten days postoperatively, the patient's parents brought him to the emergency department because they noted a change in color of the hallux. The long leg cast was bivalved and removed. A resident physician noted no abnormalities and rewrapped the cast with an ace bandage. Four days after the cast removal, the patient returned to the emergency department with definite evidence of necrosis of the hallux and little toe.

Five weeks postoperatively, the hallux was debrided at the bedside because of irreversible necrosis. Seven weeks postoperatively, the little toe was similarly debrided. The fourth toe showed doubtful viability. Fourteen and 17 months postoperatively, nonhealing ulcerations received skin grafts. The second graft completed the skin coverage. A midtarsal amputation at 3 years 10 months postoperatively was followed by a successful revision to a Syme's amputation 3 months later. The patient currently remains fully ambulatory with aid of a prosthesis.

Case Three

Shortly after birth, surgeons completed a right inguinal hernia repair with orchidopexy, a right transverse colostomy, and left nephrostomy tube placement.

In order to preserve a chance for independent ambulation, the patient, at 6 months of age, underwent a circumferential (Cincinnati) incision for the left clubfoot. Anomalies, in-



FIGURE 14.12. This posterior and plantar photograph of the left foot of case three reveals a dense scar inferior to the medial limb of the circumferential incision. The hallux is absent.

cluding coalition of the cuneiforms and absence of the posterior tibial artery, were noted at the time of surgery. Nevertheless, excellent vascular return occurred after correction of the deformity of the foot and following deflation of the tourniquet. A well-padded, long leg cast was applied and the cast was split. For the first 36 hours, normal circulation was noted. Subsequently, the toes appeared cyanotic over another day and, despite removal of the Kirschner wire and cast, the foot developed a rather dense necrosis over the medial heel. The hallux became completely necrotic and subsequently detached. The deformity recurred with a thickened residual medial scar (Figure 14.12).

Three-dimensional color Doppler examination of both limbs was carried out when the patient was a year old (see Schwartz et al., Chapter 1). That study revealed only one major vessel in the right (unoperated) leg corresponding to the course of the posterior tibial artery. The left (operated) limb contained two vessels of unequal caliber; the larger artery corresponded to the anterior tibial artery and the smaller artery corresponded to the posterior peroneal artery. Because the insonating device was larger than the patient's deformed feet, which could not be manipulated into a neutral position, the arteries beyond the ankle could not be assessed.

Discussion

Necrosis of the medial side of the foot and hallux is the common postoperative complication of these three limbs. Two of the patients had posteromedial incisions and one a circumferential incision. Necrosis first appeared in the boundary area between angiosomes of the anterior and posterior tibial arteries,[2] and all three incisions paralleled the line between angiosomes. Incisions for clubfoot surgery are safest when placed between angiosomes; the major vessels on both sides supply skin flaps with blood.

These cases demonstrate deficiencies in the distribution of the anterior tibial artery and its derivatives in two feet and in the posterior tibial in case three. Blood supply to the tissues normally supplied by the deficient arteries and their derivatives must subsist off a subdermal plexus derived from the most peripheral branches of the remaining arteries. In such limbs, incisions between angiosomes may be more hazardous than usual. Blood supply to the skin dorsal to any medial incision is supplied solely by subdermal vessels from the lateral plantar artery when the anterior tibial artery is deficient (Figure 14.13). The skin plantar to such an incision would similarly be jeopardized with a deficient posterior tibial artery.

Since the plantar arch is chiefly supplied by

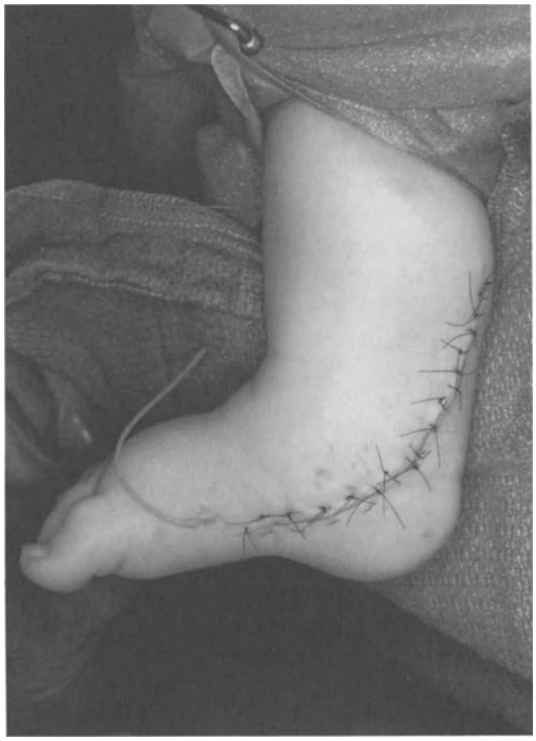


FIGURE 14.13. Photograph of the medial aspect of the foot and leg of a 6-month-old child after a clubfoot release. The tourniquet had been released for 30 seconds after elevation for 1 hour. Blanching of the dorsal flap is evident. The wound went on to heal uneventfully. Preoperative three-dimensional Doppler examination revealed absence of the anterior tibialis artery pulse and a normal posterior tibialis artery pulse. (Photograph courtesy of Carl Levy, Syracuse, New York.)

the deep branch of the dorsalis pedis artery as well as the lateral plantar artery, the deep plantar arch is likely to be medially deficient when either major artery is absent.[4] Such a deficiency implies greater jeopardy for the hallux than for the other toes because most of the vascular supply to the hallux arises directly from the first dorsal interosseous artery (Figure 14.9). The remainder comes from the medial plantar artery and from the plantar arch. The plantar arch is also deficient when the anterior tibial artery is absent. In such cases, one would expect the blood supply to be most tenuous at the dorsal edge of the medial incision and to the hallux. Interestingly, in case three, whose posterior tibial artery was deficient, the hallux was also most severely affected. This finding suggests that deficiency of either major artery can result in insufficient blood flow to the tissues normally supplied by the medial portion of the plantar arch.

Case three exhibited frank necrosis only after the 3rd postoperative day. In that case, cyanosis first appeared at 36 hours. In case one, necrosis was noted 1 week after surgery and only following cast removal. Despite the fact that the entire cast had been removed on the 10th postoperative day, the foot of case two had not displayed any frank necrosis until the 14th postoperative day. The prolonged delay in the appearance of necrosis suggests that diminished vascularity combined with elevated metabolic activity played some role. Direct surgical trauma to the posterior tibial artery did not cause necrosis in these cases because such trauma would have led to immediate pallor in the two feet supplied entirely by the posterior tibial artery. In case three, the posterior tibial artery was absent; therefore, it could not have been damaged.

The localized, delayed changes described above seem confined to the tissues supplied by "end arterioles." In the absence of the anterior tibial artery and its derivatives—the dorsalis pedis, the first dorsal interosseous, and the hallucal arteries, as well as the deep arterial branch to the plantar arch—we suggest that the burden of supplying the tissues of the great toe and the dorsomedial foot can only be obtained through the terminal branches of the posterior tibial artery. It is our view that, given the arterial deficiencies that have been described, any incision that interrupts such a tenuous blood supply endangers the distal surgical flap. Additionally, surgical insult causes an increased metabolic load.[8] Relative vascular insufficiency of wounds, as evidenced by very low partial pressures of oxygen in the tissues, remains present during the first 2 weeks postoperatively.[8] Tissue oxygen supply depends more upon local nutritive blood flow than upon oxygen carrying capacity.[8] For these reasons, we believe that every postoperative clubfoot with tenuous blood supply stands a greater risk of tissue necrosis than does a normally vascularized surgical foot.

The cases described in this article provide a

few important observations. In each limb that developed necrosis a teratogenic clubfoot was present in addition to deficiency of a main artery. Two of the three limbs required revision surgery. Since all of the currently popular skin incisions cross lines of vascularity supplied by way of a subdermal plexus, these incisions render the tissues on the arterially deficient side prone to postsurgical necrosis.

The data presented here are consistent with the concept that necrosis results from metabolic demands that exceed the level that the marginal blood supply can sustain. Although postoperative casting does not appear to initiate the necrosis, we believe that, in any foot compromised by arterial deficiency, alternatives to circumferential compression should be considered. For the optimal functional result after extensive necrosis, amputation and prosthetic application are preferable to repeated debridement and skin grafting.

Summary

Three cases of necrosis following clubfoot surgery are presented. Since previous arteriographic studies have shown that 89% of limbs with clubfoot deformity exhibit diminution or absence of the anterior tibial artery and its derivatives, several specific characteristics of these cases suggest an etiologic connection with the arterial deficiency. In one limb, the distribution of necrosis including the hallux and dorsal flap corresponds to the region of diminished vascularity in the absence of the dorsalis pedis artery. The necrosis in the second limb, which featured a delayed onset beyond the 10th postoperative day, implies a nonsurgical cause. In the third limb, the necrosis occurred in the distribution of the posterior tibial artery, which was found to be deficient by color Doppler examination. We suggest that in these cases, the incisions rendered the tissues on the arterially deficient side of the incision prone to necrosis. The data presented here appear most consistent with the hypothesis that the necrosis resulted from metabolic demands in excess of those that a marginal blood supply could provide. We believe that surgeons should assume that an abnormal vascular pattern is present in all clubfeet.

Acknowledgment

Our thanks to Nancy Snyder and Jo-Ann Pellett for expert typing. We wish to acknowledge the wit and wisdom of Harold R. Weichert, M.D. and Adam S. Hootnick, whose contributions to this study were invaluable.

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Effects of Soft Tissue Release on the Development of the Tarsal Bones in Clubfeet

G. Szabo, J. Kranicz, and A. Bellyei

The development of the tarsal bones has significant importance in the pathology of clubfeet. Tarsal maldevelopment may mislead us in the assessment of the results following treatment. Various methodological questions arise with the problem of maldevelopment of the tarsal bones. Because treatment in clubfeet starts shortly after birth, it is difficult to judge whether later disturbances of ossification are consequences of manipulation or are related to the nature of the deformity. The same problem also seems to be valid concerning operative treatment, since most tarsal bones are not visualized radiographically before 1 year of age. Another problem is that the visible portion of the ossification centers represents only a small part of the bones; a greater cartilaginous part remains translucent at the time of surgery.

Purpose

The aim of the present study is to analyze the effects of treatment on the development of tarsal bones. Variations in tarsal development of both normal feet and clubfeet are analyzed and discussed.

Material and Methods

Serial radiographs of 152 clubfeet treated operatively between 1978 and 1984 at the Department of Orthopaedics of the Medical University of Pecs were evaluated. First, radiographs were taken at the end of conservative treatment but before surgery. The earliest was at 9 months of age. Additional radiographs were taken postoperatively.

Radiographs of 150 normal feet of the same age group acted as controls. Normal tarsal development was also assessed, based on the control material (Table 14.3). In children under 5 years of age, skeletal maturity was estimated by the radiographic visibility of the third cuneiform and, in children over 5 years of age, the navicular was used. The incidence of developmental variations in normal feet, accessory bones, multiple ossification centers, etc., was analyzed (Table 14.4). In the clubfoot group the presence of flattening of the talar trochlea was carefully looked for.

TABLE 14.3. Mean time of radiographic appearance of the tarsal bone in normal feet.

	Months	Years
Talus (two nuclei)	Before birth	
Calcaneus	Before birth	
Navicular (two or more nuclei)		3.5
Cuboid	1	
First cuneiform		3
Second cuneiform		3
Third cuneiform	9	

TABLE 14.4. Control group: anatomical variations and accessory bones in 150 normal feet.*

	Number of feet	Percent
Avascular necrosis of the navicular	2	1.3
Multiple ossification centers in the navicular	3	2.0
Os tibialis externum	8	5.3
Os trigonum	12	8.0

*No case of flattop talus or talar avascular necrosis was observed in this group of 150 normal feet.

Results

Control Group

Analysis of the radiographs of the control group was used to establish radiographic developmental characteristics in the normal feet. Average time of the radiographic appearance of the tarsal bones in this group is presented in Table 14.3. Table 14.4. lists the anatomical variations and the accessory bones seen in the control group.

TABLE 14.5. Clubfoot group alterations.

Radiographic findings	Number of cases	Percent	Comment
General delayed ossification	27	17.76	Observations based on presence of cuneiform bones under 5 years; cuneiforms and naviculars over 5 years
Avascular necrosis of the navicular	4	2.63	Radiographic changes present preoperatively
Multiple ossification centers in the navicular	5	3.29	Three centers present in most cases
Multiple ossification centers in the os trigonum	2	1.33	
Flattening of dorsal talar articular surface	16	10.53	Radiographically absent in 10 cases preoperatively
Narrowing of subtalar joint space with periarticular sclerosis	3	1.97	

Clubfoot Group

The changes observed in the clubfoot group are presented in Table 14.5.

Retardation in the tarsal bones was observed in 18% of clubfeet. Radiographic "absence" of the navicular bone was detected in 11 feet (16.7%)(Figure 14.14). Absence of the ossified navicular together with absent ossification in the first and second cuneiforms was seen in 10 feet (10.4%) (Figure 14.15). Isolated absence of the ossification center of the third cuneiform was not found in this series.

Avascular necrosis of the navicular was twice as common in the clubfoot group (1.3%) in the control group and 2.6% in the clubfoot group (Figure 14.16). There were no cases of avascular necrosis of the talus nor of the calcaneus.

Flattop talus was observed in 16 feet (10.5%) in the clubfeet group. All but two of these were present prior to surgery (Figure 14.17). In the remaining two cases operative overcorrection and consequent calcaneus deformity with talar overload was possibly the cause, which subsequently resulted in flattening of the talar trochlea (Figure 14.18).

The os trigonum was present in 5.3% of control feet, whereas an os trigonum with multiple ossification centers (Figure 14.19) was found only in two feet (1.3%) in the clubfeet group.

In both groups there were feet with navicular bones with multiple ossification centers. The incidence of this variation was a bit higher among clupfeet (3.3%) than in the control group (2%) (Figure 14.16).

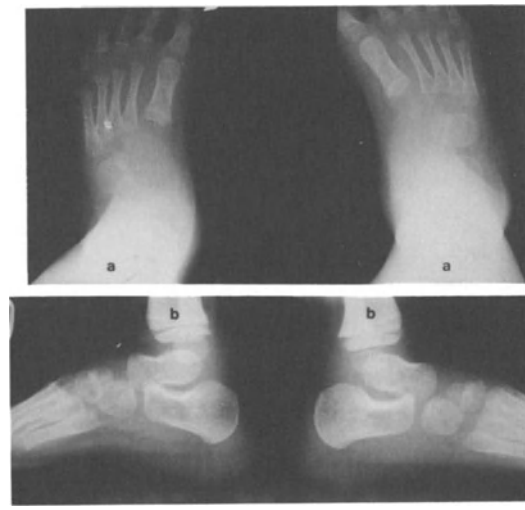


FIGURE 14.14. A 6-year-old boy with unossified navicular.

Narrowing of the subtalar joint space with periarticular sclerosis was present in 2% of the clubfoot group.

Discussion

The evaluation of clubfeet may be confused by the presence of accessory developmental variations of the tarsal bones. Therefore, an analysis of the results after treatment must take this higher incidence of bone malformation into account. Cases presenting with no accessory



FIGURE 14.15. A 5-year-old boy. The naviculars have still not ossified. Only the third cuneiforms can be seen radiographically.



FIGURE 14.16. A 6-year-old boy with three ossification centers of the navicular 5 years after clubfoot surgery.

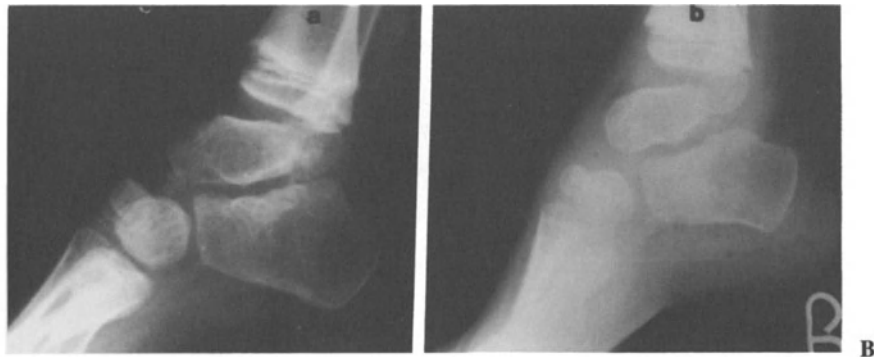


FIGURE 14.17. A: Postoperative radiographs show flattened talar trochlea at 8 years of age. The navicular is small but present. B: Same foot prior to surgery. The talar trochlea is flattened. The navicular is not ossified.

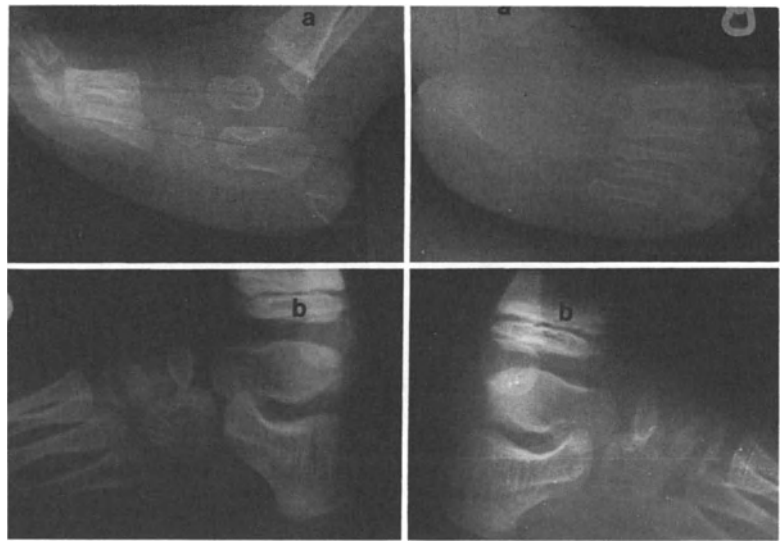


FIGURE 14.18. An 8-year-old boy. Preoperatively calcanei are in equinus. Postoperatively bilateral calcaneus position is present with mild flattening at the top of the talus.

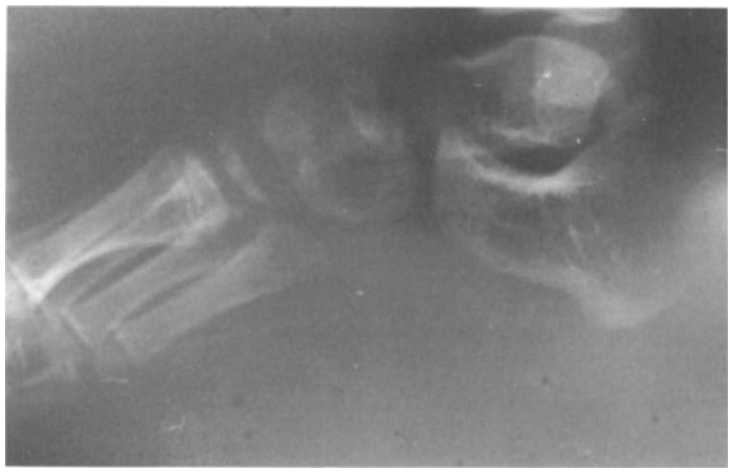


FIGURE 14.19. A 6-year-old girl from the clubfoot group with an os trigonum developing from three ossification centers.

change should not be compared with those with accessory bones.

In our clubfoot material, skeletal maturity of the feet was delayed in 17.8% in comparison with the normal controls. Beside the maldevelopment, this delay in skeletal maturity could be due to poor nutrition as the consequence of increased pressure caused by malposition of the tarsal bones. Accessory bones and multiple ossification centers are considered normal variations of ossification.

In our clubfoot material, the incidence of accessory bones was less than in the control group. Only the os trigonum, with multiple ossification centers, was found more commonly in the clubfoot group.

The incidence of multiple ossification centers within the navicular was the same in both

groups. In the clubfoot group, three centers were characteristic, which is rare among normal feet in spite of the fact that even five talar ossifications centers have been previously reported.[7] Mau[4] stated that multiple ossification centers represent a higher risk of avascular necrosis. According to Karp,[1] delayed ossification predisposes to abnormal development, whereas ossification centers that occur on time are usually normal.

The incidence of avascular necrosis of the navicular in the clubfoot group was approximately twice that of the control group. The relatively higher rate of avascular necrosis in the cuneiforms in clubfeet as compared to the control group can be the result of their pathologic position.

Avascular necrosis of the talus was not observed in our study. This means that soft tissue surgery does not grossly impair tarsal nutrition. This supports the findings of Lanz and Wachsmuth[2] that several vessel anastomoses help maintain the blood supply of the talus.

A flattop talus was observed in 16 feet in our clubfoot group (10.5%). This held for all but two cases preoperatively and cannot be considered a consequence of surgery but probably is the result of increased pressure caused by preoperative manipulation. This supports the findings of Reimann[6] and Lehman.[3] In the remaining two cases, overlengthening of the Achilles tendon resulted in a calcaneus deformity with possible increase in pressure, which could result in a flattop talus. Ponseti et al.[5] found a 56% incidence of flattop talus in their study after manipulative treatment and Achilles lengthening. Since flattop talus is a preoperative phenomenon, this points to the importance of gentle manipulation. It is logical that during conservative treatment the tarsal bones are exposed to excessive compression which, in our opinion, may alter the development of the foot.[1] There can be a marked delay in ossification in cases of long-term manipulative treatment prior to surgery. The unfavorable consequences discussed in this study could be avoided by early surgery.

Summary

The incidence of associated bone alterations such as multiple ossification centers of the navicular, os tibiale externum, os trigonum, and sequential tarsal changes such as necrosis of the navicular bone and flattening of the talar trochlea in 152 clubfeet were analyzed and compared with a control group of the same size. Tarsal development was studied on anteroposterior and lateral radiographs. The findings showed retardation of tarsal ossification in almost one-fifth of the clubfeet. Based on the radiographic features of clubfeet after serial cast applications, but prior to operative treatment, we believe that delayed bony maturity and flattening of the talar trochlea are consequences of forceful manipulations. The analysis of the operatively treated cases failed to reveal any negative changes secondary to soft tissue release. It is also believed that the correct manipulative procedures may improve the consequences of conservative treatment. Besides delayed bony maturity, a few variations of tarsal bone development were found to be of higher incidence when compared to the control material.

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Analysis of Unfavorable Late Results After Early Posteromedial Release in Clubfeet

G. Szabo and J. Kranicz

There are several different surgical techniques available for the treatment of clubfeet.[1,2,4,8,9] Clinically none is fully satisfactory for all problems and there are still problems awaiting solutions. However, few reports discuss the problems of overcorrection and undercorrection. Previous papers report a wide range of undercorrection. Porter[7] reported 19% hindfoot and 9% forefoot adductus; Otremski et al.[6] reported 56% of residual metatarsus adductus; Lowe and Hannon[3] found 55% postoperative forefoot adductus in his study; and Main and Crider[5] reported a 69% incidence.

Purpose

We have reviewed our cases from the point of view of imperfect correction. The incidence, types, and possible causes of overcorrection and undercorrection were analyzed.

Materials and Methods

Between 1970 and 1987, 427 clubfeet (all cases) were treated by posteromedial release for equinovarus deformity at the Department of Orthopaedics at the University Medical School of Pecs, Hungary; 351 patients with 390 affected feet were available for a late follow-up study. Surgery was performed between 4 and 12 months of age after serial manipulations and plaster cast applications were unsuccessful.

Surgical Technique

Achilles tendon lengthenings were performed in all cases together with ankle and subtalar capsulotomies using a longitudinal dorsal incision. Lengthenings of the posterior tibial tendons were performed with medial subtalar and perinavicular capsulotomies.

All feet were examined clinically and radiographically with anteroposterior (AP) and lateral radiographs. Based on clinical examination, the feet were divided into three groups: normal (or nearly normal), undercorrected (residual hindfoot varus, forefoot adductus, or both), and overcorrected (flattened longitudinal arch and/or hindfoot valgus). Anteroposterior and lateral talocalcaneal (APTC and Lat. TC) and talometatarsal (TM) angles were measured with careful attention to the position of the bone.

Radiographically, undercorrected feet were grouped as follows:

Feet with *absolute undercorrection* showed decreased APTC angles with medial dislocation of the navicular together with medial deviation of the forefoot and increased TM angles.

Feet with *hindfoot undercorrection* showed decreased APTC angles with medial dislocation of the navicular but without medial forefoot deviation.

Feet with *metatarsus adductus* showed isolated deviation of the TM axis without hindfoot deformity.

Feet with *compensating forefoot adductus* showed talonavicular dislocation with forefoot adductus, an increased TM angle, hindfoot valgus; in these cases malposition of the forefoot developed secondary to the hindfoot valgus.

Overcorrections were divided into two clinical groups according to foot mobility: mobile flatfeet or mildly overcorrected feet were similar to marked typical flatfeet, whereas rigid deformity was characteristic of severe flatfeet.

Results

From the 390 operated feet examined during the follow-up study, 214 (80.6%) had a normal appearance at the time of follow-up. The rest consisted of 47 (12.1%) undercorrected and 29 (7.4%) overcorrected feet.

Undercorrected Feet

Absolute undercorrection was found in 10 cases. All underwent revision surgery (Figure

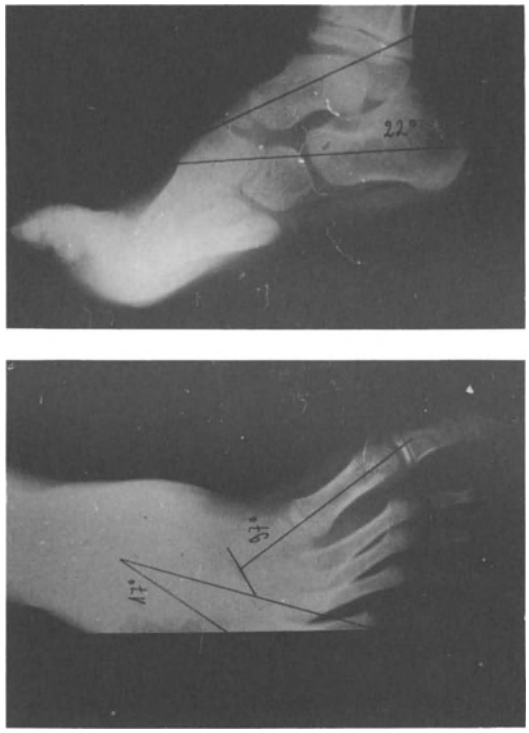


FIGURE 14.20. Absolute undercorrection in a boy operated on at 10 months of age. Age at the time of this radiograph was 21 months. Note decreased Lat. TC angle and forefoot adductus.

14.20). Early postoperative radiographs were available in six cases, of which four showed incomplete correction of the hindfoot (decreased APTC and/or Lat. TC angles). This finding made it clear that the undercorrection was due to incomplete surgical correction. In the remaining two cases, early postoperative radiographs showed fair APTC and Lat. TC angles; the inadequate postoperative treatment (short-term cast applications in one case and insufficient splinting in another) could be attributed to relapse. In four cases we failed to find any objective reason for recurrence of the deformity.

Hindfoot undercorrection was found in 6 feet out of 15 that underwent revision surgery. Retrospective analysis of early postoperative radiographs revealed incomplete operative correction of the hindfoot in four cases. In those 11 feet with an unfavorable end result due to incomplete correction, reoperation revealed contractures of the medial subtalar joint capsule; these deformities were believed to be secondary to insufficient postoperative cast applications.

Forefoot undercorrection (isolated metatarsus adductus) was found in 14 feet. None of these feet underwent surgical revision. Resistant capsular contractures were believed to have played a part in this deformity (Figure 14.21).

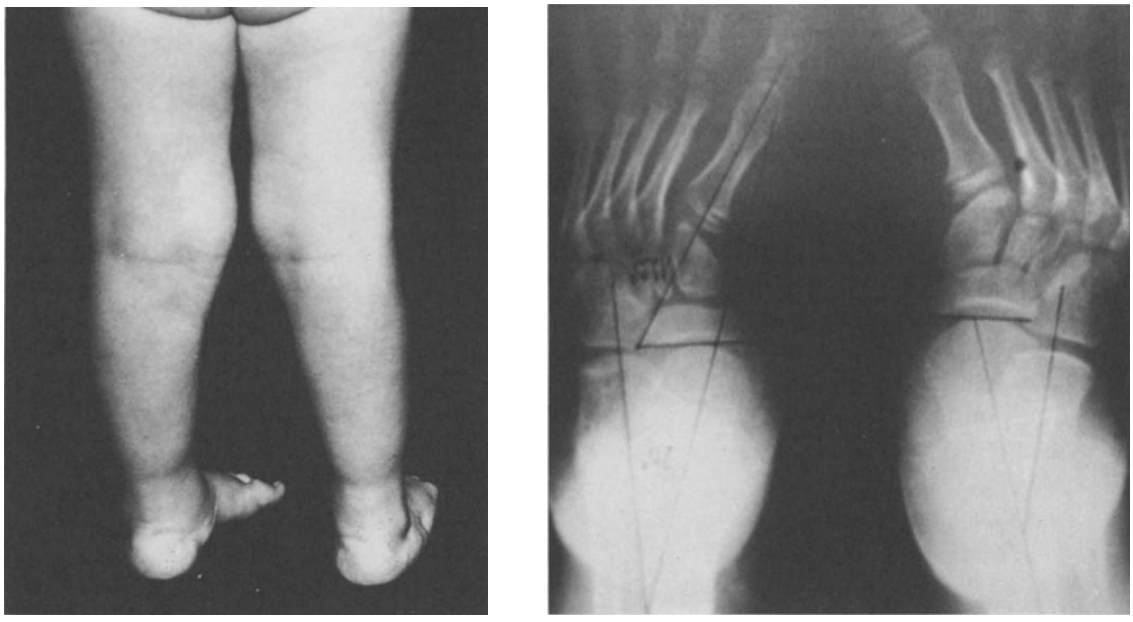
Compensating forefoot adductus was found in six feet. None underwent surgical revision. Radiographic analysis at follow-up revealed resistant hindfoot overcorrection (increased APTC and Lat. TC angles); the relative rigidity of the hindfoot led us to believe that the forefoot adductus was secondary to hindfoot valgus.

Overcorrected Feet

Twelve of the 29 feet in this study were classified clinically as mobile flatfeet and so needed no further surgery. All of these feet were treated with arch supports or corrective shoes (Figure 14.22). The remaining 12 feet were found to be severe or clinically rigid. Of these, 10 were treated by subtalar and Chopart fusion in adolescence (Figure 14.23). The remaining two patients were asymptomatic and refused reoperation. Analysis of the overcorrected feet revealed that all but two patients were between the ages of 3 and 5 months at the time of surgery. The finding led us to conclude that premature soft tissue release may lead to overcorrection (see Figure 14.22 for case report).

Discussion

We agree with other authors that posteromedial soft tissue release between 6 and 12 months of age gives good results in most cases. The high percentage of good results (80%) in our study indicates that, if well chosen, posteromedial release together with sufficient postoperative care are useful in the treatment of CTEV. In spite of these good results, however, attention should be paid to the problem of overcorrection and undercorrection. Among others, Porter,[7] Otremski et al.,[6] Lowe and Hannon,[3] and Main and Crider[5] reported findings concerning undercorrection after soft tissue operations. These reports presented a wide range of incidence of undercorrection



A B

FIGURE 14.21. Clinical and radiographic appearance of a case of bilateral isolated metatarsus varus. Note the normal position of the calcaneus and the adducted position of the forefoot bilaterally.



FIGURE 14.22. Clinical appearance of bilateral marked but mobile overcorrection. Age of the time of surgery was 4 months (with a 2-week interval between surgeries). Overcorrection was first detected when the child began to walk.



FIGURE 14.23. Radiographs of a 10-year-old boy presenting with an increased Lat. TC angle and forefoot eversion. Surgery was performed at 4 months of age. The foot was clinically rigid. Subtalar and Chopart fusion was performed at 15 years of age.

(6% to 69%). In our study, the incidence of undercorrection was 12%. Of a total of 47 undercorrected feet, 25 had surgical revision for hindfoot varus. The remaining 22 feet had residual forefoot adductus, which can stand by itself (isolated metatarsus varus) or can be a compensatory result secondary to hindfoot overcorrection.

Based on the results of our study, we believe that undercorrection is a consequence of inadequate operative technique or improper postoperative care.

Overcorrection was present in 7% of cases. Moderate to marked mobile flatfeet (overcorrected feet) did not have surgical revision. Twelve of these feet were treated with arch supports and corrective shoes. However, rigid feet and severe overcorrection represent difficult problems. Fifteen of 17 rigidly overcorrected feet needed subtalar and Chopart fusion in adolescence. Analysis of our overcorrected cases led us to conclude that premature soft tissue release may lead to overcorrection. Our results (80% fair or better) are among the best of those reported. However, further development of operative technique is needed to decrease undercorrection and overcorrection.

Summary

The review of 427 clubfeet treated by early posteromedial release revealed unfavorable results in 20% of the cases. Undercorrection (13% of the cases) was generally due to inadequate operative technique or to improper postoperative care; overcorrection (7% of the cases) was due to performing surgery too extensively and at too early an age. Rigid overcorrected feet had the worst results and, in most cases, required tarsal fusion in the adolescent years.

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Reasons for Failure with Posteromedial Release

V. Turco

The operative reports, medical records, and radiographs were reviewed in an attempt to determine the reasons for our recurrent deformities of patients with 161 clubfeet. The series included 20 of my own patients and 141 from clinics throughout the country.

Failures were due to one of three major factors: failure to obtain correction, e.g., faulty surgical technique; failure to maintain correction postoperatively; and, finally, feet that were atypical idiopathic clubfeet.

The surgical technique was to blame for recurrent deformity in 40 feet (25%). There were an additional 42 feet (26%) in which no internal fixation was used. Surgical correction was lost in the postoperative management of 27 feet (17%). Fifty-two (32%) were cases of "atypical" idiopathic clubfeet. Failure to use adequate internal fixation could be considered as either faulty surgical technique or failure to maintain correction after surgical correction.

Failure to Obtain Correction

In the majority of repeat operations the talonavicular joint is "virgin territory." When this area has been previously unexplored, a good result is usually obtained.

In one case in which a Cincinnati incision was used, surgery failed because the talonavicular joint was not exposed. Too much emphasis was placed on the posterolateral corner, which is only part of the pathology. In another case two incisions were used, again with incomplete correction due to inadequate exposure of all of the pathology. All tight structures preventing normal realignment of the tarsal bones must be excised or transected. If surgical release is incomplete, there will be persistence of deformity.

Failure To Maintain Correction

In a child who had a posterior release at 3 months of age and a posteromedial release at 15 months of age, no Kirschner wire was used in the posteromedial release. This was a failure to maintain correction.

Another patient had a wedge-shaped deformity of the medial part of the head of the talus. This is common in failures and is probably entirely or partially iatrogenic.

In other cases correction was lost postoperatively due to cast slippage, the use of below knee casts, premature cast removal, or the Kirschner wire "fell out." The cast must maintain the correction after the Kirschner wires are removed. This is particularly difficult with small, chubby feet. If the toes disappear within the cast, correction will be lost. In 13 of 500 personal operations, I noted cast slippage after the Kirschner wire was removed. In these 13 cases, 4 were failures, 4 had fair results, and 5 had satisfactory results. In a case that had surgery performed at 5 months of age, postoperatively, the foot was immobilized for only 2 months. I think immobilization must be maintained long enough for the tarsal bones to remodel stable articular surfaces. There was no internal fixation in a large number of the cases. No bony defects due to Kirschner wire were noted at skeletal maturity.

Failures of Selection

If the surgeon suspects the "atypical" idiopathic clubfoot (described in Chapter 2), surgical treatment should be delayed. The findings suggesting this "atypical" TEV are (a) laterally inserted Achilles tendon, (b) skin creases in the area of the insertion of the Achilles, (c) contralateral foot deformities, (d) long flexible foot, (e) rocker-bottom deformity, (f) delayed motor development, and (g) hypotonia. Patients with these findings are prone to develop unacceptable, severe flatfeet.

Summary

There are three prerequisites to attaining a lasting correction with the posteromedial release. First, a complete correction must be

attained surgically. Second, it must be maintained postoperatively. Most cases of so-called recurrent deformities are cases where one fails to attain a complete correction or fails to maintain the correction for at least 4 months postoperatively. Third, clubfeet must be carefully selected for the procedure. When the findings of the "atypical" clubfoot are suspected, it is recommended to delay surgical treatment.

Discussion

Coleman (Salt Lake City): Dr. Simons, how did the epidural block influence your compartment syndrome in the foot?

Simons (Milwaukee): I think it delayed the diagnosis, and the appearance of the cyanosis of the toes.

Coleman: I think there's got to be something in addition to the epidural that led to this disaster.

Simons: Definitely. It was ischemia. Because the child had previous surgery. That's probably the key. There was extensive scarring around the neurovascular bundle and when I straightened the foot, I think I put tension on the fibrous tissue around the neurovascular bundle which made his circulation borderline. Then with the epidural, the foot was peripherally vasodilated. The following day they repeated the block so, therefore, the signs of ischemia did not appear as early as they should have.

Hootnick (Syracuse, New York): I wonder whether we should call it a compartment syndrome or vascular insufficiency. I think all of these feet are at risk and the question I ask is why some have a problem but the majority don't. I was trying to narrow down the number of patients who have other stigmata of birth defects. These seem to be the people who get into trouble. Also, children with multiple operations. It doesn't seem to be the typical virgin clubfeet that develop this.

Simons: I think that multiple surgery is a very important factor. There was a comment yesterday about the increased demand for blood supply for wound healing, at 4 or 5 days following surgery. This is an interesting concept because this child really didn't have a great deal of pain until about 4 or 5 days after surgery and then the pain became very intense.

Grant (New York City): Do you have any experience or knowledge of any extensive studies in compartment pressures routinely done postoperatively in the foot?

Simons: There are two recent articles on compartment syndrome in the foot. One of them describes a new ninth compartment.[1,2]

Stevens (Lexington, Kentucky): We have had two cases in the last year where epidural blocks significantly complicated postoperative care. We're mounting a campaign to get anesthesiologists to discontinue using them.

Crider (San Francisco): Dr. Szabo, I helped Mr. Lloyd-Roberts of London review 50 of his clubfoot patients about 15 years ago. Among them were a large number of apparent flattop tali. We eventually realized that we were simply looking at an oblique x-ray. We were not looking at the true lateral of the talus but in fact, we were looking at the foot and ankle in an oblique projection. The number of true flattop tali of course, was much smaller. Do you find that the true flattop tali cause clinical symptoms?

Szabo (Pecs, Hungary): I don't think we have any problems with flattop tali in childhood. It may be a precursor of future osteoarthritis of the ankle joint, however.

Crider: Over about a 7-year period, we didn't find any clinical problems with flattop tali but that was a relatively short-term follow-up.

Turco (Hartford): Early in my series, I operated on a child at 5 months of age who had a wound problem. I called the plastic surgeon—

which I will never do again—because the first thing he did was to put the foot back into equinus. The wound healed but the equinus persisted. If you have a wound problem, be very patient, let it heal by secondary intention, and you won't lose the correction.

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Editor's Comments

It is interesting that both the foot reported by **Simons** and one of the three feet reported by **Hootnick et al.** had absent posterior tibial arteries. Although **Simons'** report documented this absence by direct observation after opening the neurovascular bundle, in **Hootnick et al.'s** case the authors simply stated that the artery was not observed to be present. They did not mention whether the neurovascular bundle was opened. Color Doppler examination revealed a very small posterior tibial artery proximal to the ankle at 1 year of age. Whether this was present prior to surgery or remained patent distal to the ankle is not known. There is also no mention of whether an anomalous deep peroneal vessel was present. The color Doppler study seems to indicate that the major artery was the anterior tibial artery, the artery that is usually absent or deficient in clubfeet (see Chapter 5, p. 172).

Hootnick and colleagues reviewed the possible causes of necrosis following surgery for CTEV. All three of their patients had associated congenital defects, whereas **Simons'** patient had bilateral clubfeet but no other congenital defects. Two of the three patients in **Hootnick et al.'s** series had previous surgery (as did **Simons'** patient) and two had a posteromedial incision, whereas one had the Cincinnati incision (**Simons'** patient also had a Cincinnati incision). **Hootnick et al.'s** study noted only one case of cyanosis, which started at 36 hours postoperatively. In **Simons'** case, cyanosis was first noted on the 2nd postoperative day, but cyanosis might have been observed earlier had not the patient received epidural blocks during and following surgery. Necrosis in **Hootnick et al.'s** three patients occurred at 3 days, 7 days, and 14 days, respectively.

Whether the epidural block delayed observation of cyanosis in **Simons'** patient is uncertain, but its masking effect of physical findings has been recently reported elsewhere.[5] Stevens also reports a case (see Discussion).

That hyperbaric oxygen helped prevent necrosis in Simons' patient is also speculative. Ischemia was probably directly related to the patient's previous surgery with subsequent scarring around the neurovascular bundle. When the position of the foot was markedly altered and placed into correct alignment, the surrounding scar very possibly could have caused stretching and/or a compression of the blood supply.

Szabo et al. observed a delay in skeletal maturity in almost 20% of the clubfeet as compared with their control group, whereas the incidence of avascular necrosis of the navicular was approximately the same in both groups. However, they did not observe avascular necrosis of the talus or the calcaneus in their study. It is interesting to contrast these figures with those of a frequently cited study[1] that reports a significant incidence of avascular necrosis of the talus, particularly when the lateral side of the subtalar joint is opened (which was not the case with Szabo's series). We have found avascular necrosis of the talus to be extremely rare (one case) despite our routine use of complete subtalar release. Schlafly et al.'s[4] series, as well as personal communication with colleagues who have had considerable experience with extensive lateral releases, verify the rarity of this complication.[2,3]

Turco states that failure to obtain correction is one of the three major reasons for failure with the posteromedial release. This has been our experience also, specifically, failure to

identify the talonavicular joint and differentiate it from the tibiotalar articulation. Finally, having identified the talonavicular joint, release of this joint has often been incomplete in the hands of relatively inexperienced surgeons.

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15
Comparative Evaluation of Surgical Techniques

Introduction

Seringe and **Miladi** report a series of patients on whom subtalar release was performed without complete release of the talocalcaneal ligament and another series of cases in whom the subtalar joint was not opened. In this paper, Seringe and his colleague describe the concept of the "calcaneo-pedal block." This concept is essentially the same as described by McKay and others in the Introduction to this monograph.

Dimeglio compares his results over a 15-year period at 5-year intervals between 1975 and 1990. Each period was marked by a major change in technique. These results are also related to his four categories of clubfeet.

In the second paper **Nimityongskul et al.** report on a comparative review of the one-stage posterior medial release with the one-stage complete subtalar release.

Porat makes a comparative evaluation of the Turco, Carroll, and McKay procedures. He evaluates these procedures in relationship to healing, quality of the scar, accessibility of various structures, and ability to rotate the calcaneus at the subtalar joint.

Magone, **Torch**, and **colleagues** report a comprehensive comparative review of surgery performed by three different techniques (Turco, Carroll, and McKay) by surgeons at the same institution. Included in their evaluation are the total range of ankle motion postoperatively, range of great toe flexion, the persistence of uncorrected calcaneal rotation beneath the talus postoperatively, dorsal and lateral overcorrection of the talonavicular joint, and the association of cavus with dorsal talonavicular subluxation. They also attempt to determine the applicability of a new rating system.

Comparative Evaluation of Two Surgical Techniques with and Without Subtalar Release

R. Seringe and L. Miladi

Prior to 1973, a posteromedial release similar to the procedure described by Turco[10] was the operative procedure of choice at Hospital Saint Vincent de Paul. However, this procedure did not always correct the existing deformities. Recurrences and overcorrections also occurred after this procedure.

At that time, our experience led us to believe that the main residual deformity in clubfoot (CTEV) was the adduction of the calcaneo-pedal block (calcaneus and forefoot, CFF) with rotation of the calcaneus under the talus around the interosseous ligament. The distal part of the foot was displaced medially, whereas the calcaneal tuberosity was displaced laterally toward the fibular malleolus. In order to accomplish full derotation of the CFF, the senior author (R.S.) developed a new technique of soft tissue release that consisted of posterolateral, anteromedial, and anterolateral release. Preliminary reports were presented at the Pediatric Orthopaedic International Seminar[5] and at the SOFCOT Congress in 1975.[2] Other publications confirmed the correctness of this new concept and new surgical technique.[6–8]

Between 1974 and 1979, variations of this soft tissue release were performed with and without opening the subtalar joint, and while leaving the interosseous ligament fully or partially intact.

Purpose

The purpose of this study is to evaluate the influence of opening the subtalar joint on the results of the extensive soft tissue releases for idiopathic clubfeet.

Material and Methods

The surgical release was performed in 46 patients (33 males, 13 females) with 58 idiopathic clubfeet (34 unilateral, 12 bilateral). All procedures were performed by the same surgeon (R.S.) during the period from 1974 to 1979.

The medial capsule of the subtalar joint was opened in 22 feet and a partial incision of the interosseous ligament was performed in four feet.

Two different groups were studied. Group I consisted of 30 *previously unoperated* feet that were resistant to manipulative treatment. The mean age at the time of surgery was 1 year 4 months, with a minimum of 4 months and a maximum of 4 years 6 months. The mean follow-up was 10 years 10 months, with a minimum of 2 years 2 months and a maximum of 16 years 2 months.

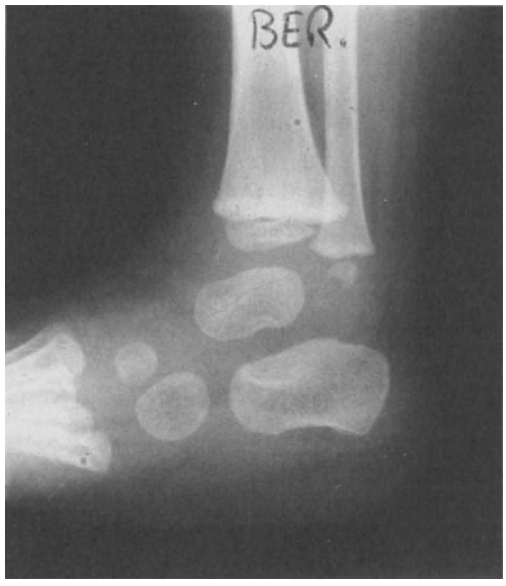
Group II consisted of 28 *previously operated* feet. The mean age at the time of surgery was 3 years 10 months, with a minimum of 1 year 3 months and a maximum of 7 years 3 months. The mean follow-up was 9 years 6 months, with a minimum of 4 years 4 months and a maximum of 14 years 2 months.

Surgical Technique

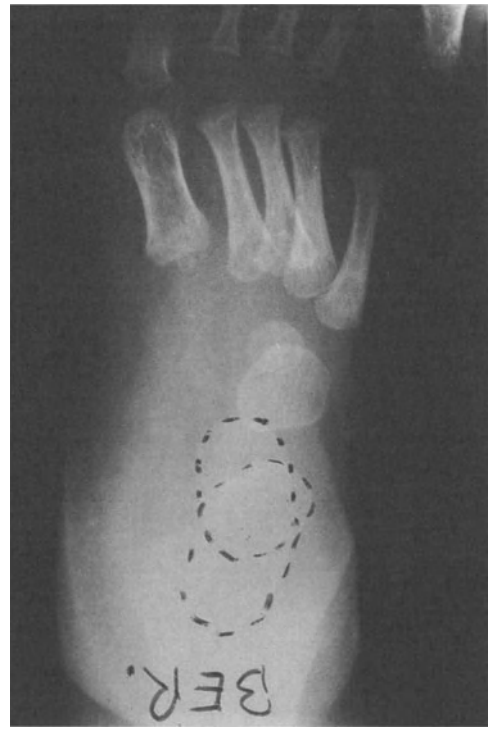
The standard posteromedial incision was used. A complementary anterolateral incision was sometimes also used. The release was performed in four basic stages.

Stage I included posterior and posterolateral releases with Achilles tendon lengthening, ankle capsulotomy, and release of the posterolateral knot (the lower part of the ankle fascia, superior peroneal retinaculum, and calcaneofibular ligament). The posterior capsule of the subtalar joint was incised early in the series. The calcaneal tuberosity could then be displaced downward and inward.

Stage II included anteromedial release with tibialis posterior lengthening, abductor hallucis proximal release, incision of Henry's knot, talonavicular capsulotomy, and spring ligament incision. The medial capsule of the subtalar joint and the medial half of the interosseous ligament were incised early in our series. At



A



B



C



D

FIGURE 15.1. Preoperative radiographs in a 2-year-old girl. A: Lateral view with passive dorsiflexion. B: AP view with passive eversion. C and D: Intraoperative radiographs after extensive surgical release without opening the subtalar joint.

TABLE 15.1. Clinical and radiological rating system.

Hindfoot (5 points)	0° to 5° valgus	5
	5° to 10° valgus or a few degrees varus	3
	Definitive varus or more than 10° valgus	0
	Lateral translation of the foot	−10
Forefoot adduction (3 points)	No residual adduction	3
	More than 5° adduction	0
Forefoot supination (3 points)	No residual supination	3
	Supination	0
Cavus (5 points)	Absent	5
	Present	0
	With dorsal navicular subluxation	−5
Global adduction (5 points)	≤20°	5
	>20°	0
Bimalleolar axis (10 points)	≤25°	10
	26° to 35°	5
	>35°	0
Heel walking (5 points)	Possible	5
	Difficult	3
	Impossible	0
Unipodal jumping (10 points)	Normal	10
	Difficult	5
	Impossible	0
Global motion of the foot (20 points) (flexion-extension)	≥70°	20
	60° to 69°	15
	50° to 59°	10
	40° to 49°	5
	<40°	0
Dorsiflexion of the ankle (5 points)	≥10°	5
	<10°	0
Pain (12 points)	Never	12
	With heavy activity	8
	With routine activity	5
	With walking	0
Function (12 points)	Never limits	12
	Limits heavy activity	8
	Limits routine activity	5
	Limits walking	0
Subtalar radiographic index (5 points) (AP TC + lateral TC)	≥50°	5
	30° to 50°	3
	<30°	0
Total: 100 points		
Results: Excellent	from 90 to 100 points	
Good	from 80 to 89 points	
Fair	from 70 to 79 points	
Poor	less than 70 points	

the end of this stage, usually the CFF will completely rotate under the talus. The interosseous ligament was retained for three reasons: (a) to conduct the motion of abduction of the CFF, (b) to avoid an overcorrection into valgus, and (c) to preserve the vascularization of the talus.

Stage III included a tarsometatarsal capsulotomy and selective plantar release in order to correct the adduction of the forefoot.

Stage IV was necessary if there was insufficient correction of CFF adduction. It included an anterolateral release with the incision of the extensor retinaculum and sometimes of the lateral talocalcaneal capsule. Over the age of

2 years, a wedge osteotomy of the distal part of the calcaneus may be performed.

In all cases, the flexor retinaculum and sheaths of the tibialis posterior and flexor tendons were retained under the tibial malleolus.

A Kirschner wire was inserted across the talonavicular joint according to the principle of correction of the CFF adduction. While an assistant turned the leg and the talus into medial rotation, the surgeon moved the CFF into abduction and plantar flexion (thus avoiding a dorsal subluxation of the navicular), and passed the pin through the talonavicular joint from the first cuneiform. The correction was assessed with intraoperative radiographs (Figure 15.1). When the subtalar joint was not opened, the talonavicular pin was sufficient. A cast was applied at 7 days; the foot was in a cast for a period of 3 months, at which time the pin and cast were removed.

Method of Assessment

A very critical rating system (Table 15.1) was designed, with 100 points indicating a normal foot. Our judgment about morphology and function is more critical than those previously published. Radiographs were given only 5 points because they were thought to be repetitious with most clinical criteria.

Results

In group I (previously unoperated feet) the results were quite different depending upon whether the subtalar joint was opened. Of 10 feet with subtalar release, results were good in 4, fair in 2, and poor in 4. Of 20 feet without subtalar release, results were excellent in 6, good in 12, fair in 1, and poor in 1.

In group II (previously operated feet) the results were nearly similar in the two subgroups. Of 12 feet with subtalar release, results were excellent in 2, good in 4, fair in 2, and poor in 4. Of 16 feet without subtalar release, results were good in 7, fair in 4, and poor in 5.

Pain was observed in 15 cases (14 were painful with heavy activity and one with routine activity). Of the 5 painful feet in group I, 4 were observed in the subgroup of 10 feet operated on with subtalar release. Of the 10 painful feet in group II, there was no significant difference between the two subgroups (with and without subtalar release).

Inability to jump on one leg was noted in 3 feet in group II. Hopping on one leg was difficult in 13 feet (6 in group I and 7 in group II).

Additional surgery for recurrence was performed on four feet, all in group I (in three cases with subtalar release and one without subtalar release).

Overcorrection was observed in four cases, three of which occurred after subtalar release (of these three, two had lateral translation of the foot), and one of which occurred without subtalar release.

In only one case was dorsal subluxation of the navicular noted and it followed subtalar release. A moderate cavus deformity was present in 13 other cases (Meary's angle between 6° and 23°).

Discussion

The late results of the whole series confirmed the correctness of the concept of calcaneal rotation under the talus. That new concept has since been verified by McKay,[3] Simons,[9] and Bensahel et al.[1] This study demonstrates that in previously-unoperated feet (group I) the extensive soft tissue release without subtalar release gives the best results. Recurrence, over-correction, and pain were significantly more frequent after subtalar release.

In previously operated feet (group II) there was no significant difference between the two subgroups with and without subtalar release. In group II, the poor results were explained by other factors, i.e, stiffness and triceps weakness in relation to repeated surgery. In group II, if we eliminate the functional criteria, the results according to morphologic criteria are more satisfactory with subtalar release. We can consider that opening the subtalar joint may be necessary to obtain good correction of the deformities of previously operated feet.

The majority of authors believe that subtalar release is a necessary component of clubfoot surgery in order to correct the horizontal rotational abnormality of the calcaneus.[4,9,10] However, our experience demonstrates that it is possible to correct a clubfoot without subtalar release, while retaining the interosseous ligament and the sheaths of the flexor retinaculum under the tibial malleolus (Figure 15.1). We

can then preserve the vascularization of the talus and the mobility of the hindfoot.

In conclusion, the extensive soft tissue release without opening the subtalar joint is an effective surgical method of correction of the abnormalities of previously unoperated clubfoot.

Summary

The purpose of this study is to evaluate the influence of opening the subtalar joint on the results of the extensive soft tissue releases for idiopathic clubfeet. The surgical release was performed in 46 patients with 58 clubfeet. All procedures were performed by the same surgeon during the period from 1974 to 1979, according to the concept of calcaneal rotation under the talus with posterolateral and anteromedial release.

Group I consisted of 30 previously unoperated feet; the mean age at the time of surgery was 1 year 4 months and the mean follow-up was 10 years 10 months. Group II consisted of 28 previously unoperated feet; the mean age at the time of surgery was 3 years 10 months and the mean follow-up was 9 years 6 months.

This study demonstrates that in previously unoperated feet (group I) the extensive soft tissue release without subtalar release gives the best results. Recurrence, overcorrection, and pain were significantly more frequent after subtalar release.

In previously operated feet (group II) there was no significant difference between the two subgroups with and without subtalar release. We therefore concluded that in previously unoperated feet the extensive soft tissue release without opening the subtalar joint is an effective surgical method of correction of clubfoot.

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Comparison of Older with Newer Surgical Techniques for Talipes Equinovarus

A. Dimeglio

The experience of the Montpellier team is based on 513 clubfeet followed for more than 15 years. The results have continued to improve with time. Experience and technical refinements have been the deciding factors in the progressive improvement.

The authors noted 59% good and excellent results in cases operated on prior to 1975. In 1990, this figure has risen to 88% for all categories of clubfeet. Prior to 1975, fair results accounted for 29% of the total. In 1990, there were 10%. In 1975, poor results made up 12% of all cases, second procedures being required in 30%. In 1990, the authors reported 2% poor results with less than 10% requiring second operations.

From 1975 to 1980, the authors advocated early surgery (before the 3rd month of life, and even neonatal surgery). Such surgery was justified considering the limited improvement obtained with casts or physiotherapy. However, neonatal surgery did not live up to expectations. The reduction achieved with surgery was spectacular, but late recurrence was frequent. At age 1, poor results represented 10% of the total; at age 5 they exceeded 25%. Subsequent surgery was needed in 40% of the feet operated during the neonatal period. The results therefore deteriorated with time. The reason for these disappointing results was that extensive dissection was required to correct the foot. This resulted in postoperative fibrosis with progressive stiffness. The postoperative fibrous reaction is all the more intense when the child is young. For this reason, the authors discontinued surgery before the 3rd month.

Between 1980 and 1985, 175 clubfeet were operated on after the age of 3 months. The results improved considerably. These operations were limited, with preservation of the tendon sheaths and with as little dissection as possible.

The operation was carried out according to Turco's principles.[2,3] However, it was modified. Some procedures, which could be called mini-Turco, were slightly more limited and included a posterior and medial release. Others could be regarded as maxi-Turco procedures, with posterior, medial, plantar, and lateral releases. The results were as follows: for all categories of feet, good results 79%, fair results 13%, and poor results 8%.

However, after 1985, the authors progressively modified the technique and adopted the procedures proposed by Simons.[1] Surgery became even more selective and varied for each (of the author's) category of clubfeet (stiff-stiff foot, stiff-soft foot, soft-stiff foot, soft-soft foot) (see Chapter 3). Surgery on the posterolateral aspect of the foot became more accurate, with careful dissection of the peroneal tendon sheaths and the posterolateral fibrosis. The subtalar joint was more systematically opened. The approach on the lateral aspect of the foot, in the calcaneocuboid region, became more frequent. The authors then witnessed further improvement in their results, and produced 88% good results, 10% fair results, and 2% poor results.

On the basis of this evolution, my conclusions are as follows:

1. Incomplete surgery often yields poor results. Before 1985, the so-called mini-Turco procedure was used in 18% of cases; now it is performed in about 8% only.
2. Only very precise surgery preserving the tendons and sheaths can prevent postoperative fibrosis.
3. Better correction can be achieved by opening the subtalar joint.
4. Surgery on the lateral aspect of the foot and the calcaneocuboid joint improved the results in severe cases (stiff-stiff foot and stiff-soft foot). This procedure was used in 24% of cases before 1985, and now is used in more than 40%.

Summary

The results of the author's cases are compared at 5-year intervals: before 1975, between 1975

and 1980, between 1980 and 1985, and after 1985. Before 1975, Turco's procedure was used. Between 1975 and 1980, early surgery, including neonatal surgery, was emphasized. After 1980, more varied procedures were used and neonatal surgery was abandoned. Mini- and maxi-Turco procedures were performed. After 1985, the complete subtalar release (CSTR) was used and modified with selective surgery being performed for each of the author's four categories of foot deformity. Each half-decade showed a progressive improvement in results.

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Clubfoot: Experience at the University of South Alabama Medical Center

P. Nimityongskul, L.D. Anderson, F.N. Meyer, J.B. Ray, and D.E. Herbert

Nonsurgical treatment of clubfeet should always be attempted initially; however, when adequate nonsurgical treatment fails to correct the deformities, surgery is usually indicated.[4,16] Since Turco[18] first introduced the one-stage posteromedial release (PMR) for resistant clubfeet in 1971, the procedure has been widely used and supported.[1,9,13,17,19]

A more common problem with the posteromedial release is incomplete correction or undercorrection, resulting in residual metatarsus adductus, hindfoot varus, equinus or talonavicular subluxation, and in-toeing gait.[14] Thompson et al.[17] reported no cases of overcorrection following the one-stage PMR in 93 feet. McKay[10] presented a new approach to clubfoot treatment in which he stressed the concept of abnormal horizontal calcaneal rotation. The importance of calcaneal rotation has been supported by Ghali et al.[8]

Simons[14] in 1985 presented a "complete subtalar release" (CSTR). In principle, his concepts and procedures agreed with those of McKay.[10] At the present time, CSTR appears to be the most extensive single-stage release for clubfeet.

In this report, we reviewed and compared the results of PMR (16 feet) and CSTR (12 feet) performed at the University of South Alabama Medical Center between 1977 and 1989.

Materials and Methods

Nineteen patients (28 feet) underwent clubfoot release because of failure to obtain a satisfactory correction by serial casting. Two groups of patients (profiled in Table 15.2) were identified. Group I (1977 to 1984) consisted of 16 feet in 11 patients who underwent one-stage PMR as described by Turco.[18] The approach used in this group was the medial longitudinal incision with vertical extension along the Achilles tendon.

Group II (1985 to 1989) consisted of 12 feet in 8 patients who had the more extensive one-stage release as described by McKay[10] and Simons,[14] the so-called complete subtalar release (CSTR). The approach used in this group was the Cincinnati incision described by Crawford et al.[5] All operative reports were reviewed to determine which structures were released or lengthened (Table 15.3).

Results were evaluated clinically and radio-

TABLE 15.2. Data on the two groups of patients.

	Group I 1977–1984	Group II 1985–1989	Groups I & II 1977–1989
No. of patients	11	8	19
No. of feet	16	12	28
No. of patients w/ unilat. clubfoot	6	4	10
No. of patients w/ bilat. clubfoot	5	4	9
No. of blacks	5	5	10
No. of whites	6	3	9
Age at surgery—mo. range	5–45	6–24	5–45
average	10.6	13.7	11.9
Follow-up—mo. range	98–161	24–69	24–161
average	104.9	45.25	79.45

TABLE 15.3. Percentage of structures released or lengthened (as indicated in the operative reports).

	Group I 1977–1984	Group II 1985–1989	Groups I & II 1977–1989
1. Tendoachilles lengthening	100%	100%	100%
2. Post. tibialis lengthening	100	100	100
3. Flexor hallucis longus lengthening	69	83	75
4. Flexor digitorum longus lengthening	69	83	75
5. Anterior tibialis transfer	12	0	7
6. Adductor hallucis and plantar fascia release	12	50	29
7. Subtalar capsulotomy			
Posterior	100	100	100
Medial	62	83	71
Anterior	50	17	36
Lateral	0	42	18
8. Ankle capsulotomy			
Posterior	100	100	100
Medial	0	0	0
Anterior	0	0	0
Lateral	12	25	18
9. Interosseous talocalcaneal ligament release	31	25	29
10. Deltoid ligament release			
Superficial	87	58	75
Deep	0	0	0
11. Talonavicular capsulotomy			
Medial	81	75	78
Dorsal	75	67	71
Plantar	25	75	46
Lateral	12	0	7
12. Calcaneofibular ligament release	56	75	64
13. Post. talofibular ligament release	37	50	43
14. Calcaneocuboid capsulotomy	6	0	4
15. Master knot of Henry release	44	50	46
16. Spring ligament	44	42	43
17. Bifurcate ligament release	44	17	32
18. Number of pins used			
0	0	17	7
1	6	67	32
2	87	17	57
3	6	0	4

TABLE 15.4. Follow-up range of motion (ROM) of ankle and hindfoot expressed as percentage of normal.

		Dorsiflexion (DF)	Plantar flexion (PF)	DF + PF	Inversion (IN)	Eversion (EV)	IN + EV	Total ankle and hindfoot ROM
Group I	Range	0–75	25–87	25–83	17–67	0–75	10–70	18–77
	Average	39	62	55	42.6	43.7	43	50
Group II	Range	50–100	50–87	50–92	33–67	50–100	40–90	45–82
	Average	77	76	76	60	75	64	71
I & II	Range	0–100	25–87	25–92	17–67	0–100	10–90	18–82
	Average	55	68	64	50	54	53	59

*$p < .0001$; †$p = .001$.

TABLE 15.5. Data on result of bimalleolar/foot axis residual metatarsus adductus, heel varus/valgus and ability to stand on tiptoe.

		Bimalleolar/foot axis (degrees)*	Residual metatarsus adductus (degrees)†	Residual heel varus (−) or valgus (+) (degrees)‡	Ability to stand or walk on tiptoes**
Group I	Range	60–80	0–18	−5 to +5	0 to 2
	Average	72	7.8	+0.2 (valgus)	1.18
Group II	Range	70–85	0–13	−3 to +10	0 to 2
	Average	80	3.3	+3.1 (valgus)	1.6
I & II	Range	60–80	0–18	−5 to +10	0 to 2
	Average	75	5.9	+1.4 (valgus)	1.35

*Normal 85°–90°, $p = .0003$; significant.
†Measured on foot tracing. Heel bisector against 2nd toe axis; $p = .02$; significant.
‡Normal heel 0 to +5 (valgus); insignificant; both fall within normal range.
**0, cannot rise on tiptoe; 1, can but weak; 2, normal; $p = .05$.

TABLE 15.6. Data on foot size (unilateral cases only).*

	Loss in length (percentage of normal foot length)		Loss (−) / gain (+) of width (percentage of normal width)	
	Range	Average	Range	Average
Group I ($n = 6$)	11% to 14%	12%	0% to +23%	+4.5%
Group II ($n = 4$)	3% to 22%	12%	−1 to −10%	−3.5%
I & II ($n = 10$)	3% to 22%	12%	−10 to +23%	+1.4%

*Shows the loss or gain in length and width of the foot at follow-up in each group. Only the unilaterally involved cases are used to calculate this.
Data too few to be statistically meaningful. On average, foot is 12% shorter and slightly (1.4%) wider.

graphically and the incidence of secondary procedures required in each group was compared. Six clinical parameters (Tables 15.4–15.6) and six radiographic parameters (Tables 15.7 and 15.8) were used to evaluate the results.

Clinical Evaluation Parameters

The following clinical parameters were evaluated:

1. Range of motion of the ankle and hindfoot (primarily the subtalar joint). This was measured according to the methods described in the AMA *Guides to the Evaluation of Permanent Impairments*[7] (Figure 15.2).
2. Bimalleolar-foot angle as described by McKay.[10] This is the angle formed by the bimalleolar axis and the axis of the foot (Figure 15.3).
3. Metatarsus adductus angle. This angle was

TABLE 15.7. Improvement in anteroposterior talocalcaneal (APTC) and lateral talocalcaneal (Lat. TC) angles talocalcaneal, measured in degrees.

		Group I	Group II	Groups I & II
Preoperative	Range	0–15 ($n = 8$)*	5–21 ($n = 7$)†	0–21 ($n = 15$)
APTC angle	Average	10.1	9.0	9.6
Postoperative	Range	13–43	16–44	13–44
APTC angle	Average	23.1	26.1	24.4
Preoperative	Range	0–22 ($n = 7$)	5–25 ($n = 8$)	0–25 ($n = 15$)
Lat. TC angle	Average	12.6	15.9	14.3
Postoperative	Range	16–44	32–54	16–54
Lat. TC angle	Average	30.9	38.8	34.3

*Due to a flood in the city in early 1980, some x-rays were permanently damaged and discarded. This results in incomplete data on the preoperative AP and lateral talocalcaneal angle of some patients.
†Only seven cases have complete x-rays for this measurement.

TABLE 15.8. Percentage of unsatisfactory radiographic results in talocalcaneal divergence, navicular position on AP and navicular position.

	Talocalcaneal divergence*	AP navicular postion†	Lateral navicular postion†
Group I ($n = 16$)	69%	25%	19%
Group II ($n = 12$)	8%	0%	33%
I & II ($n = 28$)	46%	14%	25%

*$p = .0009$, significant.
†Not significant.

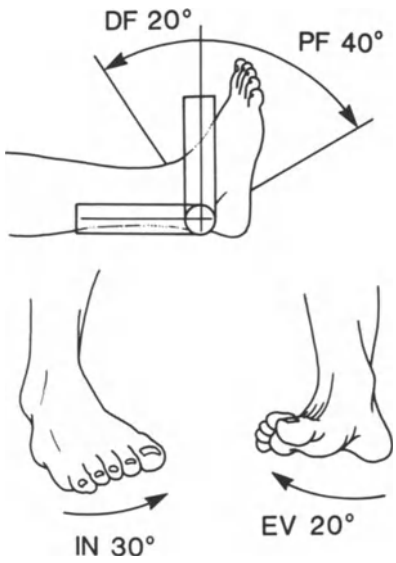


FIGURE 15.2. Normal ranges of motion of ankle and hindfoot. DF, dorsiflexion; PF, plantar flexion; IN, inversion; EV, eversion.

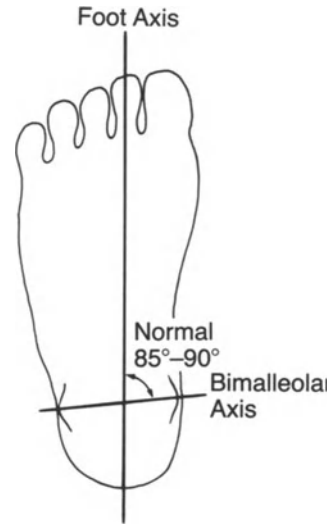


FIGURE 15.3. Bimalleolar/foot angle is the angle between the bimalleolar axis and the foot axis (according to McKay[10]).

measured on the foot tracings using the heel bisector line described by Bleck[2] and the axis of the second ray (Figure 15.4).

4. Residual heel varus or valgus on weight-bearing. This is estimated using the method described by Bleck[3] (Figure 15.5).
5. Gross evaluation of plantar flexor strength. This is estimated by asking the patient to stand or walk on tiptoes. Points were given as follows: 0, cannot walk on tiptoes; 1, walks on tiptoes weakly; 2, walks on tiptoes normally.
6. Difference in foot sizes. Measurements on foot tracings were compared with the nor-

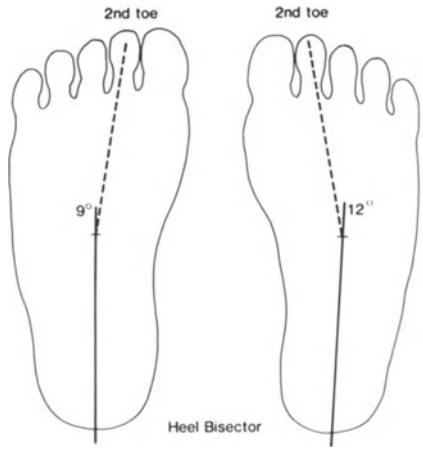


FIGURE 15.4. Metatarsus adductus angle is the angle between the heel bisector line and the axis of the 2nd ray.

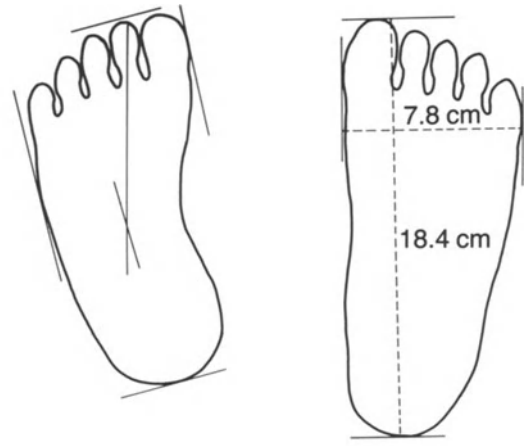


FIGURE 15.6. Measurement of foot length and width on foot tracing.



FIGURE 15.5. Estimation of residual heel varus or valgus on weight-bearing (according to Bleck[3]).



FIGURE 15.7. AP talocalcaneal angle.

mal foot in unilaterally involved patients (Figure 15.6).

Radiographic Evaluation Parameters

The following radiographic parameters were evaluated:

1. Improvement of the anteroposterior talocalcaneal (APTC) angle (Figure 15.7).
2. Improvement of the lateral talocalcaneal (Lat. TC) angle (Figure 15.8).

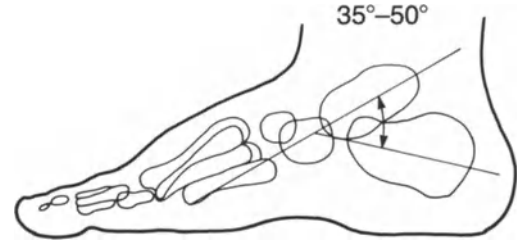


FIGURE 15.8. Lateral talocalcaneal angle (modified from Simons,[14] who uses the plantar surface rather than the long axis as one side of the angle).

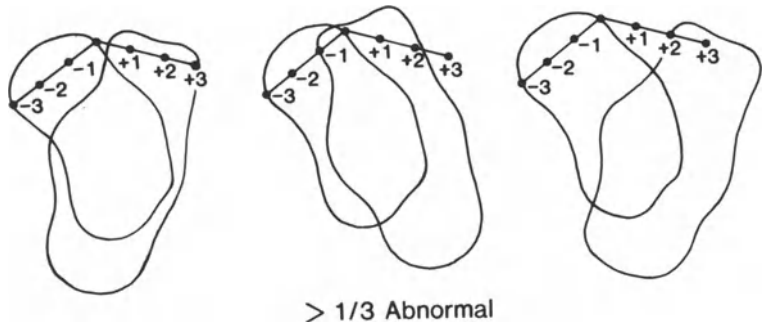


FIGURE 15.9. AP talocalcaneal angle divergence (modified from Simons).[14]

3. Talocalcaneal divergence on AP x-rays of the foot (Figure 15.9). The talus and calcaneus normally overlap about 25% on AP x-rays of the foot, according to Simons.[14] More than 25% divergence is considered abnormal and indicates overcorrection of the hindfoot (varus). However, our measurements revealed that up to 35% of talocalcaneal divergence is quite common in the normal foot. Therefore, we used a modified criteria of more than one-third divergence between the talus and calcaneus instead of one-fourth as an unsatisfactory result.
4. Navicular position on the anteroposterior view.[14] Simons considers this unsatisfactory if the navicular deviates medially more than one-fourth the diameter of the talar head (this indicates medial talonavicular subluxation) or deviates laterally more than one-half the diameter of the talar head (this indicates lateral talonavicular subluxation) (Figure 15.10). Where the ossific nucleus of the navicular was absent, on the AP view, deviation of the talar axis of more than one full width of the base of the 1st metatarsal is considered an unsatisfactory result (major complication) by Simons.
5. Navicular position on the lateral view.[14] This is considered unsatisfactory if the navicular ossification center deviates more than one-third of the height of the ossified navicular above the talar head (Figure 15.11). Where the ossific nucleus of the navicular was absent, lines were drawn through the talar axis and along the 1st metatarsal axis. The distance between these two parallel lines represents the distance that the navicular is dorsally subluxated. Grades are determined by comparing the distance between the two lines to the height of the talar head, i.e., zero to one-third, +1; one-third to two-thirds, +2; and two-

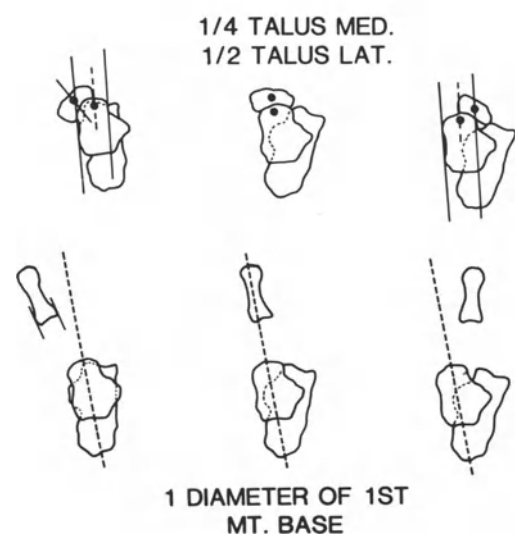


FIGURE 15.10. AP navicular position according to Simons.[14]

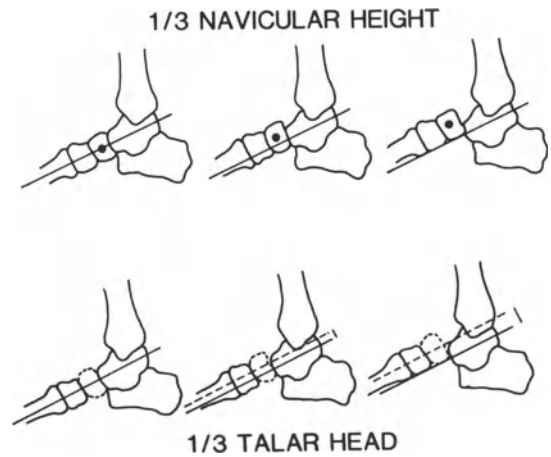


FIGURE 15.11. Lateral navicular position according to Simons.[14]



FIGURE 15.12. An example of flattop talus.

thirds to one, +3.* Occasionally, overlapping metatarsals make identification of the 1st metatarsal impossible. In that case, a line along the superior surface of the most dorsal metatarsal may be used. If it passes above the talar head, the navicular is dorsally subluxated. Normal position is graded zero, +1 position is satisfactory, and more than +1 is unsatisfactory. In the presence of a cavus deformity, this measurement is unreliable (Figure 15.11).

6. The presence or absence of flattop talus was also compared in the two groups of patients (Figure 15.12).

Results

Structures Lengthened or Released in Groups I and II

We would expect that the complete subtalar release group (group II) would have a higher percentage of structures released and lengthened. However, as documented in our operative reports (Table 15.3), the PMR group (group I) had a higher percentage of superficial deltoid ligament releases, anterior subtalar capsulotomies, and lateral talonavicular capsulotomies. Although the calcaneofibular ligament should be released in 100% of patients in group II (if the techniques described by Simons and McKay were strictly followed), it was released in only 56% in group I and in only 75% in group II. The interosseous talocalcaneal ligament was released in 31% of the patients in group I and 25% in group II (an overall average of 29%). The operative reports showed that no patient in either group had the deep deltoid ligament released. Calcaneocuboid capsulotomies were performed in 6% of patients in group I and none in group II. We believe this may reflect the dictating surgeons' failure to report all the structures that were released.

Clinical Results

Ankle Range of Motion (Table 15.4)

A normal ankle has a range of motion of 60° in the sagittal plane, which consists of 20° of dorsiflexion and 40° of plantar flexion.[7] Stauffer et al.[15] noted that the stance phase of gait in normal walking requires a minimum range of motion of 10° of ankle dorsiflexion and 15° of plantar flexion—or a total minimum normal range of ankle motion of 25° (42% of the total normal range of motion). Group I had 55% of the normal ankle range of motion; group II had 76%. Both exceeded the 42% minimum range of motion required for walking. This may explain why, despite a range of motion significantly less than normal, our patients continued to walk with little or no problem.

In group I, there was about 40% of normal

*This measurement is no longer used. The talar aixs–1st metatarsal base relationship is now used; i.e., the talar axis normally crosses the base of the 1st metatarsal. The distance above or below the base of the 1st metatarsal determines the amount of dorsal or volar subluxation. See Cummings et al., Chapter 3—ED.

ankle dorsiflexion and about 60% of normal plantar flexion. In group II, there was an average of 75% of both normal dorsiflexion and normal plantar flexion; the difference was statistically significant ($p < .0001$).

In group I, there was about 40% of normal inversion of the hindfoot and, in group II, 60% of normal inversion of the hindfoot. In group I, eversion was about 40% of normal, and in group II, eversion was 75% of normal. The difference was significant ($p = .0001$). In group I, there was about 45% of normal subtalar motion in both inversion and eversion of hindfoot (primarily the subtalar joint) and, in group II, about 65% percent of normal subtalar motion.

The average total range of ankle and subtalar motion in group I was 50% and in group II approximately 70%. When groups I and II were combined, there was an average of 60% of the total normal range of motion for the ankle and hindfoot.

Bimalleolar/Foot Axis, Residual Metatarsus Adductus, Residual Heel Varus and Valgus, and Plantar Flexor Strength (Table 15.5)

The bimalleolar/foot axis averaged 72° in group I and 80° in group II. The difference was significant ($p = .0003$). Residual metatarsus adductus averaged 7.8° in group I and 3.3° in group II. This was also statistically significant ($p = .02$).

Residual heel varus or valgus were not significant in the two groups, since both fell within the normal range of 0° to 5° valgus. The gross estimation of plantar flexor strength (the ability to stand or walk on tiptoes) also showed that the CSTR group was statistically better ($p = .05$) than the PMR group.

Foot Size (Table 15.6)

Both the PMR and CSTR groups had a smaller foot (an average of 12% less than normal). However, group I had a slightly wider foot (4.5% wider) when compared to the normal opposite foot, and group II had a slightly narrower foot (3.5% narrower). This measurement reflects the higher degrees of residual forefoot adduction in group I. We do not consider the data in this measurement parameter statistically significant. In bilateral clubfeet, the foot that looks and feels better to the patient and parents is usually the longer and wider foot as measured by foot tracings.

Radiographic Results

APTC and Lat. TC Angles (Table 15.7)

The average improvement of APTC angle postoperatively in group I was 13°, and 17° postoperatively in group II. Although group II appears to have a better average improvement in this angle, due to the small numbers of x-rays available for these measurements, the difference was not significant. The Lat. TC angle improved from 12.6° to 30.9° in group I and from 15.9° to 38.8° in group II. The difference was statistically significant ($p = .0009$). Turco[19] believed that improvement in the Lat. TC angle was the most useful and reliable index in surgical treatment of clubfeet.

In this entire study, the APTC angle improved an average of approximately 15° and the Lat. TC angle improved an average of approximately 20°.

Talocalcaneal Overlap and Navicular Position on AP and Lateral Views (Table 15.8)

Measurements of AP-talocalcaneal divergence showed that the PMR group had 69% unsatisfactory and the CSTR group had 8% unsatisfactory results. The difference was significant.

The AP navicular position was unsatisfactory in 25% of the patients in the PMR group and all were satisfactory in the CSTR group. The lateral navicular position was unsatisfactory in 33% of patients in the CSTR group and 19% in the PMR group. The unsatisfactory results in the navicular positions of both groups were not statistically different in either the AP or lateral x-rays. The follow-up in group II was shorter and, in most cases, the navicular had just begun to ossify or had not yet ossified. We believe this makes measurements of group II patients less reliable than those in group I, where the navicular is much better developed and easier to measure on the radiograph.

Although there is a high percentage of unsatisfactory radiographic results in this category, our review showed no definite correlation between this radiographic measurement and pain, function, or limitation of activities.

Complications

Flattop Talus

A true flattop talus following clubfoot treatment is believed to be the result of forced dorsiflexion of the ankle against a tight posterior structure, producing a so-called nutcracker effect.[4] This complication was noted in 10 of 16 or 62.5% of group I patients and 1 of 12 or 8.3% of group II patients. The incidence of flattop talus for the whole series was 11 of 28 feet or 39.3 percent.

The high incidence of flattop talus in group I most likely represents an undercorrected or incompletely corrected foot that was forced into dorsiflexion by subsequent casting or ambulation. Dunn and Samuelson,[6] reporting the long-term results of flattop talus, found that it commonly followed closed treatment of clubfoot, but does not correlate with pain or function. Our results agree with this finding.

Skin Problems Following Cincinnati Incision

None of the patients in group I or II had problems with wound healing or skin necrosis.

Secondary Procedures

Secondary procedures were required in 6 of 16 feet or 37.5% in group I: a Heyman-Herndon procedure and plantar fascia release (one foot); repeat Achilles tendon lengthening, posterior capsulotomy, and supramalleolar osteotomy (one foot); abductor hallucis release and plantar fascia release (two feet); metatarsal osteotomies and plantar fascia release (two feet).

Another 3 of 16 feet or 19% are being considered for secondary procedures. Overall, approximately 55% of patients in group I had, or will have, secondary procedures.

The group II feet have not yet required a secondary procedure. However, 3 of 12 feet or 25% were noted to have mild residual metatarsus adductus. Two of these three feet may need a secondary procedure for this deformity. Although the follow-up in group II is shorter (average 45 months vs. 104 months in group I), most of the residual deformities in group I were observed within 18 months after surgery. On this basis, we believe there will not be a substantial change of results in group II with longer follow-up. However, this remains to be seen, and we intend to follow all the patients to at least skeletal maturity.

Functional Results

A plantar grade, painless, functional foot is the goal in the surgical treatment of clubfeet; however, this goal is rarely, if ever, achieved.[1,9,12,14,19] Most of our patients continue to walk and function with mild discomfort, have occasional mild pain with strenuous activity, wear normal shoes, and are generally active.

Discussion

The one-stage surgical release of clubfoot has gained worldwide popularity since the introduction of the one-stage posteromedial release by Turco[18,19] and the complete subtalar release by McKay[10–12] and Simons.[14] Yet, the best surgical method remains a subject of controversy. More controversial is the best method for evaluating the results of clubfoot treatment.

There are many variables involved in the treatment and evaluation of results in clubfoot: differences in degree and severity of pathology in each clubfoot, differences in method and duration of conservative treatment, differences in the thoroughness of each step of surgical release, and differences in postoperative immobilization. The measurement of range of motion of hindfoot and subtalar joints, at best, only approximates the true motion. These variables make it difficult to draw a definite conclusion in a study like this.

In our 29 clubfeet, we had better correction with the more complete subtalar release procedure advocated by McKay and Simons than with the Turco posteromedial release.

Our data indicate that the posteromedial release resulted in a slightly undercorrected foot and the complete subtalar release resulted in a corrected or sometimes slightly overcorrected foot. This is demonstrated by the significant improvement in the range of motion of the subtalar joint, significant improvement in the bimalleolar/foot axis, reduction of residual metatarsus adductus, and slightly higher degrees of residual heel valgus in the CSTR group. The radiographic parameters also show

significant improvement in the complete subtalar release group over the posteromedial release group.

The Cincinnati incision provided better exposure for more complete posterior and lateral release than the longitudinal-vertical incision used by Turco. The Cincinnati incision also provides an easier approach to the posterior and lateral structures and allows more complete releases of the posterior and lateral subtalar capsules. We have performed the Cincinnati approach with the patient in both the supine and the prone position and have found that the prone position allows better access to the subtalar joint and does not interfere with access to the medial aspect of the foot. Although our experience is limited (29 cases), it agrees with that of Crawford et al.,[5] McKay,[12] and Simons.[14]

Despite our better results with the complete subtalar release group, both the posteromedial release and the complete subtalar release resulted in a functional foot without major physical handicaps. All of these children are in general active and able to wear regular shoes with minor adjustments.

We realize in this retrospective study that our results with the complete subtalar release group may partly reflect the "learning curve" in the operative treatment of clubfoot at our institution. In conclusion, our experience indicates that the more extensive one-stage complete subtalar release appears to give a better result than the one-stage posteromedial release.

Summary

Between 1977 and 1989 at the University of South Alabama Medical Center, two groups of children with clubfeet were operated on, with follow-up ranging from 2 to $13\frac{1}{2}$ years, an average of 79 months. Group I (16 feet, average follow-up 104 months) underwent a modified Turco posteromedial release. The functional results were satisfactory in general, but approximately one-third of this group required a second procedure to correct persistent intoeing or residual metatarsus adductus.

Group II (12 feet, average follow-up 45 months) underwent a modified complete subtalar release (McKay and Simons) utilizing the Cincinnati incision. So far no patient in this second group required a second procedure.

Although follow-up in group II is much shorter than in group I, we believe that 2 years of minimum follow-up in group II is meaningful, since most of the recurrence or residual deformities were noticed within 18 months following surgery. The Cincinnati incision allowed better exposure and a more complete release. Skin-flap necrosis was not a problem in this series.

In our experience, the more complete subtalar release procedure of McKay and Simons resulted in better correction than the Turco posteromedial release.

Acknowledgment

The authors wish to thank Sarah O'Donnell for her help in the preparation of this manuscript.

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Evaluation of Surgical Treatment in Resistant Clubfoot: A Comparison of the Turco, Carroll, and Cincinnati Approaches

S. Porat

Evolution of clubfoot surgery has been developed from minimal surgery, such as Achilles tendon lengthening,[9] to the most radical complete release.[10,12,13] The modern principles of surgical treatment of resistant clubfeet were introduced by Bradford[2] in 1892 and Codivilla[7] in 1906. Brockman[3,4] described his extensive soft tissue release, carried out in two stages, in 1930. Attenborough[1] stressed the importance of early surgical release in order to prevent bone deformities. Turco[14–16] performed his radical release in one stage. His approach was a turning point in the ongoing process of improving the surgical techniques in clubfoot surgery.

Carroll et al.[5,6] further developed the surgical technique by adding the release of the lateral tether, including the calcaneocuboid joint, and splitting the incision into two parts.

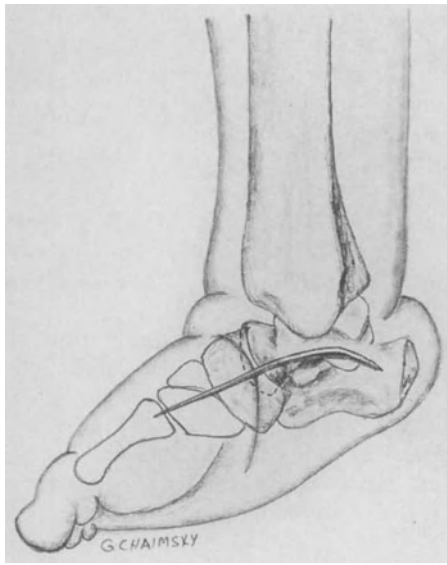
Crawford et al.[8] introduced the Cincinnati incision, a circumferential incision the length and extensibility of which varies according to the individual case. The incision is the most commonly used for clubfoot surgery in North America and in some other parts of the world.

Purpose

The purpose of this paper is to compare three extensive surgical procedures, delineate their indications, and stress the advantages and disadvantages of each.

Initial Treatment and Indications for Surgical Treatment

We start treatment with manipulations and casting immediately after birth. By 6 weeks, we are usually able to define the resistant clubfeet that will later receive a surgical release. The in-



A



B

FIGURE 15.13. The medial incision in Carroll's approach. A: Schematic representation. B: Intraoperative marking before incising the skin.

dication for surgery is failure of the manipulative and cast treatment.

The exact timing of surgery is decided upon according to the baby's development and the size of the foot, although most babies have surgery between 4 and 6 months of age.

We used Turco's approach until 1981. Between 1981 and 1988, Carroll's approach was the technique of choice, but the Cincinnati incision has been used since 1988.

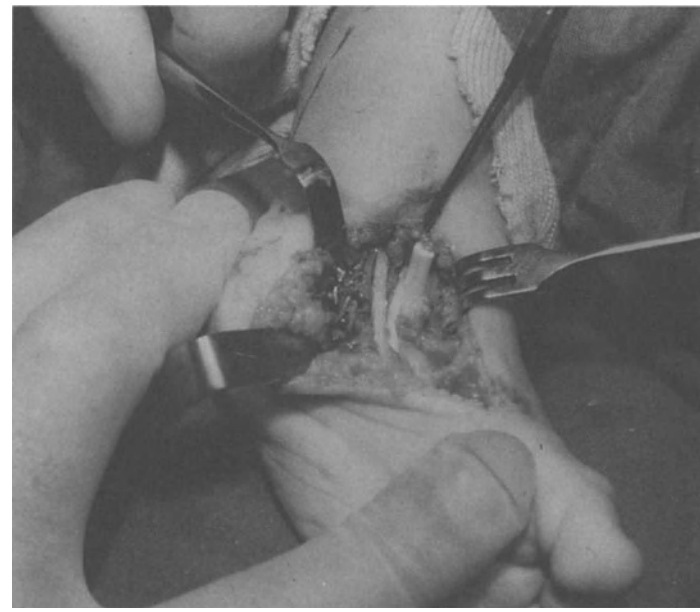
At present, we use both Carroll's and the Cincinnati approaches for the primary surgical release, whereas for the revision cases only the Cincinnati approach is used.

Turco's[14–16] surgical technique is not described in this paper as we have not used it since 1981.

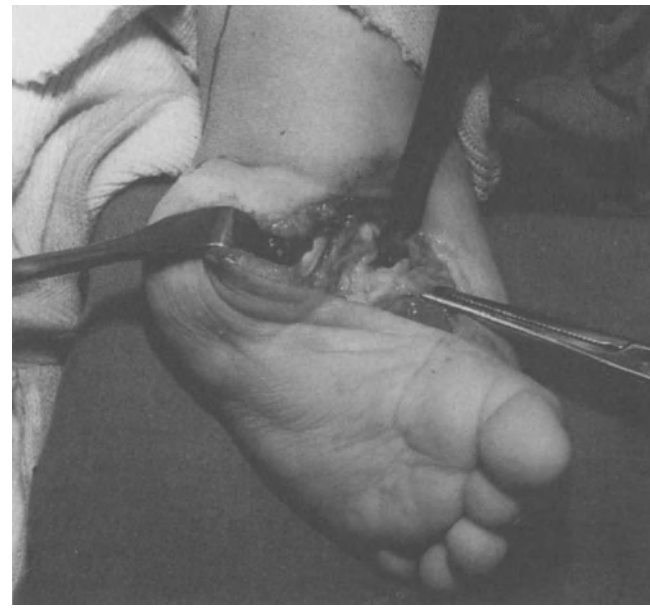
Carroll's Technique

Before the baby is positioned prone, a pneumatic tourniquet is applied in supine position. When prone, the pelvis is raised by a small folded towel on the contralateral side of the clubfoot. The first part of the operation is the medial plantar release. The incision begins at the base of the 1st metatarsus and continues to the anterior border of the heel. It is located between the medial and plantar aspects of the foot (Figure 15.13). The skin flaps are raised by deep dissection at the level of the deep fascia in order to preserve their blood supply. The abductor hallucis muscle is released from its origin and excised. The fascia covering the neurovascular bundle is longitudinally incised and the neurovascular bundle is isolated and raised on a vascular loop. The bifurcation of the posterior tibial nerve is found and the lateral plantar nerve is traced plantarly and laterally. In cases where plantar fasciotomy is indicated, the plantar fascia is isolated superficially and deeply, taking care to avoid injury to the lateral plantar nerve and to the plantar skin. The plantar fascia is incised posteriorly, just anterior to the calcaneus with a Mayo scissors.

The dissection is now carried to the plantar aspect of the foot by retracting the nerves and blood vessels plantarward. Mobilization of the flexor tendons is performed by release of the tendon sheath and Henry's knot. The tendons are retracted plantarly together with the neurovascular bundle (Figure 15.14). Fatty tissue is cleared by blunt dissection, exposing the plantar aspect of the middle third of the foot where the peroneus longus crosses from posterolateral to the anteromedial border of the foot. The tendon sheath is incised and the peroneus



A

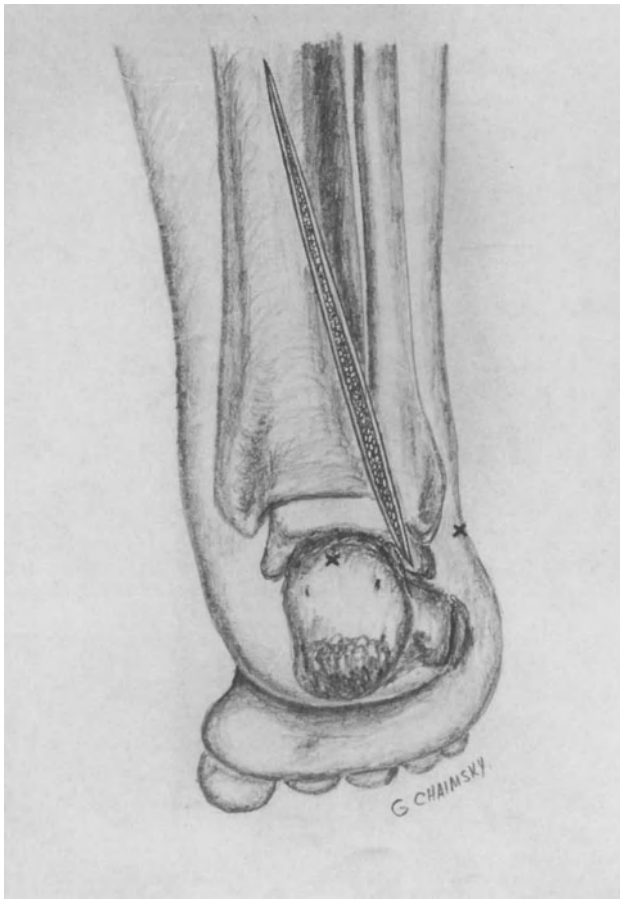


B

FIGURE 15.14. Intraoperative photograph shows different stages in the medial-plantar release in Carroll's approach. A: After mobilization of the neurovascular bundle and flexor tendons, including the tibialis posterior. B: After capsulotomy of talonavicular joint. The blunt dissector is located in the joint.

longus tendon is retracted with the right-angle retractor. Capsulotomy of the calcaneocuboid joint in its plantar, medial, and dorsal aspects is performed. Sometimes the identification of the calcaneocuboid joint is difficult, necessitating capsulotomy first of the talonavicular joint and, thereafter, of the calcaneocuboid joint.

In order to facilitate the talonavicular capsulotomy, the tibialis posterior tendon is identified, its sheath opened, and elongation of the tendon is carried out. The distal stump leads to the navicular, which is usually subluxed medially to the talar head. The capsule of the talonavicular joint is hidden deeply, and only pulling on the navicular exposes this capsule for the initial capsulotomy. Once this initial capsulotomy is performed, a blunt dissector is inserted for further opening of this joint space



A



B

FIGURE 15.15. The posterolateral incision in Carroll's approach. A: Schematic representation. B: Intraoperative marking before incising the skin.

until the capsulotomy is completed (Figure 15.14B). Between the talonavicular and the calcaneocuboid joints a connective tissue bridge is resected, a step that creates the normal space between the bones. Now the midfoot is completely supple and may be reduced anatomically on the hindfoot.

The second part of the operation consists of the posterolateral release. The incision starts halfway between the lateral malleolus and the Achilles tendon, and extends proximally to posterior midline of the calf (Figure 15.15). The sural nerve and vein are identified and protected. Elongation of the Achilles tendon is performed. The posterior neurovascular bundle is identified and isolated, being raised from the periosteum on a vascular loop. Metzenbaum scissors are introduced from the posterior wound toward the medial wound gently freeing the neurovascular bundle from the periosteum by blunt dissection. A right-angle retractor is introduced in the same manner, retracting the neurovascular bundle away from the ankle joint capsule. The flexor hallucis longus is identified and freed from its sheath and retracted with the neurovascular bundle. On the lateral side, mobilization of the peroneal tendons is performed by partial opening of their tendon sheaths. Capsulotomy, usually of the subtalar joint, is done first. It extends from the posterior aspect of the subtalar joint anteriorly to the talonavicular joint medially and calcaneocuboid joint laterally. The interosseous ligament is not incised at this stage. Capsulotomy of the ankle joint is performed with special care to avoid cutting the deep part of

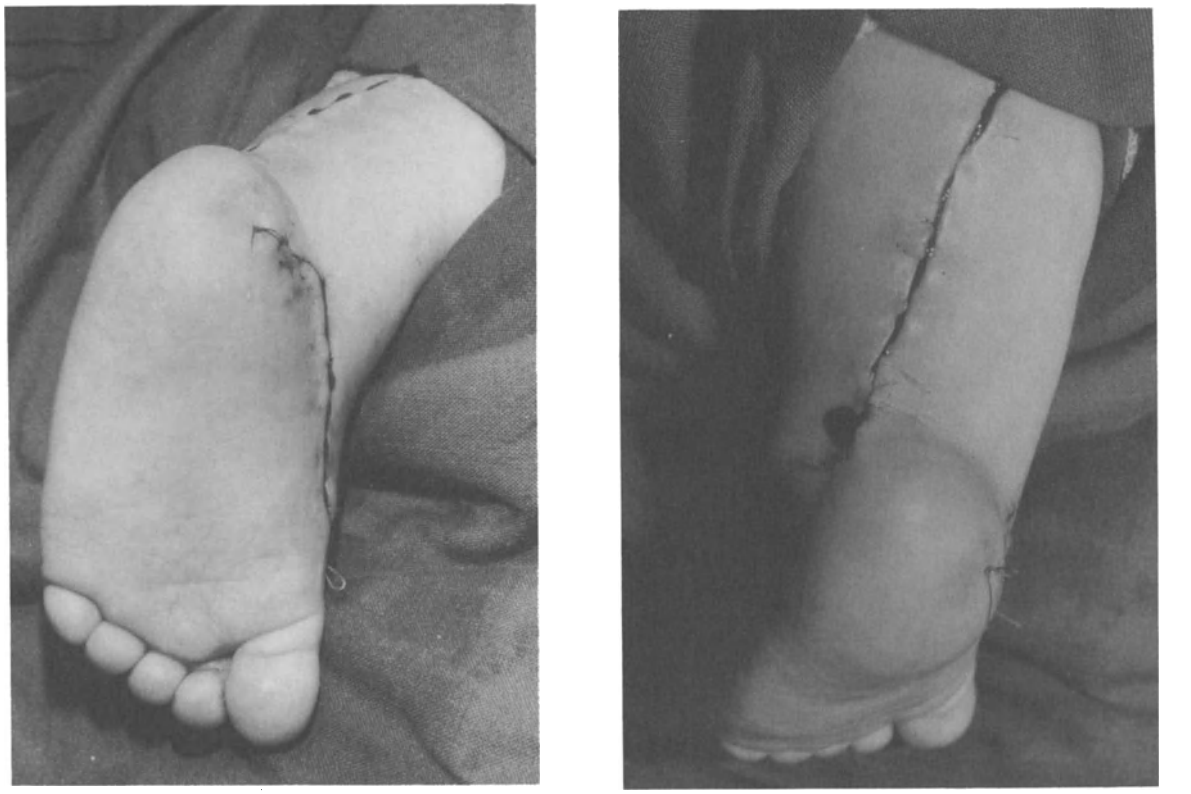


FIGURE 15.16. Clinical photograph of a clubfoot at the end of Carroll's procedure of surgical release. A: Plantar view. B: Posterior view.

the deltoid ligament. On the lateral side incision of the calcaneofibular and talofibular ligaments is the most significant step in the lateral untethering. At this stage, the anatomic reconstruction is carried out. A Kirschner wire is introduced from the posterior aspect of the talus, aiming laterally to exit in the center of the talar head.

This wire is used as a lever arm to rotate the talus around a vertical axis medially. The forefoot is reduced on the hindfoot with special attention to the exact reduction of the talonavicular joint, which is fixed by anterior advancement of the K wire across the joint and through the navicular. If the talus is not free enough to be relocated, further release of the interosseous ligament is performed. Now the calcaneus along with the entire midfoot and forefoot is turned laterally at the subtalar joint, keeping the talus in its corrected position. While doing this, the calcaneus is pushed into a mild valgus position, the tuberosity of the calcaneus is pulled inferiorly, and the anterior part moves superiorly. When performing this anatomic reconstruction, incongruency is often created. The talus and calcaneus are fixed by a vertical Kirschner wire introduced from the plantar aspect of the heel into the talus. The operation is completed by suturing the tibialis posterior tendon, Achilles tendon, subcutaneous tissue, and skin. The Kirschner wires are cut short to be covered by the skin. The tourniquet is released and a soft dressing is applied with equal pressure on all parts of the foot and leg (Figure 15.16). Six days postoperatively an above-knee cast is applied with the foot in the fully corrected position. At 6 weeks postoperatively, the Kirschner wires are removed under local anesthesia and the second cast is applied for another 4 weeks. Afterward, the feet are kept in a counterrotation system (CRS)* (Figure 15.17).

*CRS is a trademark of Langer Biomechanics Group, Inc., Deer Park, NY.



FIGURE 15.17. The counter-rotation system (CRS) of Langer is used after the second cast is removed. It provides efficient, comfortable alignment of the corrected feet, thus helping to maintain the correction.

The Cincinnati Incision

This circumferential incision provides an extensive approach to both the hindfoot and midfoot. The term *Cincinnati incision* applies only to the skin incision. The actual clubfoot release, which is carried out on the deeper structures, is performed according to the personal views and experience of the surgeon as well as to the individual needs of the operated foot. The description of this procedure is as follows:

The skin incision begins at the naviculocuneiform joint and curves posteriorly beneath the tip of the medial malleolus. From there it is carried laterally at the level of the ankle joint parallel to the skin creases. It crosses the lateral malleolus and continues toward the sinus tarsi (Figure 15.18). The length of the anterior part of the incision on both the medial and lateral sides varies according to the planned dissection. The dissection of the skin flaps must be developed deeply in order to preserve their blood supply. First, the Achilles tendon is elongated. Thereafter, the neurovascular bundle is isolated, mobilized, and retracted by a vascular loop. The bundle must be mobilized sufficiently proximally and distally to the plantar aspect of the foot. Laterally, slight mobilization of the peroneal tendons is carried out by a small opening in their tendon sheaths.

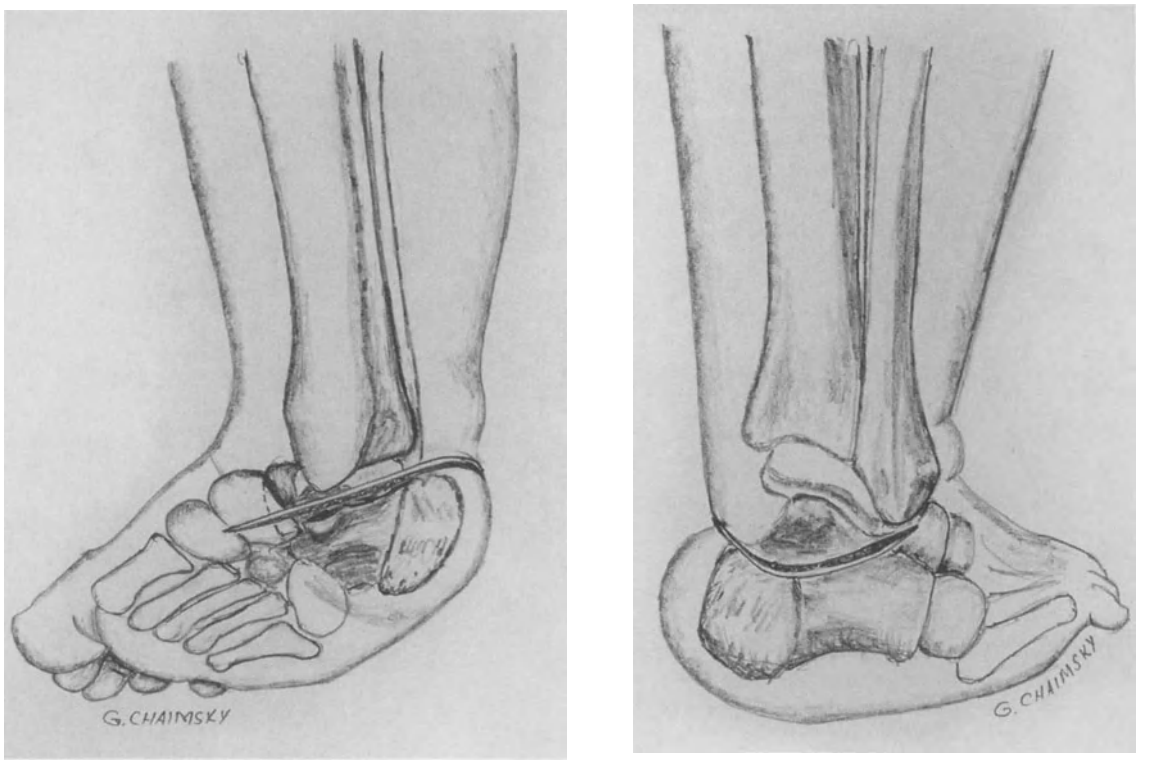
The flexor tendons are also released and mobilized, especially the flexor hallucis longus, before capsulotomy of the subtalar joint is performed. The capsulotomies are performed by Carroll's technique. Figure 15.19 shows the posterior and posteromedial aspect of the foot after capsulotomies.

The calcaneocuboid joint is released from the lateral side in all its aspects, including the fibrous tissue bridge between it and the talonavicular joint. The talonavicular joint and the medial plantar release are performed by anterior elongation of the medial arm of the incision. The anatomic reconstruction is performed by Carroll's technique. When the calcaneus is in severe equinus, the foot is left in less than full correction. One week later, the first cast is applied with the foot in full correction. The postoperative treatment is the same as described with Carroll's technique.

Complications

Skin necrosis occurred in all three approaches. It was most frequent with Turco's and least frequent with Carroll's approach. In the Cincinnati approach (Figure 15.20), it occurs more often in older children and in revision cases. There are three main factors for this complication: (a) superficial dissection of the skin flaps, (b) forceful retraction of the skin edges, and (c) positioning in full correction when the suture line is under tension at the time of closure. Recently, another pathoetiological factor of deficient or abnormal blood supply has been raised to explain postoperative necrosis.

Other complications included Kirschner wire



A B

FIGURE 15.18. Schematic representation of the Cincinnati circumferential incision. A: The posteromedial part. B: The posterolateral part.

migration and skin burn under the tourniquet. During the last 9 years, there were five cases of tourniquet burns.[11] Now we avoid any contact between the tourniquet and the heating mattress. In addition, the tourniquet is wrapped in Steri-drape, which avoids fluid penetration under the tourniquet. The main factor causing this complication now seems to be pressure.

Discussion

Each approach has its advantages and disadvantages. After experience with all three approaches, I conclude that the Cincinnati incision offers more than the other techniques. The differences between the three approaches is not only in the location and shape of the skin incision, but also in wound healing, scar quality, accessibility to the different structures to be released, and completeness of the subtalar release. In Turco's technique, many venous channels are divided in the long curved incision, a situation that might influence the skin healing. The double incision of Carroll provides better wound healing. The scar of Turco's approach is often hypertrophic and contracted, which might lead to recurrent forefoot adduction. The scars of Carroll's approach are usually thin and nonadherent, and they do not contribute to recurrent deformity.

In the Cincinnati incision, the scar is also thick and free from adhesions to the deep tissues if wound necrosis has not occurred. Accessibility to most of the structures that must be released is best with the Cincinnati approach, good with Carroll's, and insufficient with Turco's approach. This is especially true for the lateral tether. Table 15.9 summarizes the advantages and disadvantages of each approach. In recent years much more attention has paid to the calcaneocuboid joint.[5,6,10,12,13] In Turco's approach the calcaneocuboid joint is not dealt with at all, which might contribute to the recurrence of forefoot adduction. In the Cincinnati approach surgery frequently in-

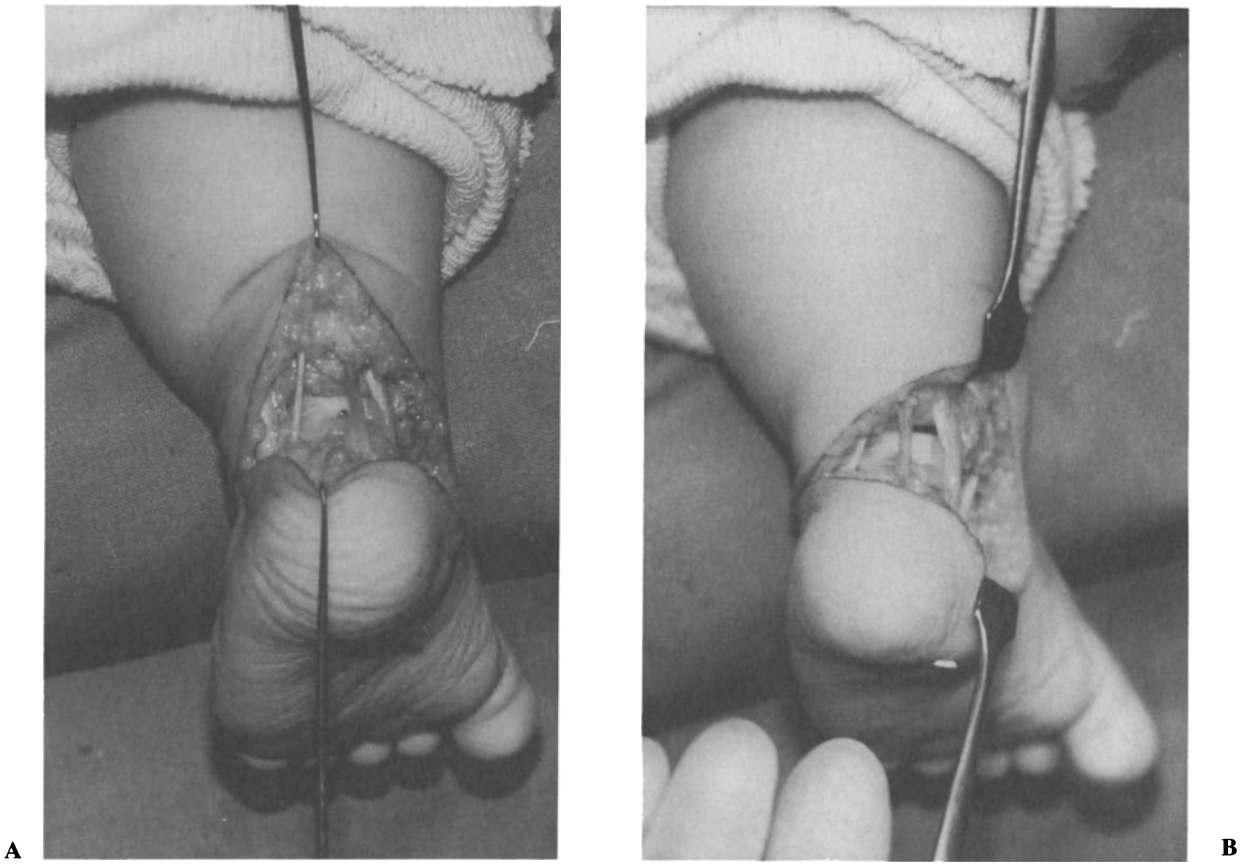


FIGURE 15.19. Intraoperative photograph of a clubfoot surgically released by the Cincinnati approach. A: Posteromedial aspect shows descent of the heel after capsulotomies, anatomic reconstruction, and Kirschner wire fixation. B: Posteromedial aspect shows the mild valgus position of the heel.

cludes release of this joint, whereas in Carroll's approach the calcaneocuboid joint is routinely released.

The most important step in surgery is the anatomical reconstruction. The capacity to derotate the calcaneus (with the whole foot) at the subtalar joint, while maintaining the talus in the corrected position, is greatest with the Cincinnati approach, good with Carroll's approach, but incomplete with Turco's approach. The complete subtalar reconstruction depends on the completeness of the peritalar release. Carroll's approach provides easy access to the anterior parts of the subtalar joint on both the medial and lateral sides, where the release of the talonavicular and calcaneocuboid joints is continued. The Cincinnati incision provides easy access to all parts of the subtalar joints. In two cases with poor results following Carroll's approach, revision surgery using the Cincinnati incision disclosed an incomplete subtalar release, which was then completely released (Figure 15.21). The importance of complete subtalar release was stressed by McKay[10] and Simons.[12,13]

For revision cases, we always use the Cincinnati incision. For the primary cases we use either the Carroll approach or the Cincinnati incision, although more Cincinnati approaches are now being used.

Summary

Three extensive surgical procedures were evaluated and compared. The procedures of



FIGURE 15.20. Superficial skin necrosis along the posteromedial part of the Cincinnati incision.

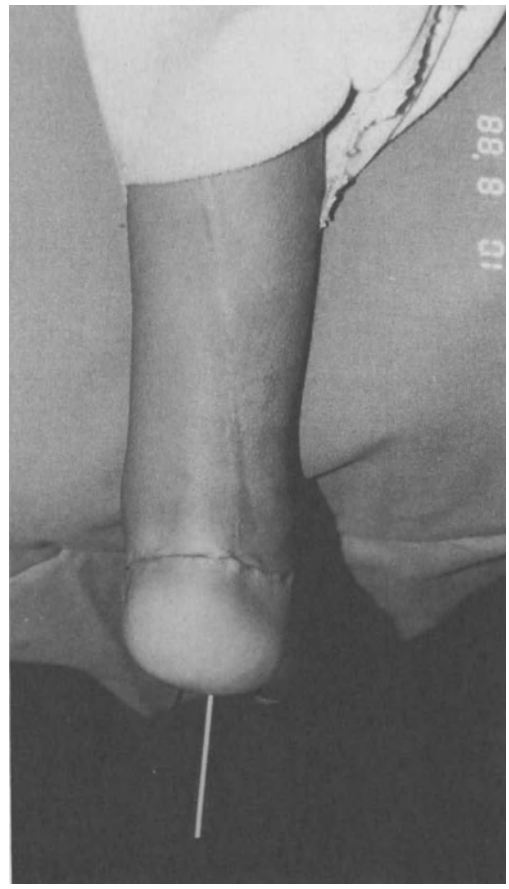


FIGURE 15.21. Clinical photograph of a clubfoot at the end of revision surgery. The primary surgical release performed at 4 months using Carroll's approach. The revision surgery performed through the Cincinnati incision at the age of 4 years involved mainly a proper subtalar release with rotation of the calcaneus laterally.

TABLE 15.9. Comparison of three surgical techniques in clubfoot surgery: the Turco, Carroll, and Cincinnati approaches.

	Turco	Carroll	Cincinnati
Healing of the skin incision	+	+++	++
Quality of scar	+++	+++	++
Accessibility to medial plantar structures	+++	+++	++
Accessibility to lateral structures	+	++	+++
Accessibility for complete subtalar release	+	++	+++
Accessibility to calcaneocuboid joint	0	++	+++
Accessibility for Kirschner wire fixation	+	+++	+++
Ability to derotate the calcaneus at the subtalar joint	+	++	+++

Turco, Carroll, and McKay were analyzed from the standpoint of their indications, advantages, and disadvantages. Complications common to all three types were seen. Skin necrosis was more frequent with Turco's procedure and least frequent with Carroll's. There were five cases of tourniquet burns that seemed to be due to pressure. These could not be attributed to any one procedure. Eight aspects were evaluated for each procedure, including accessibility to specific areas in general as well as total accessibility, skin healing, and the ability to derotate the calcaneus beneath the talus.

It was concluded that the Cincinnati incision offers more than the other incisions. Although Carroll's approach is frequently used in primary cases, the Cincinnati incision is now used more frequently and is the procedure of choice in all revision cases.

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Comparative Review of Surgical Treatment of the Idiopathic Clubfoot by Three Different Procedures

J.P. Magone, M. Torch, R. Clark, and J. Kean

Most orthopedists would agree that the initial management of the clubfoot is by closed manipulation and serial casting. Only when the clubfoot demonstrates resistance to conservative treatment is operative soft tissue release indicated, and here opinion diverges as to the proper surgical procedure. Most children's hospitals, where many clubfeet are treated, adhere to one general philosophy of pathoanatomy and one surgical approach to the clubfoot. At Columbus Children's Hospital, a large tertiary pediatric care center for central Ohio, eastern Kentucky, and West Virginia, we have a relatively unique situation: our three busiest pediatric orthopedic surgeons treat clubfoot by three different techniques of soft tissue releases as described by Turco[34,35], Carroll et al.,[4] and McKay.[16–18]

Purpose

The first purpose of this study was to retrospectively review and compare our early results of the different procedures for congenital talipes equinovarus (CTEV). The second purpose was to determine the applicability of a new rating system for the postoperative clubfoot. We wanted to answer the question, What are the characteristics of a well-treated clubfoot? In the past many authors have weighted the correction of static preoperative deformities more heavily than dynamic functional results.[1,36] In addition, despite many authors placing special emphasis on the roentgenographic criteria of clubfoot correction, two of our senior authors are skeptical as to the role these measurements play. Finally, although it is natural for the surgeon to critically evaluate his results in terms of his own objective criteria, it was Bjonnes[2] who reminded us that "the patient is the final judge of whether he has a good foot." We need to allow adequate time for the patient to "use" his corrected clubfoot to determine satisfaction in terms of pain and activities of daily living.

Background

Prior to Turco's preliminary report[33] in 1971, surgical correction of resistant clubfoot included "piecemeal" procedures and incomplete corrections, resulting in multiple operations with far less than satisfactory results. Since that time, many "philosophies" of the morbid anatomy of the clubfoot have evolved, resulting in different procedures that attempt to correct the pathology in different ways.[12–18,21,28,29,33,36] This paper briefly reviews the three procedures employed at Columbus Children's Hospital, including the authors' concepts of pathoanatomy, age at the time of surgery, operative approach, and postoperative treatment.

Procedures

Turco published a preliminary report (1971)[33] and later a follow-up report of 15 years experience (1979)[35] of his one-stage posteromedial release with internal fixation. He agreed with Scarpa[23] that the basic deformity in clubfoot is a congenital dislocation of the talocalcaneonavicular joint, in which the navicular and calcaneus are displaced medially and beneath the talus. Resultant secondary soft tissue contractures are divided into four groups: posterior, medial plantar, subtalar, and plantar. Turco believed surgery should be delayed until the child is 12 months of age. His best results were obtained in children between 1 and 2 years of age at the time of surgery. He found a greater incidence of failure in children operated on under 1 year of age. His reasoning included (a) loss of correction in plaster after removal of the internal fixation; (b) an unacceptable overcorrection, which is more likely to occur in infancy because minimal overcorrection becomes magnified with growth; and (c) the normal physiologic stimulus for tarsal remodeling, i.e., walking.

The foot is approached by a single, medial incision extending from the base of the 1st metatarsal proximally under the medial malleolus to the Achilles tendon. The lateral extent of the posterior release is a "blind" transection of the talofibular and calcaneofibular ligaments. Both the Achilles tendon and posterior tibial tendon are lengthened, whereas only the sheaths of the flexor digitorum longus and flexor hallucis longus tendons are incised. Two Kirschner wires are employed for internal fixation, one to transfix the talonavicular joint and the other to transfix the talocalcaneal joint. Postoperatively, the child is placed in a long leg cast. Three weeks after the operation, the cast is changed and the foot manipulated into more dorsiflexion, all under a general anesthetic. At 6 weeks the sutures and Kirschner wires are removed and a new long leg cast is applied. Immobilization is continued for 4 months. After 4 months, the child is placed in a Denis Browne splint at night for 1 year.

Carroll et al.[4] published their philosophy of pathoanatomy and operative treatment of the idiopathic clubfoot in 1978. They believe that the talus is externally rotated within the ankle mortise as the initial hindfoot event. Compensatory changes include the head of the talus pressing on the front of the calcaneus, which caused the calcaneus to tip into equinus and rotate into varus. Also, the navicular can secondarily sublux medially toward the medial malleolus and the lateral malleolus is directed

posteriorly. Carroll et al. recommend operating on the resistant clubfoot early, as young as 2 months, believing that, at this time, the foot is of sufficient size to identify the pertinent anatomy. This early surgery permits the corrected foot to remodel the pliable, cartilaginous surfaces of the ankle, subtalar, and talonavicular joints.

The foot is approached through two incisions. The medial incision is similar to that used by Turco.[34] The second extends along the lateral border of the Achilles tendon. This second incision affords a better view of the lateral structures and allows a more complete posterolateral release, including the posterior talofibular ligament and the interosseous talocalcaneal ligament. The flexor hallucis longus tendon is not primarily repaired or lengthened, but sewn into the Achilles tendon to produce flexion of the great toe in phase with plantar flexion of the ankle. Only one Kirschner wire is used to transfix the talonavicular joint. Postoperatively, the child is placed in a long leg cast, paying particular attention to externally rotate the foot with respect to the leg. At 3 weeks the cast is changed and the foot is dorsiflexed and externally rotated further. At 6 weeks the Kirschner wires are removed and the child is kept in a short leg cast for another 6 weeks. At this point, if the child's foot is large enough, a stiff-soled abduction boot is placed on the child's foot.

McKay presented his theories of the morbid anatomy and surgical approach of the clubfoot in 1982[16] and 1983,[17] respectively. He related a radically different concept, explaining that the underlying structural problem of the clubfoot was rotational deformity in the subtalar complex, consisting of three joints (the talocalcaneal, talonavicular, and calcaneocuboid joints), in which the calcaneus moved medially under the head of the talus at the anterior ankle joint and laterally toward the fibular malleolus at the posterior ankle joint. Like Carroll, McKay[17] recommended operating on the clubfoot early, as young as 2 months, for the same reasons. McKay also stressed the use of early surgery to maximize preservation of articular cartilage and promote growth of the talus.

The foot is approached through the transverse Cincinnati incision[6] that extends medially from the base of the 1st metatarsal around the heel laterally to the level of the calcaneocuboid joint. This incision, especially laterally, affords a direct view for complete release of the lateral ankle and subtalar joints, as well as the calcaneocuboid joint. Three Kirschner wires are used to internally fix the operated clubfoot. The first transfixes the talonavicular joint, while the other two, considered critical by McKay and Carroll, hold the derotated calcaneus beneath the talus. Postoperatively, once the swelling subsides, the child is placed in a long leg cast brace to allow early range of motion. At 6 weeks the cast brace and Kirschner wires are discontinued and the child is placed in a short leg cast brace for an additional 6 weeks.

Materials and Methods

For simplicity's sake, throughout the remainder of the paper, we will refer to the posteromedial release as the Turco procedure (group I), the posteromedial and limited lateral release as the Carroll procedure (group II), and the full posteromedial and full lateral release as the McKay procedure (group III).

The Turco procedure has been utilized as our standard soft tissue release since Turco's report in 1971.[33] In an effort to obtain a population of patients with postoperative follow-up comparable to groups II and III, the operative records of one surgeon were reviewed from 1980 to 1985. During that time 24 patients with 37 feet were operated upon. One patient with arthrogryposis multiplex congenita and bilateral teratologic clubfeet was eliminated from the review. This left a subtotal of 23 patients with 35 clubfeet. Twelve patients were unable to return, leaving 11 patients with 16 clubfeet. In addition to these, five patients with eight idiopathic clubfeet were seen for their regular follow-up visit following Turco's procedure. Despite their longer postoperative follow-up, a review of their charts and operative notes confirmed adherence to the procedure and postoperative management as originally outlined by Turco. For this reason, these patients were included, bringing the total of patients to 16 with 24 idiopathic clubfeet returning for examination and constituting group I.

The Carroll procedure was first performed at our institution in 1981. Between then and 1985, 45 patients with 70 clubfeet were oper-

ated upon. Of these, four patients (two with arthrogryposis multiplex congenita, one with so-called reverse clubfoot, and one with an as-yet-unidentified syndrome) with seven teratologic clubfeet were eliminated from review. This left a subtotal of 41 patients with 63 clubfeet. Of this group, 16 patients were unable to return. Twenty-five patients with a total of 35 idiopathic clubfeet returned for examination and constitute group II.

The McKay procedure was first performed in 1982. Between then and 1985, 48 patients with 63 clubfeet were operated upon. Of these, 15 patients (all with myelomeningocele) with 21 teratologic clubfeet were eliminated from review. This left a subtotal of 33 patients with 42 clubfeet. Of this group, 20 patients were unable to return. Thirteen patients with a total of 17 idiopathic clubfeet returned for examination and constitute group III.

The parents of all patients filled out a questionnaire that provided us with information relative to foot pain, shoe wear, limitation in activity, and overall satisfaction with the final result. Clinic and office charts were reviewed to provide information relative to pregnancy history, birth history, family history of clubfoot, other musculoskeletal anomalies, and any anatomic anomalies noted at surgery. Age at diagnosis, duration of conservative care, complications secondary to conservative care, and any additional surgery or bracing were also recorded.

All 54 patients had an orthopedic and neurological examination in which muscle strength, gait, active and passive ranges of motion, residual deformity, bony prominences, and calf circumferences were recorded. In addition, all patients had their feet traced to determine length and width of the foot as well as their bimalleolar axes (the angle formed by the long axis of the foot with a line drawn between the medial and lateral malleoli (Figure 15.22).

A rating system for functional results was designed, with 100 points indicating a normal foot. We intentionally weighted more heavily ankle motion and the patient's subjective impressions in reference to pain and function (Table 15.10). The results were classified according to the scores as follows: excellent, 90–100 points; good, 80–89 points; fair, 70–79, points; and poor, less than 70 points.

Our radiographic evaluation included an anteroposterior and two lateral roentgenograms as standardized by Simons.[24–26] The anteroposterior roentgenograms were made with the foot positioned on a plexiglass plate so that the ankle (and not the midfoot) could be dorsiflexed 15° with the beam angled 30° from the vertical directed at the talus. Two lateral roentgenograms were made with the foot in maximum dorsiflexion and maximum plantar flexion, again using the plexiglass plate so the foot bent at the tibiotalar joint. On the anteroposterior roentgenogram, we measured the angle between the longitudinal axis of the talus and calcaneus (Kite's angle) and the angle between the longitudinal axis of the talus and the 1st metatarsal, according to the method of Simons. On the dorsiflexion lateral roentgenogram we again measured the talocalcaneal angle as described by Simons, as well as the angles *subtended* by the longitudinal axis of the talus and the longitudinal axis of the 1st metatarsal described by Meary.[20] By measuring the angle between identical landmarks on the talus and distal tibia on both plantar flexion and dorsiflexion lateral roentgenograms, an absolute value for the total ankle motion was obtained. We also recorded whether the navicular was ossified and whether it was subluxed dorsally or laterally. Flattening of the talus and increased sclerosis suggesting avascular necrosis

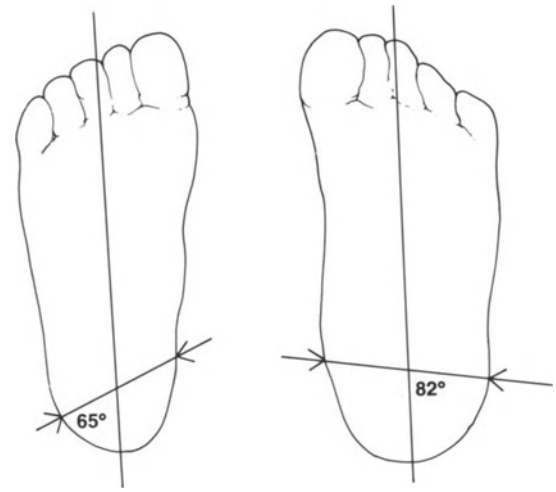


FIGURE 15.22. Sample of a foot tracing of a $2\frac{1}{2}$-year-old with left unilateral clubfoot, following a previous Turco procedure, which demonstrates measurement of the bimalleolar axis. The clubfoot is shorter and narrower than the normal right foot.

TABLE 15.10. Rating system for clubfeet.

Category	Points
1. Hindfoot (5 pts)	
Neutral to 5° valgus	5
Greater than 5° valgus	3
Varus	0
2. Forefoot (3 pts)	
Neutral to 5° adduction	3
Greater than 5° adduction	0
3. Equinus (5 pts)	
Dorsiflexion to 90°	5
Less than 90°	0
4. Cavus (5 pts)	
Absent	5
Present	0
5. Supination (3 pts)	
Absent	3
Present	0
6. Ankle motion by x-ray (25 pts)	
Greater than 40°	25
31° to 40°	20
21° to 30°	15
11° to 20°	8
Less than 11°	0
7. Flexion of great toe (5 pts)	
Present	5
Absent	0
8. Bimalleolar axis (10 pts)	
75° to 85°	10
70° to 74°; 86° to 90°	8
65° to 69°; greater than 90°	4
Less than 65°	2
9. Heel walking (5 pts)	
Present; not applicable*	5
Absent	0
10. Toe walking (5 pts)	
Present; not applicable*	5
Absent	0
11. Pain (12 pts)	
Never	12
With heavy activity	8
With routine activity	6
With walking	3
12. Function (12 pts)	
Never limits	12
Limits heavy activity	8
Limits routine activity	6
Limits walking	3
13. Satisfaction (5 pts)	
Satisfied	5
Neither	3
Dissatisfied	0

* Did not penalize if too young to cooperate with task.

TABLE 15.11. Summary of patient population.

	Number of patients	Number of clubfeet
Group I (Turco)	16	24
Group II (Carroll)	25	35
Group III (McKay)	13	17
Total	54	76

of the talus, navicular, or calcaneus were also noted.

Of the 54 patients who returned for examination, 23 had one normal foot. We used the same test for function and the same roentgenographic measurement for these feet as for the surgically treated clubfeet. In addition, we were able to trace 11 normal feet in 8 additional patients who came to the general pediatric clinic with no prior history of foot problems, bringing a total population of 31 patients with 34 feet to determine a normal value for the bimalleolar axis. Clinical and roentgenographic variables in the normal feet and the clubfeet in each group were compared (Table 15.11).

Results

Clinical Results

Of the 54 patients available for study, 37 (68.5%) were male and 17 (31.5%) were female. Forty-seven (87.0%) were Caucasian, six (11.1%) were black, and one (1.9%) was Oriental. Eight (14.8%) were breech and two (3.7%) were born to oligohydramniotic mothers. Twelve (22.2%) patients had other musculoskeletal anomalies unrelated to the extremity with clubfoot, such as syndactylies of either the hands or contralateral foot, congenital dislocation of the hip, and pilonidal dimple without cyst. One-half of the patients's parents could confirm the incidence of idiopathic clubfoot within their nuclear or extended families.

Of the 76 clubfeet, 42 (55.3%) were right and 34 (44.7% were left. There were 22 patients of 54 (40.7%) with bilateral clubfeet.

In all of the patients with unilateral clubfoot, the normal foot was longer and wider than the clubfoot and the circumference of the leg was

TABLE 15.12. Group I: Turco procedure clinical summary.

Case	Sex	Foot	Age at surgery (yrs./mos.)	Residual deformity					Bimalleolar axis (degrees)	Rating	Follow-up (mos.)
				FA	VR	EQ	CA	SUP			
1	M	R	2/1	+	○	○	+	+	69	44	61
		L	2/1	+	○	○	+	+	84	35	61
2	M	L	0/6	○	○	○	+	○	86	83	48
3	F	R	0/8	○	○	○	○	○	57	67	91
		L	3/0	○	○	○	+	+	62	53	51
4	F	R	1/11	○	+	+	+	○	82	51	121
		L	1/11	○	○	○	○	○	76	83	121
5	M	R	0/9	○	○	○	○	○	81	83	34
6	F	R	1/2	+	○	+	+	+	68	43	54
		L	1/2	○	○	○	○	○	84	83	54
7	M	R	0/10	○	○	○	○	○	70	88	51
8	M	R	0/11	○	○	○	○	○	76	85	42
		L	0/11	○	○	○	+	○	83	75	42
9	M	R	3/7	○	○	○	+	+	82	79	12
10	M	R	1/10	○	○	○	○	○	77	100	67
		L	1/3	○	○	○	○	○	85	100	73
11	M	R	0/8	○	○	○	○	○	97	84	131
		L	0/8	○	○	○	○	○	83	95	131
12	M	R	0/4	+	○	○	+	+	64	58	18
		L	0/4	+	○	○	+	+	74	64	18
13	M	R	0/9	○	○	○	○	○	88	67	66
14	M	L	1/6	○	○	○	○	○	77	78	62
15	M	L	0/9	○	○	○	+	+	77	70	68
16	M	R	0/10	○	○	○	○	○	81	83	61
				(20.8%)	(4.2%)	(8.3%)	(45.8%)	(33.3%)			
Mean			1/3						78	73	64

FA, forefoot adductus; VR, varus; EQ, equinus; CA, cavus; SUP, forefoot supination; +, present; ○, absent.

greater on the normal side than on the side with the clubfoot. The mean difference between the lengths of the feet was 1.2 cm between the widths of the feet, 0.5 cm; and between the circumferences of the legs, 3.3 cm.

Group I

Of the 16 patients in group I who underwent the Turco procedure, 5 patients had a total of six prior surgical procedures including three previous attempts at Turco-type releases. The average age at surgery for the 24 clubfeet was 1 year and 3 months. Average postoperative follow-up was 64 months (standard deviation 33 months) with a range of 12 to 131 months.

Although all patients on examination did demonstrate a well-formed sinus tarsi, one patient did not have normal medial bony prominences or a well-formed heel. As seen in Table 15.12, 4.2% had residual hindfoot varus, 8.3% residual equinus, 45.8% cavus, 33.3% forefoot supination, and 20.8% residual forefoot adductus averaging 19.4°.

Our measured value for the bimalleolar axis in the 34 normal feet that were traced averaged 77°, with a standard deviation of 8°. In group I the bimalleolar axis averaged 78° (standard deviation 9°).

The mean rating of the 24 clubfeet in group I was 73.0 points, with a standard deviation of 17.6 points, and a range of 35 to 100 points.

TABLE 15.13. Group II: Carroll procedure clinical summary.

Case	Sex	Foot	Age at surgery (yrs./mos.)	Residual deformity					Bimalleolar axis (degrees)	Rating	Follow-up (mos.)
				FA	VR	EQ	CA	SUP			
1	F	L	2/1	+	o	o	+	+	83	84	8
2	M	R	0/8	+	o	o	o	+	55	81	35
3	M	L	2/10	o	o	o	+	o	70	75	28
4	M	R	0/7	o	o	o	o	o	53	75	8
		L	0/7	o	o	o	o	o	76	90	8
5	F	R	0/9	o	o	o	o	o	78	90	8
6	M	R	4/0	o	o	o	o	+	77	88	15
7	F	L	0/11	+	o	o	o	+	73	75	13
8	M	R	0/5	+	o	o	+	+	77	90	13
		L	0/5	o	o	o	o	o	84	64	13
9	F	L	3/3	+	o	+	+	+	86	65	10
10	F	R	1/2	o	o	o	o	o	73	93	9
		L	1/2	+	+	+	+	+	69	51	9
11	M	R	0/5	+	o	o	o	+	91	78	5
		L	0/5	+	o	o	o	+	76	84	5
12	M	R	0/3	o	o	+	+	o	79	80	17
		L	0/3	o	o	+	+	o	67	74	17
13	M	L	0/7	+	o	o	+	+	86	77	20
14	F	R	1/2	+	o	o	o	o	77	87	16
15	M	R	0/8	+	o	o	o	+	60	69	22
16	F	R	1/9	+	o	o	+	+	71	77	23
17	M	R	3/6	o	o	o	o	o	75	79	25
		L	3/6	o	o	+	o	o	81	74	25
18	F	R	1/6	o	o	o	o	o	78	81	23
19	F	L	0/4	o	o	o	o	+	88	85	32
20	F	R	0/4	+	o	o	+	o	67	63	35
		L	0/4	+	o	o	+	o	70	67	35
21	M	R	0/5	+	o	o	o	+	71	67	39
22	M	R	0/3	o	o	o	+	+	79	87	49
		L	0/3	o	o	o	+	+	81	87	49
23	M	L	1/5	+	+	o	+	+	88	55	51
24	F	R	0/7	+	o	o	+	+	73	77	52
		L	0/7	+	o	o	o	+	79	84	52
25	F	R	0/5	o	o	o	o	o	78	83	48
		L	0/5	o	o	o	o	o	73	81	48
				(51.4%)	(5.7%)	(14.3%)	(42.9%)	(54.3%)			
Mean			1/1						75	78	25

FA, forefoot adductus; VR, varus; EQ, equinus; CA, cavus; SUP, forefoot supination; + , present; o , absent.

TABLE 15.14. Group III: McKay procedure clinical summary.

Case	Sex	Foot	Age at surgery (yrs./mos.)	Residual deformity					Bimalleolar axis (degrees)	Rating	Follow-up (mos.)
				FA	VR	EQ	CA	SUP			
1	M	R	1/11	o	o	o	+	o	88	NA*	7
2	M	R	0/5	o	o	+	+	o	87	81	15
3	M	R	2/7	+	o	o	+	o	71	69	25
4	M	R	1/0	o	o	o	o	o	89	81	10
		L	1/0	o	o	o	o	o	71	81	10
5	F	R	0/10	o	o	o	o	o	80	83	22
		L	0/10	o	o	o	o	o	81	90	22
6	M	L	4/1	o	o	o	o	o	78	90	7
7	M	R	1/8	o	+	o	+	o	78	80	8
		L	0/5	o	o	o	+	+	76	82	23
8	M	R	1/6	o	o	o	o	o	92	77	9
9	F	R	2/1	o	o	o	o	+	66	66	27
10	M	R	0/7	o	+	o	o	+	78	87	20
		L	1/8	o	o	o	o	+	71	78	6
11	M	L	0/5	+	o	o	+	+	73	62	20
12	M	R	0/3	o	o	o	o	o	88	88	13
13	M	R	4/9	o	o	o	+	o	84	65	21
				(11.8%)	(11.8%)	(5.9%)	(41.2%)	(29.4%)			
Mean			1/6						79	79	16

*Not available (see text).

The results were rated as excellent in 12.5% of the feet, good in 33.3% fair in 16.7%, and poor in 37.5%.

Group II

Of the 25 patients in group II who underwent the Carroll procedure, 5 patients had a total of nine prior surgical procedures including three previous Turco releases, with relapsing deformity. The average age at surgery for the 35 clubfeet was 1 year and 1 month. Average postoperative follow-up was 25 months (standard deviation 15 months) with a range of 5 to 52 months.

On examination all patients demonstrated a well-formed sinus tarsi laterally, normal medial bony prominences medially, and good heel formation. As seen in Table 15.13, 5.7% had residual hindfoot varus, 14.3% residual equinus, 42.9% cavus, 54.3% forefoot supination, and 51.4% residual forefoot adductus averaging 18.5°.

In group II the bimalleolar axis averaged 75° (standard deviation 8°).

The mean rating of the 35 clubfeet in group II was 77.6 points, with a standard deviation of 9.9 points, and a range of 51 to 93 points. The results were rated as excellent in 11% of the feet, good in 37%, fair in 29% and poor in 23%.

Group III

Of the 13 patients in group III who underwent the McKay procedure, 5 patients had a total of six prior surgical procedures including two previous Turco releases, with relapsing deformity. The average age at surgery for the 17 clubfeet was 1 year and 6 months. Average postoperative follow-up was 16 months (standard deviation 7 months) with a range of 6 to 27 months.

On examination all patients demonstrated a well-formed sinus tarsi laterally, normal medial bony prominences medially, and good heel formation. As seen in Table 15.14, 11.8% had residual hindfoot varus, 5.9% residual equinus, 41.2% cavus, 29.4% forefoot supination, and 11.8% residual forefoot adductus averaging 17.0°.

TABLE 15.15. Radiographic evaluation summary.

Angle measured	Group I	Group II	Group III	Normal feet
Anteroposterior talocalcaneal angle				
Mean	32°	46°	37°	33°
Standard deviation	11°	9°	10°	6°
Anteroposterior talar–1st metatarsal angle				
Mean	1°	−8°	−8°	−10°
Standard deviation	12°	7°	7°	7°
Lateral talocalcaneal angle				
Mean	26°	35°	24°	37°
Standard deviation	6°	12°	10°	7°
Lateral talar–1st metatarsal angle				
Mean	14°	15°	14°	10°
Standard deviation	10°	11°	8°	8°
Lateral calcaneal–1st metatarsal angle				
Mean	142°	145°	146°	149°
Standard deviation	9°	10°	10°	9°
Total ankle motion				
Mean	21°	16°	24°	51°
Standard deviation	8°	7°	17°	12°

In group III the bimalleolar axis averaged 79° (standard deviation 7°).

The mean rating of the 17 clubfeet in group III was 78.8 points, with a standard deviation of 8.6 points, and a range of 62 to 90 points. The results were rated as excellent in 12.5% of the feet, good in 50%, fair in 12.5%, and poor in 25%. One patient failed to complete the subjective portion of the questionnaire and could not be adequately rated.

Radiographic Results

Table 15.15 summarizes the results of our roentgenographic evaluation for all three groups as well as our population of normal feet.

Both the anteroposterior and lateral talocalcaneal angles reflect the varus-valgus position of the heel. The anteroposterior talar–1st metatarsal angle used in conjunction with the anteroposterior talocalcaneal angle can offer information regarding subluxation at the talonavicular joint in the face of an unossified navicular. The two remaining angles measured on the lateral roentgenogram, the talar–1st metatarsal and calcaneal–1st metatarsal angles, reflect any cavus deformity.

In addition to considerable controversy concerning the use of radiographic techniques in the evaluation of clubfeet, there is also diversity of opinion as to acceptable normal range of some angles measured. For the anteroposterior talocalcaneal angle, Templeton et al.[32] advocated the range of 30° to 50° for children under 5 years of age. In children 5 years of age or older, the range narrows to 15° to 30°. Simons[24–26] agrees with Kite in using 20° to 40° as normal. For the lateral talocalcaneal angle, whereas Templeton reports the range of 25° to 50° as normal, Simons uses the range of 35° to 50°. All authors agree a value less than 25° reflects inadequate correction of the hindfoot.[7,24–26,32] A normal talar–1st metatarsal angle on the anteroposterior radiograph ranges from 0° to (−)20°.

In evaluating residual cavus deformity, Meary[20] found a value greater than 15° for the lateral talar–1st metatarsal angle abnormal. Simons[24–26] used a value less than 135° for the *abnormal* lateral calcaneal–1st metatarsal angle.

Group I

Of the 24 clubfeet in group I (Turco), 21 had a navicular that was ossified. On the anteroposterior radiograph, nine were centrally positioned, seven were laterally displaced one-quarter of the talar head, and three were laterally displaced between one-half and three-quarters of the talar head. There was one incidence of medial displacement of the navicular by one-quarter of the talar head. On

the lateral radiograph, in addition to seven cases of a dorsally subluxated navicular, there was one case of a plantarly displaced navicular. Of the 11 clubfeet with cavus, two did not demonstrate an ossified navicular. Of the nine remaining cases, six naviculars were dorsally subluxed, two were centrally located, and one was plantarly displaced. Of the seven dorsally subluxed naviculars, six had a cavus and one did not. There was one incidence of avascular necrosis of the navicular. Six (25%) cases demonstrated talar dome flattening. There was one example each of avascular necrosis of the talus and of the calcaneus (separate feet).

Group II

Of the 35 clubfeet in group II (Carroll), 16 had a navicular that was ossified. On the anteroposterior radiograph, three naviculars were centrally positioned on the talar head, three were laterally displaced (overcorrected) by one-quarter of the talar head, and one was medially displaced (undercorrected) by one-quarter of the talar head. On the lateral radiograph, only 3 of the 16 ossified naviculars were centrally located on the distal end of the talus, whereas 13 were dorsally subluxed.

We attempted to correlate clinical cavus deformity with a dorsally subluxed navicular. Of the 15 clubfeet with cavus, eight did not demonstrate an ossified navicular. Of the seven remaining cases, six naviculars were dorsally subluxed, and one was centrally located. Of the 13 dorsally subluxed naviculars, six had a cavus and seven did not. There were two incidences of avascular necrosis of the navicular and 12 (34.3%) cases demonstrating talar dome flattening.

Group III

Of the 17 clubfeet in group III (McKay), six had a navicular that was ossified. On the anteroposterior radiograph, three naviculars were centrally positioned, two were laterally displaced by one-quarter of the talar head, and one was laterally displaced between one-quarter and one-half of the talar head. There were no incidences of medial navicular displacement or undercorrections. On the lateral radiograph, five of the six ossified naviculars were dorsally subluxed. Of the seven clubfeet with cavus, five did not demonstrate an ossified navicular. Of the two remaining cases, both naviculars were dorsally subluxed. Of the five dorsally subluxed naviculars, two had a cavus and three did not. There was one incidence of avascular necrosis of the navicular, and five (29.4%) cases demonstrating talar dome flattening. In addition, there were five (29.4%) clubfeet with roentgenographic evidence of avascular necrosis of the calcaneus.

Of the 23 normal feet radiographed, 12 had a navicular that was ossified. On the anteroposterior radiograph, seven were centrally located, three were laterally displaced one-quarter of the talar head, and two were laterally displaced between one-quarter and one-half of the talar head. On the lateral radiograph, 11 of 12 ossified naviculars were centrally positioned, and one was dorsally subluxed.

Complications

Simons[28,29] defined radiographic measurements in terms of clinically insignificant minor complications and clinically significant major complications that may require further surgery. For the talonavicular articulation on the anteroposterior radiograph, the central position of the navicular with respect to the talar head is the normal position, but lateral displacement up to one-half of the talar head can be seen in hypermobile flatfeet and, therefore, though still considered overcorrection, is only a minor complication, clinically insignificant. Simons considered medial navicular displacement up to one-quarter of the talar head is undercorrection but is not a major complication. Medial displacement greater than this was a major complication.

By these criteria, in group I there were 11 minor and one major complication, in group II there were 13 minor, and in group III there were three minor complications. For the talonavicular articulation on the lateral radiograph, again the central position is normal and up to one-third dorsal subluxation of the navicular on the talar head is considered overcorrection, but only a minor complication consistent with a satisfactory result. Dorsal subluxation to a greater degree or any plantar subluxation is considered a major complication. There were eight major complications in group I, 13 in group II, and five in group III. The correlation of this major complication with clinical cavus deformity will be discussed

later. We have already addressed the issue of avascular necrosis and talar dome flattening.

A resultant calcaneal gait secondary to overlengthening of the Achilles tendon was not seen during follow-up examinations in any feet in groups II and III. It was present, however, in 24 feet in group I, representing a major complication.

Secondary Procedures

To date, 11 feet in the combined groups have undergone 14 secondary procedures because of failure to correct deformities at the time of initial surgery. In group I, one patient required simultaneous lateral column closing-wedge and medial column opening-wedge osteotomies, one patient had a Dwyer calcaneal osteotomy and Achilles tendon lengthening, one patient had a talectomy, and three patients had a repeat Turco procedure. In group II, one patient underwent subsequent lateral column closing-wedge osteotomy and anterior tibial tendon transfer, one patient had a metatarsal osteotomy, and one patient had a repeat Carroll procedure. In group III, one patient required a Heyman-Herndon procedure for persistent forefoot adductus and one patient underwent a repeat McKay release. One foot in group III had a minor wound dehiscence that responded to dressing changes alone. This has been a reported complication with the Cincinnati[6] type incision. Otherwise, there were no wound problems in any of the other feet or any pin track infections.

Discussion

When discussing results of clubfoot management we frequently hear the statement "that foot looks good, for a clubfoot." This attitude is dogmatic at best, for our goal in clubfoot management—despite the method of treatment—is to approach the normal foot as much as possible in terms, not only of static deformity, but more importantly, of dynamic functional results. We are reminded, however, that especially in the case of the unilateral clubfoot, the calf and foot will always be smaller than the contralateral normal side and this is a result of primary muscle pathology.[9,10] Prior evaluation schemas for the treated clubfoot were very forgiving in that they did not give much consideration to foot function, but rather to correction of static deformity. In search of an answer to the question, What features make up a good clubfoot? we designed a new rating system for the postoperative clubfoot that puts more emphasis on functional results.

Total ankle motion as measured on standardized lateral radiographs received 25 of a possible 100 points. We began penalizing for a range of motion of less than 40° and arbitrarily divided range of motion into 10° increments. A criticism of clubfoot operatively treated is their stiffness and decreased ankle motion. Indeed, when studied roentgenographically, it is seen that most plantar flexion and dorsiflexion is occurring, not in the true ankle joint, but rather at the midtarsus. Boone and Ayen[3] reported an estimate of 71° total ankle motion for normal male children. Giannestras[8] listed normal passive ankle motion in children as 60°. The average ankle range of motion in our normal subjects was 51°. Coleman[5] reminds us that active ranges of motion differ substantially from passive ranges, largely because muscle action normally is not capable of isolating the different components of ankle and midtarsal motion. Stauffer et al.[31] reported that the average range of ankle motion during normal waking gait is 24.4°. Simons[27] is the only investigator to prospectively compare radiographic true ankle motion in clubfeet preoperatively and after soft tissue release postoperatively. Average preoperative range of motion was 31° and postoperatively 29°, but the arc of motion was directed more toward dorsiflexion by 10°. Our average postoperative ankle range of motion for each of the three treatment groups is seen in Table 15.15. Lacking in our data is a value of preoperative range of motion to determine if any one procedure more consistently improved ankle range of motion. It was felt that most likely the philosophy of McKay's[17,18] postoperative ankle cast brace would demonstrate a greater resultant rate of motion, but in fact group III had the lowest average range of motion. McKay reported a total ankle range of motion of 58° postoperatively using the cast brace, but this has yet to be duplicated.

Is active great toe flexion expendable for a normal functional gait? Some authors[11] report disability following traumatic rupture of the flexor hallucis longus tendon and advocate re-

pair. In our rating system, we penalized for inability to flex the interphalangeal joint of the great toe. Nine of 24 (37.5%) feet in group I lacked active function. This complication of the Turco procedure has been reported[19] with an incidence as high as 80% and is thought to be secondary to medial and distal plantar scarring.

Although no patient in group II was able to independently activate the flexor hallucis longus following tenodesis between it and the Achilles tendon, all functioned strongly in phase with plantar flexion of the ankle. Whether this ultimately affects gait awaits formal gait analysis. All patients in group III had independent active flexor hallucis longus function.

Some authors[28,29,36] have discussed the problem of the corrected forefoot adductus with persistent toeing-in and a resultant lateral malleolus at the posterior aspect of the foot. Roberts and Drvaric[22] referred to this as "persistent medial spin" and said that it is most commonly a problem following the Turco procedure. Although Carroll et al.[4] address this issue intraoperatively (but after the skin is closed), paying attention to externally rotate the foot with respect to the leg and holding it in a cast, McKay[17] aligns the bimalleolar axis openly before any subtalar transfixion pins are placed. Though McKay advocated orienting the bimalleolar axis at 90°, primarily because it is a reproducible angle that can be easily aligned with the child prone on the operating room table, we contend that, although the technical aspect is attractive, 90° is not physiologic. Staheli et al.[30] reported the normal bimalleolar axis in children as the difference between the "thigh-foot angle" and the "transmalleolar axis." Their mean in normal children was 80° with a standard deviation of 5°. Our average value for the bimalleolar angle in 34 normal feet was 77° with a standard deviation of 8°. McKay[19] admits that his intraoperative alignment is one of convenience and reproducibility, and that more work is needed to properly align the bimalleolar axis.

Roberts and Drvaric[22] have brought attention to the problem of dorsal subluxation of the navicular and correlation with clinical cavus deformity. They reported that the problem does not appear until years after surgery, when the foot enlarges and the child has shoeing troubles because of the high arch. Indeed, all of our patients's pain rating deductions were directly due to a resultant cavus foot, which was prevalent in over 40% of the total patient population. Roberts and Drvaric felt the cause to be due to inadequate correction of midfoot supination to match a corrected hindfoot and advocated a more extensive plantar release to include the long and short plantar ligaments and transfer or partial release of the anterior tibial tendon when it is identified as a contributing causative factor. Simons,[29] however, demonstrated that pinning of the navicular in a dorsally subluxed position at the time of surgery was responsible for most of the overcorrection, and not a gradual change in position over a period of time. We did not have a sufficient number of patients with ossified naviculars to unequivocally support either hypothesis; however, we do lean toward Simons' philosophy that intraoperative pinning of the navicular in the dorsally subluxed position is probably the primary event. In our total population of clubfeet we did find that, of 18 feet with cavus and an ossified navicular, 14 had an associated dorsally subluxed talonavicular articulation. Of 25 feet with dorsal subluxation at the talonavicular articulation, only 14 had an associated clinical cavus deformity.

The natural first question to ask is which of the three procedures is "better" for the idiopathic clubfoot based on this study. The answer, at least for now, is indeterminate. As mentioned previously, ours is but a review of our early operative results. Indeed, 16 of 76 feet had less than the standard 1-year follow-up. As well, only postoperative radiographs were available without the opportunity to compare preoperative values to quantify roentgenographic measurement of correction. We do feel, however, that certain conclusions can be made concerning the technical aspects of approaching clubfeet operatively:

1. Once soft tissue release is achieved and bony realignment is undertaken, especially in the talonavicular articulation, more care needs to be given to anatomic alignment and pin fixation. It is not "good enough" to be content with casual or random fixation of the talus and navicular, but rather, care needs to be taken in reestablishing proper joint congruity.

2. Consideration to proper alignment of the bimalleolar axis is necessary; it has not been determined whether a more accurate value results from Carroll's or McKay's approach. We do contend, however, that it is more physiologic in the child to aim for a resultant bimalleolar axis of 84° as opposed to McKay's advocated 90°.
3. The significance of decreased range of motion resulting from stiff feet and ankles over the long term is still to be determined. We believe that the postoperative use of the hinged ankle cast brace should be investigated until there is proof that it has no affect on the range of motion that can be achieved in the ankle.

Summary

Ninety-nine feet in 54 children were both clinically and roentgenographically evaluated following one of three different procedures for soft tissue clubfoot release: Turco, Carroll, or McKay. A new rating system more heavily weighing dynamic functional results was employed to compare results.

Of 24 clubfeet in 16 patients following Turco's procedure, 12.5% rated as excellent, 33.3% good, 16.7% fair, and 37.5% poor. Average follow-up was 64 months.

Of 35 clubfeet in 25 patients following Carroll's procedure, 11% rated excellent, 37% good, 29% fair, and 23% poor. Average follow-up was 25 months.

Of 17 clubfeet in 13 patients following McKay's procedure, 12.5% rated as excellent, 50% good, 12.5% fair, and 25% poor. Average follow-up was 16 months.

Twenty-three patients had one normal foot, which constituted a comparison population.

Roentgenographic complications included both over- and undercorrection at the talonavicular joint; avascular necrosis of the talus, the navicular, and the calcaneus; and talar dome flattening.

Recommendations concerning technical aspects of operatively approaching clubfeet include (a) more physiologic orientation of the bimalleolar axis, (b) anatomic alignment at the talonavicular joint, and (c) use of hinged ankle cast brace to increase final ankle range of motion.

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Discussion

Crawford (Cincinnati): Progress in understanding clubfoot has come about in several ways. Dr. J. Leonard Goldner, our historian for this session, could tell us about many of the earlier efforts. In 1978 or 1979, John Roberts, Doug McKay, and George Simons met to look more closely at the pathoanatomy of the lateral aspect of the foot and to examine how surgical releases could improve results on that side of the foot without producing overcorrection. We had all seen clubfeet where a footprint was perfect except that the foot turned inward when the child stood or walked and was anatomically aligned except in its relationship with the leg. The mother would ask, "Well, what's wrong with him; why does he still turn his foot inward?"

McKay, Roberts, and Simons got together, looked at the lateral side of the foot, and came up with such terms as *medial spin* and the *banana theory* to describe how the calcaneus changes position as it moves at the subtalar joint. My associates have been trying for 2 years to explain what "rolling of the banana at

the talocalcaneal joint" meant and they are still trying to explain this to me. Anyway, I think their observations have made a difference in our collective approach to clubfeet.

There is a tendency toward "more is better" (surgically) that I'm gathering from this congress. I don't know whether it is because of new technology, because of our better understanding of the pathoanatomy, or because of superior surgical exposure, but several papers are gravitating toward "more is better."

We have not followed these patients long enough to determine whether "more is better" equals better correction, total correction, or overcorrection. But I think these questions will have to be carefully examined and answered.

Barnett (Minneapolis): The bimalleolar angle has been mentioned as one measurement of the postoperative results. I think we should clarify the difference between the bimalleolar angle of McKay and the bimalleolar axis.

Klaue (Bern, Switzerland): The bimalleolar angle is a clinical measurement. It is the angle between a line joining the two malleoli and a line down the 2nd metatarsal. The bimalleolar axis is an imaginary line through the malleoli.

Watts (Los Angeles): Dr. Seringe, how did you select the cases on which you didn't perform subtalar joint releases? Were they randomly selected? Was this a prospective study, because you only did the subtalar release in 10 feet as compared to 20 feet where the subtalar joint was left intact?

Seringe (Paris): There was no preselection of cases. The study was performed during my early research in clubfeet 15 years ago. Initially, I systematically opened the subtalar joint and observed overcorrections. Then I did a partial opening of the subtalar joint; in a third group I did not open the subtalar joint. Now I believe it's not necessary to open the subtalar joint to observe the calcaneus and the talus. Since the study in 1975, I have progressively limited my release of the subtalar joint.

Watts (Los Angeles): We have just completed a clinical study on the measurement of angles; the difference of measurability between examiners was in the neighborhood of about 30°.

Klaue: I doubt that I would have these differences.

Brown (Halifax, Nova Scotia): In comparing the different techniques, Dr. Torch and Dr. Porat, how do you measure the range of motion at the ankle joint? Dr. Torch said that one must get the right number of degrees of dorsiflexion and the right length of the heel cord so we will never see calcaneal gaits again. Sometimes the most disappointing thing is a foot with a calcaneal gait—the child who no longer can run on his toes.

Porat (Jerusalem): The baby is prone and the judgment is clinical. You keep the heel in varus while suturing the Achilles tendon. Take two steps away from the table to view the foot from the lateral side. The angle should be 90°. The medial side is deceiving. The lateral side gives a better view of the angle between the foot and the leg.

Barnett: Dr. Klaue, how do you obtain the lateral x-ray with respect to placement of the cassette? Is it placed on the lateral side of the foot or on the medial side of the foot?

Klaue: It's a weight-bearing lateral view, which is obtained by placing the cassette on the lateral side of the hindfoot. This avoids the mistake one can make if there is adduction of the midfoot or forefoot (bean-shaped foot), which gives the false appearance of a flattop talus. This may occur if the x-ray is taken with the cassette placed on the medial side of the foot with the great toe and the heel touching the cassette. When there is adduction of the midfoot or forefoot, the foot is placed in a position of external rotation in relationship to the cassette. Thus, one obtains an anterior oblique view. This appears to show flattening of the dome of the talus which, in fact, is not present. When the foot is placed in the proper position, this apparent flattop talus disappears. Thus, the axis through the two malleoli should be perpendicular to the cassette; we then disregard the forefoot.

Turco (Hartford): My initial article (1971) states that one has to do a complete posterior, medial, plantar, and subtalar release. Some of the other authors had a high incidence of recurrence because they didn't do the subtalar release. Granted, one doesn't have to do much of an interosseous ligament release in all cases. In younger children, one is less likely to have

to do it. In older children, there are many cases where one cannot unlock the calcaneus unless the interosseous ligament is released. That is part of the initial procedure. I also stressed in the initial procedure that, when doing the posterior release, one has to release everything posteriorly, including the posterior talofibular ligament, the calcaneofibular ligament, and the peroneal sheaths. Later I added the intermuscular septum. If you can't reach these structures through the medial incision, they can be released through the lateral portion of a Cincinnati incision. Our improved results are partly due to the learning curve that the surgeons were experiencing at that time. Later on they did a more complete release. One cannot get a lasting correction until one completely mobilizes the calcaneus. Therefore, the learning curve in Dr. Nimityongskul's paper is particularly significant.

Editor's Comments

Seringe and **Miladi** give three reasons for not releasing the interosseous talocalcaneal ligament: (a) the need for an intact interosseous talocalcaneal ligament to guide abduction of the calcaneo-pedal block (CFF),(b) overcorrection of the calcaneus into valgus, and (c) avascular necrosis of the talus. Although the first reason may be true in the normal subtalar joint, in clubfeet contractures of the subtalar capsule *and interosseous ligaments* markedly restrict movement preoperatively as well as postoperatively. Thus, it seems doubtful that a contracted interosseous ligament can guide movement to any significant degree.

Overcorrection of the calcaneus into *valgus* was a significant problem in my early cases of CSTR, but this deformity has been relatively infrequent since discovering the reasons for its occurrence. These are (a) lateral overreduction of the navicular on the talar head at the time of pinning[1]; (b) uncorrected calcaneocuboid subluxation, leading to valgus of the hindfoot (see Chapter 8); and (c) ligamentous laxity (allowing a gradual drift into valgus over a 1- or 2-year period). The latter probably accounts for less than 10% of the cases.

Talar avascular necrosis has been extremely rare in my experience, despite routinely opening the lateral subtalar joint. This has also been the experience of several of my colleagues who perform similar or identical techniques (**Barnett** and **McKay**). I believe that the key to preventing avascular necrosis of the talus is to preserve the dorsolateral vessels to the talar neck, rather than to retain the interosseous ligament. Any small vessel within the interosseous ligament that supplies blood to the talus should be evident when the ligament is incised. However, I have never observed bleeding from this ligament. Furthermore, arthrographic studies of CTEV appear to be devoid of vasculature in the area of the sinus tarsi, where there is usually a ring of vessels arising from the dorsalis pedis.[2]

Seringe and **Miladi** also cite three complications that they believe to be more frequent with subtalar release: (a) recurrence of deformity, (b) overcorrection, and (c) pain.

The reasons for the second complication, *overcorrection*, have been discussed above.

In the past, when the surgeon failed to verify full correction of the deformities with interoperative radiographs, it became all too easy to attribute the unsuccessful correction to the mysterious *recurrence* of deformity seen on postoperative radiographs, when in fact, complete correction was never achieved. Consequently, "recurrences" (incomplete correction of the mid– and hindfoot) have been all but eliminated now that the subtalar release is an essential part of our extensive procedure. This also includes the standard use of radiographs to verify correction intraoperatively.

We have found that *pain* has not been a common complaint in our patients who required subtalar release; however, our follow-up is much shorter than **Seringe's** and pain is more likely as a late complication. In the first few

TABLE 15.16. Comparative results of Turco, Carroll, and McKay procedures.

	Satisfactory	Unsatisfactory
Group I	45%	54%
Group II	48%	52%
Group III	62.5%	37.5%

years after surgery, pain due to valgus has been surprisingly infrequent, despite marked degrees of deformity. Frequency of pain 10 or more years after surgery may prove to be a significant detriment and must be fully evaluated in the future.

Magone, Torch, et al. attempted to compare three operative procedures—those of Turco, Carroll, and McKay—to find which gave superior results. The authors state that their study was indeterminate since it was a review of early operative results: one-fifth of the feet had less than a year follow-up and they lacked preoperative and intraoperative radiographs for comparison. However, they did reach some important conclusions regarding results, one of which is that talonavicular reduction requires great care in anatomic realignment and fixation; it is not "good enough" to be content with casual and random fixation of the talus and navicular.

Keeping in mind the limitations of their study, **Magone**, **Torch**, **et al.** have provided a wealth of data to consider regarding results and complications.

A statistically significant difference in results emerged when the three series were evaluated by combining the excellent and good results into a single "satisfactory" group and the fair and poor results into a single "unsatisfactory" group. If one then compares these combined results in each of the three major groups (i.e., **Turco**, **Carroll**, and **McKay**), this difference can be seen (Table 15.16).

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16
Neglected Clubfeet/Revision Surgery

Introduction

Pandey and colleagues describe different treatment for the neglected clubfoot in patients in various age groups. They define the neglected clubfoot as the untreated clubfoot presenting after 9 months of age. The specific soft tissue release used in children between 9 months and 3 years of age is discussed. After 3 years of age they recommend a posterior inferior medial soft tissue release combined with a T osteotomy of the calcaneus and an oblique sliding osteotomy through the forefoot and midfoot. In children beyond 9 years of age, routine triple arthrodesis is recommended, whereas in adult patients, conservative management seems to be the procedure of choice; however, surgery is occasionally performed when foot strain is present. Very rarely, a triple arthrodesis will be performed in the elderly patient.

Lehman, Atar, Grant, et al. present a paper on revision surgery in clubfeet in which they review their experience with multiply operated feet. They present the possible causes for failure in preceding operative procedures and conclude by presenting an algorithm for the treatment of the previously operated clubfoot.

Kuo and colleagues reviewed their experience with clubfoot revision surgery. They evaluated their operative failures by dividing them into three groups according to the type of initial surgery. Each was evaluated for the reasons for revision surgery as well as for the type of surgery that ultimately gave the best results.

Management of Neglected Clubfeet

S. Pandey, A.K. Pandey, and N. Jha

This paper concerns the observations made while managing 537 neglected clubfeet in the age group of 17 months to 50 years, and followed for an average of 37 months. Untreated clubfeet presenting after 9 months of age are "neglected clubfeet." By 1 year of age, most (70%) require surgical corrections—soft tissue release (with tendon transfers) and bony procedures (beyond 3 years of age).

A postero-infero-medial soft tissue release is

performed through double incisions and is combined with a circumtibial posterior tibial tendon transfer.

A T osteotomy is made through the body of the calcaneus. This simultaneously corrects the persistent varus, mild cavus and mild adduction of the forefoot. It further broadens the small, narrow heel.[1]

An "oblique sliding osteotomy" performed through the forefoot and midfoot simultaneously, corrects persistent moderate-to-severe cavus, mild-to-moderate equinus, and adduction of the forefoot. To correct very severe cavus and severe equinus, varying bony slices are removed from the distal end of the proximal segment of the foot during the oblique sliding osteotomy. For severe adduction of the forefoot, the osteotomy line of the oblique sliding osteotomy is performed with a larger wedge removed from the proximal segment.

In children beyond 9 years of age, the equinovarus deformities are corrected by modified triple arthrodesis, with a possible soft tissue release performed during the same intervention.

In adults with either psychological cosmetic needs or constant foot strain, two-stage surgery is usually performed, one to correct the cavus and equinus by an oblique sliding osteotomy of the foot, and the other to correct persistent clawing.

Elderly patients with a neglected clubfoot usually present with pain in the ankle region; this is usually managed by conservative measures (intra-articular corticoids, physical therapy, and supportive orthotics). However, a few patients with persistent pain have had ankle arthrodesis with satisfactory results.

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Revision Surgery in Clubfeet

W.B. Lehman, D. Atar, A.D. Grant, and A.M. Strongwater

Poor results have been reported following surgical correction of clubfeet by various authors.[8,9,30,34,35,41–43,45,47,50,57,62] These results average 25% with a range of 13% to 50%. Most of these feet have required additional surgical procedures. However, there are very few reports on revision surgery in congenital talipes equinovarus (CTEV).[2,11,22,24,25,56] The authors were unable to find any reports of long-term results on reoperated clubfeet.

As a secondary referral center, about 25% of the clubfeet referred to us require repeat surgical intervention.

During the last several years, the authors developed a protocol that proved useful in decision-making for reintervention in relapsed or residual clubfeet deformities in different age groups.

Materials and Methods

Between 1979 and 1987, a total of 200 patients with CTEV were operated on at our institution; 117 patients (159 feet, 42 bilateral) were operated on by the senior author (W.B.L.).

Forty of the 159 feet (32 patients, 25%) were revision cases. Most of them (80%) were referred to us after being operated on once or twice (Table 16.1).

All of these feet were considered poor results by subjective evaluation of appearance, motion, pain, and gait, as well as by objective clinical assessment, according to several suggested functional rating systems[8,40,41,43,58,61] and the authors' functional rating system (FRS). The FRS includes objective clinical assessment and roentgenographic evaluation and is currently used for evaluating results of

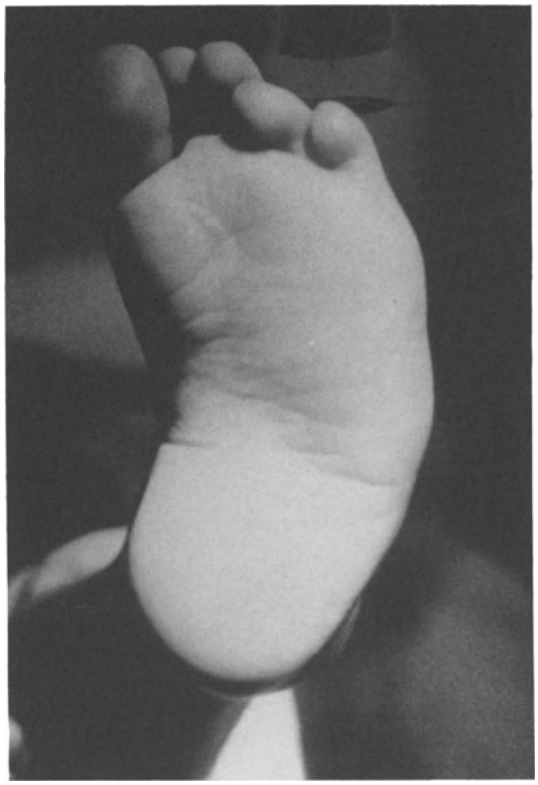
TABLE 16.1. Patients, surgical intervention, and follow-up.

Patient	Sex	Side	Age at 1st operation	Type of surgery	Surgery done	Age at revision	Type of revision	Re-revision	Age at re-revision	Follow-up	Remarks
G.S.	M	B	9 m	B post. release	Elsewhere	5 y 11 m	L STCFR & D.E.	—	—	25 m	Distal arthrogry-posis T-C Bar
F.L.	M	B	6 m	B post. release	Elsewhere	5 y 8 m	R STCFR & D.E.	—	—	34 m	
						5 y 9 m	L STCFR & D.E.	—	—	33 m	
R.N.	F	L	6 m	PMR	Elsewhere	6 y 10 m	STCFR & D.E.	Plantar rel. & metat. osteotomy	9 y 10 m	44 m	T-C Bar
G.A.	M	R	6 m	PMR	Elsewhere	5 y 2 m	STCFR & D.E.	Refusion CC	5 y 8 m	38 m	T-C Bar
B.M.	M	R	4 m	PMR	By us	4 y 8 m	STCFR & D.E.	—	—	9 m	T-C Bar
T.J.	M	B	4 m	B PMR	By us	4 y	R STCFR & D.E.	—	—	9 m	Imperforated anus, hemi-vertebra L3, scoliosis
							L STCFR & D.E. & T.A. transf.			9 m	
V.R.	M	B	R 5 y L 7 y	Post. release	Elsewhere	11 y	B STCFR & Steindler & D.E.	—	—	44 m	—
W.E.	F	B	8 m	B PMR	By us	4 y	R STCFR & D.E. L tarsometat. capsulo-tomies & Steindler	—	—	34 m	—
S.M.	M	R	6 m	PMR	Elsewhere	3 y 2 m	STCFR	—	—	78 m	—
T.M.	M	R	5 m	Post. release	Elsewhere	1 y	STCFR	—	—	33 m	—
D.B.	M	R	7 m	PMR	Elsewhere	1 y	STCFR	—	—	27 m	—
W.C.	F	R	18 m	PMR	Elsewhere	2 y	STCFR	—	—	65 m	—
L.J.P.	M	L	6 m	PMR	Elsewhere	2 y 6 m	STCFR & Steindler	—	—	61 m	—

TABLE 16.1. Cont.

Patient	Sex	Side	Age at 1st operation	Type of surgery	Surgery done	Age at revision	Type of revision	Re-revision	Age at re-revision	Follow-up	Remarks
R.J.	M	B	8 m	B PMR	Elsewhere	2 y	L STCFR & Steindler & capsulotomies CC, N–1st cuneiform	—	—	14 m	—
K.G.	M	L	3 m	PMR	Elsewhere	3 y	STCFR & Steindler & CC capsulotomies & . lat. T-N	—	—	49 m	—
			1 y	Revision (RE) PMR & Tarsometat. capsulotomies							
G.D.	M	B	6 m 11 m	L PMR R PMR	Elsewhere	4 y	R STCFR & Steindler & CC capsulotomies lat. & lat. T-N	—	—	13 m	—
C.J.	M	L	1 y	PMR	Elsewhere	3 y	STCFR & split T.A. transfer	—	—	55 m	T.C. bar
R.R.	F	R	7 y	PMR	Elsewhere	12 y	Post. rel. & TAL	—	—	36 m	—
C.J.	M	B	2 y 6 y	B Post. rel B PMR	Elsewhere Elsewhere	6 y 8 m	B Tarsomet. capsulotomies & abduct. hal. res.	—	—	—	Polydactyly L hand
P.J.	M	L	5 m	PMR	Elsewhere	6 y 3 m	Tarsometatar. capsulotomies & Steindler & abduct hal. res.	—	—	46 m	Lymphocytic leukemia
R.J.	M	L	8 m	PMR	By us	6 y					
L.I.	M	L	9 m	PMR	By us	5 y 9 m	D.E. & abduct hal. res.	—	—	9 m	—
							D.E. & tarsometatar. capsulotomies	—	—	18 m	—
T.M.	M	B	3 m	B PMR	Elsewhere	7 y 10 m					
T.M.	F	B	1 y	B PMR Z-plasty constriction band R	Elsewhere	9 y	L Dwyer & Steindler	RE Dwyer B.G.	8 y	67 m	—
							R triple arthrodesis & metat. osteotomies	—	—	77 m	Constriction band R leg

Legends: Bilateral (B); soft tissue clubfoot release (STCFR); Dillwyn Evans (D.E.); calcaneocuboid (CC); posterior release (Post. rel.); Talonavicular (T–N); Navicular first cuneiform (N–1st cuneiform); Posterior medial release (PMR).



A



B

FIGURE 16.1. A: Case F.L. 5 years after Achilles tendon lengthening (TAL), before revision (Evans' procedure). B: Radiograph before revision; talar-1st metatarsal angle 40°.

both initial and revision clubfoot surgery at our institution.

Only 24 patients (75%, 29 feet, 5 bilateral) could be retrieved for this study. Of these, 19 were male and 5 were female. Age at the second operative intervention ranged from 1 to 12 years (average 5 years 4 months). The time between the first and the second intervention ranged from 5 months to 18 years (average 3 years 8 months). Previous surgeries included 20 posteromedial releases and 4 posterior releases. Follow-up averaged 30 months (range 9 to 36 months).

The surgical method most commonly used for the revision of clubfeet was repeat soft tissue clubfoot release (STCFR). In some feet this was combined with calcaneocuboid joint fusion, plantar release, and/or capsulotomies [navicular–first cuneiform, and/or tarsal–1st metatarsal joints (21 out of 29 cases)] (Table 16.1). (Figures 16.1 and 16.2).

In a typical revision STCFR the usual finding was heavily scarred tissue in which the neurovascular bundle, the flexor hallucis longus tendon, flexor digitorum tendon, tibialis posterior tendon, and Achilles tendon were embedded in scar tissue. The neurovascular bundle was dissected free throughout its course—proximal to the ankle and distally into the sole of the foot. The tendons (posterotibial, flexor hallucis longus, flexor digitorum longus, the Achilles, and abductor hallucis) were therefore excised. Then capsulotomies of the posterior ankle joint, the posteromedial side of the subtalar joint, and the talonavicular joint on its superior, inferior, and medial sides were performed. If, at this stage, correction of the deformity was not achieved, the authors added a Steindler



A



B

plantar release and capsulotomies of the navicular–first cuneiform and first cuneiform–1st metatarsal joint as needed. The interosseous ligament, if found, was resected.

If the forefoot was not fully corrected, then the calcaneocuboid joint was opened through a lateral incision and the calcaneocuboid joint was excised or fused, depending on the age of the patient.[1,18,56]

Results

In evaluation of the results of revision clubfoot surgery, it should be emphasized that even the best results cannot be regarded as a normal-looking foot, since shortening of the affected foot and hypoplasia of the calf are constant and permanent deformities.[35,51,58]

After a second or third intervention, one would expect hypoplasia of the calf, as well as the shortening of the affected foot, to be even more significant. But, in the authors' patients, the figures were the same as those reported after one intervention.[35,61] These include:

1. shortening of the affected foot (average 1.6 cm, range 0 to 4 cm)
2. difference between the width of the feet (average 0.3 cm, range 0 to 0.6 cm)

FIGURE 16.2. Case F.L.: Clinical appearance 3 years later. A: Plantar view. B: Posterior view. C: AP radiograph. Fusion of calcaneocuboid joint. Talar-1st metatarsal angle 20°. D: Lateral radiograph. Note the fused calcaneocuboid joint and dorsal subluxation of the navicular.



C



D



FIGURE 16.3. Case L.J.P. at age 8 years (5 years after repeat soft tissue procedure). Note the flattop talus, the subtalar changes, and the wedged navicular.

TABLE 16.2. Algorithm for repeated surgical intervention in clubfeet.

Age at revision	Method of treatment
6–24 months	1. Re-STCFR 2. If prominent plantar crease, add plantar release 3. If FFA not corrected, add capsulotomies (N-Cuneiform–1st metatarsal as needed)
2–4 years	Follow steps 1, 2, 3 4. If FFA not corrected, add excision of cartilage of CC joint[56] or decancellectomy of cuboid[44,52,55,59]
4–8 years	Follow steps 1, 2, 3 5. If FFA not fully corrected, add a) Fusion of CC joint (D.E.)[1,18,56] *or* b) Excision of distal calcaneus (Lichtblau[39]) *or* c) Cuboid decancellation[44,52,55,59] *or* d) Open-wedge first cuneiform osteotomy[28] *or* e) Tarsometatarsal capsulotomies*[27] *or* f) Metatarsal osteotomies (over age 5) 6. If overacting tibialis anterior vs. weak peroneal, add tibialis anterior transfer[31] 7. If heel varus is still not corrected, add Dwyer[16,17]
Over 8 years	Up to age 10 it is possible to start with steps 1, 2, 3, then proceed according to remaining deformities: Calcaneus: Stage 7 FFA: Stages 5a, b, c, f (above) 8. If persistent cavus, add midtarsal osteotomy 9. Distraction osteogenesis (Ilizarov) as the only procedure 10. Over age 10 years, add triple arthrodesis as the only procedure[29,32,36]
Overcorrected (valgus heel) flexible foot	
<4 years	11. Conservative treatment—UCB, AFO
4–10 years	12. Subtalar arthrodesis (Grice[23], Dennyson[14])
>10 years	13. Triple arthrodesis
Overcorrected (valgus heel) rigid foot	
<4 years	14. Re-STCFR
4–10 years	15. RE-SCTFR plus subtalar arthrodesis
>10 years	16. Triple arthrodesis *or* distraction osteogenesis (Ilizarov)

*Not recommended by either the literature[53] or our experience.

3. difference between the circumference of the calves (average 2.5 cm, range 0 to 5.5 cm)
4. Leg length difference—measurement from the anterosuperior iliac spine to medial malleolus (average 0.6 cm, range 0 to 5 cm).

Flattop talus, a wedged and slightly dorsally displaced navicular, and substantial subtalar changes were found in all patients (Figure 16.3). The same findings were documented by many authors after conservative and operative treatments of clubfeet.[5,12,15,30,48,60]

Of the 29 revised feet, 8 had excellent results, 11 had good results, 8 had fair results, and 2 feet were failures. If we include fair as an acceptable result, then the overall satisfactory result is 93%.

The procedures most commonly used were the extensive STCFR alone or with a plantar release, Evans' procedure, or capsulotomy of the calcaneocuboid joint and capsulotomy of the naviculocuneiform joint (21 of 29 feet, 71%—with an FRS average score of 83, range 74 to 95).

In those cases with tarsometatarsal capsulotomies (3 of 29), the average FRS score was 63, which is in agreement with the literature.[53]

Three patients who had either an underlying disease or a syndrome had poor results: constriction band, lymphocytic leukemia, and a syndrome with imperforated anus, hemivertebra L3, and scoliosis. FRS scores in this group ranged from 47 to 70 with an average of 58. In four patients, overcorrection (heel valgus more than 5°) was the prominent cause for fair/poor results with a score of 47 to 66, an average of 59.

Discussion

The current concept of the initial treatment for clubfeet is repetition of manipulations followed by the application of serial casts.[13] About 30% to 50% of the feet that have this form of treatment will have unsuccessful results and will then need surgical correction.[10,19,20,37,40,49,57,61] An average of 25% (13% to 50%) of the operated feet will have poor results and will need additional surgical intervention.[8,9,30,34,35,41–43,45,50,57,62]

What are the possible causes for this substantial failure rate of surgery? The authors can suggest some possible explanations:

1. In 22% of our revised clubfeet we found talocalcaneal bars (bony or cartilaginous), which might be an important contributing factor to recurrence. The bars might be iatrogenic (injury to the subtalar joint during previous surgery or overlooked during the previous procedure).
2. In all of the revised feet that were operated on, where z-lengthening of the flexor tendons and the tibialis posterior were done, the tendons were encased in scars and nonfunctioning. This might contribute to the recurrent deformity. In view of this observation, the authors now prefer to perform fractional lengthening of those tendons in virgin clubfeet as reported elsewhere.[3]
3. Overcorrection (heel valgus) is another cause of poor results. It seems that the integrity of the interosseous ligament plays an important role in prevention of this disabling deformity.
4. Infection (with scar formation).
5. Inadequate postoperative treatment by the surgeon.
6. Noncompliant parents.

The authors have developed a surgical algorithm that has proved to be useful in decision-making in the reoperated clubfoot (Table 16.2). (For a detailed discussion of how to construct such algorithms, see Fahmy's paper in Chapter 17.—Ed.)

It is hoped that our FRS and treatment protocol will help orthopedic surgeons in selecting the proper treatment and in evaluating their long-term results in this increasingly frequent problem of revision clubfoot surgery.

Summary

The surgical procedure used most frequently for revision surgery was repeat complete soft tissue release alone or combined with plantar release, the Dillwyn Evans procedure, and capsulotomies of the navicular–first cuneiform–1st metatarsal joints. A functional rating system (FRS) was used that included clinical, objective, subjective, and radiographic criteria. The results were 7 "excellent," 11 "good," 8 "fair," and 2 "poor." Collectively, the "excellent" and "good" results amounted to 73% of the cases.

A detailed algorithm that suggests surgical

solutions to a variety of clubfoot deformities in different age groups is presented.

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Clubfoot Revision Surgery

K.N. Kuo, S. Andrews, and J. Lubicky

Even with the best results in the published literature, a certain percent of operated clubfeet will require further revision surgery to correct the deformities.[1,3,4,5] It is our purpose to review the clubfeet that required reoperation and to correlate the types of surgical procedures used with those initial procedures in relation to the final functional, clinical, and radiographic results.

Materials and Methods

From 1981 through 1987 there were 70 patients with 86 idiopathic clubfeet who had previous clubfoot surgery that were referred to the Shriner's Hospital for Crippled Children, Chicago for additional surgical procedures. There were 133 procedures performed on these 86 clubfeet before they were referred to our institution. We performed an additional 98 procedures on these feet at the Shriner's Hospital. The average follow-up was 3.25 years following the last surgery. The average age at initial surgery was 12 months and the average age at revision surgery was 5.5 years. The average number of prior surgeries was 1.5 per foot and the revision surgeries averaged 1.1 per foot.

They were divided into three groups based on the type of the initial operation: group 1, 47 feet with Achilles tendon lengthening; group 2, 6 feet with posterior releases; and group 3, 29 feet with posteromedial releases.

Results

The clinical result was evaluated according to Laaveg and Ponseti's[1] functional rating. The radiographic results were evaluated according to Simons'[2] criteria.

The overall *functional* results showed 18% excellent, 37% good, 24% fair, and 21% poor (Figure 16.4). The results were in reverse proportion to the number of surgical procedures (Figure 16.5). Those feet that had an initial posteromedial release had fewer revisions overall and the best functional results.

Those feet that had the initial posteromedial release performed before 6 months of age had the highest percentage of excellent results (44%) and the fewest poor results (0%) following reoperation. In the group that had initial surgery performed between 6 months and 12 months of age, there were 22% excellent results and 22% poor results (Figure 16.6). Posteromedial releases performed as revision surgery had 78% excellent and good, 9% fair, and 13% poor results.

The radiographic measurements that best

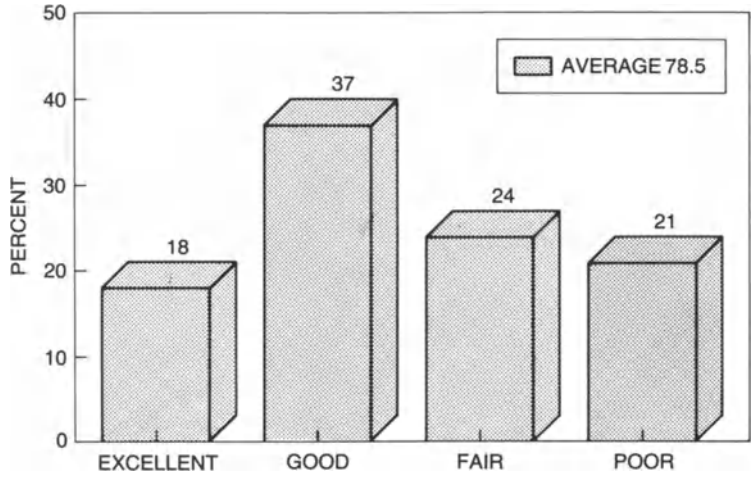


FIGURE 16.4. Overall functional results.

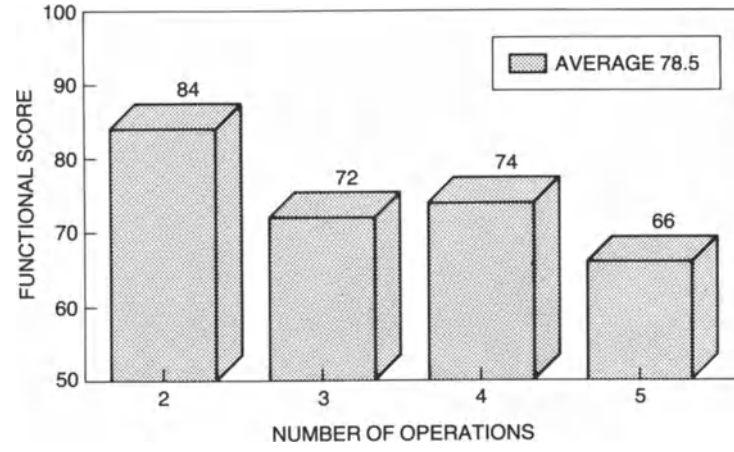


FIGURE 16.5. Number of operations versus functional result.

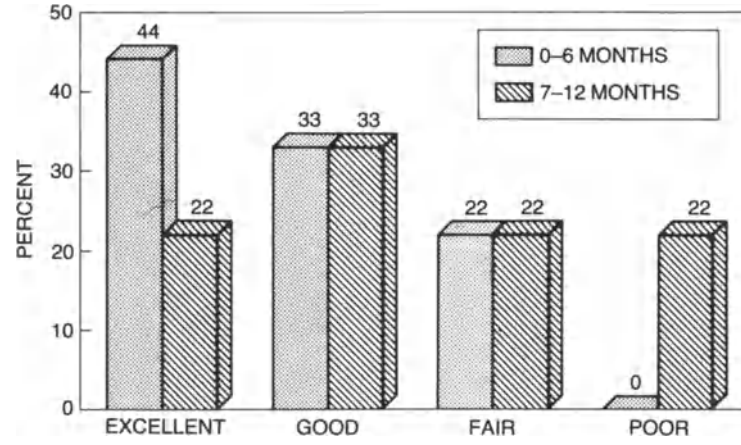


FIGURE 16.6. Age of initial posteromedial release versus functional results.

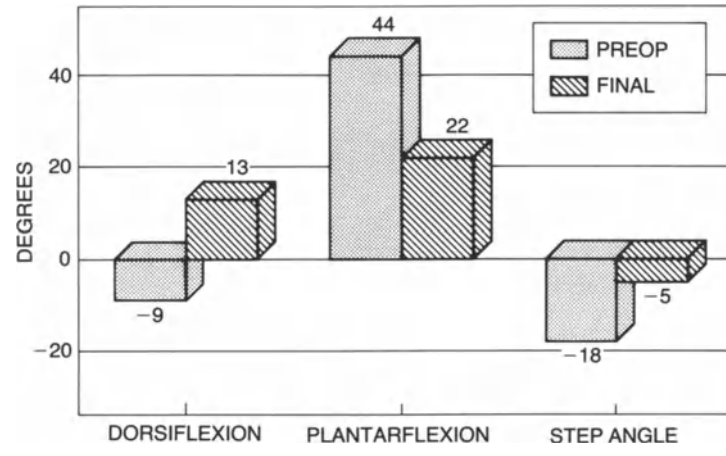


FIGURE 16.7. Clinical results of posteromedial release reoperations.

correlated with the functional outcome were the talar-1st metatarsal angle and the lateral talocalcaneal angle. The increased ankle dorsiflexion following repeat operation was at the expense of decreased plantar flexion; thus, there was no change in the total range of motion (Figure 16.7).

The total period of casting did not influence the final result. Our posteromedial releases performed as revision surgery are comparable with others reported in the literature.[3–5]

Summary

A complete initial posteromedial release yields better (final) results for correction of clubfoot deformities than limited release. Furthermore, patients who had posteromedial release performed before the age of 6 months had the best final result, even though a further operation may have been required. The total range of motion of the ankle joint remained constant, in spite of revision surgery.

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Discussion

Turco (Hartford, Connecticut): We've heard a number of comments criticizing the amount of surgery that was done on some of these patients. Therefore, I would like to present a short historical background. When I first started operating on clubfeet, the standard treatment was to treat children for 4 to 6 years with many operations, followed by years of plaster immobilization. On the last visit at 5 or 6 years of age, the child would be given a brace and the parents told to return when the child was old enough for a triple arthrodesis. I think we have come a long way since those days. We may now be operating on too many feet but I think we're doing much better.

Goldner (Durham, North Carolina): After the Dillwyn Evans procedure, the foot grows more on the medial side than the lateral side as the lateral side acts like a tether. The medial side may overgrow the lateral side if surgery is performed too early, that is, under 5 or 6 years of age. Therefore, I stopped doing the Dillwyn Evans procedure. I now remove a wedge from the cuboid to straighten the forefoot. This straightens the foot but leaves the articular cartilage of the calcaneocuboid joint intact. The wedge resection of the cuboid can be done until the patient is 10 or 11 years of age.

Garcia-Ariz (San Juan, Puerto Rico): I perform a cuboid decancellation of the talus for neglected clubfeet. I make a small window on the lateral aspect of the sinus tarsi, decancellate the whole talus, manipulate and squash it. These feet have had previous soft tissue releases. Then decancellation of the talus is done at 8 to 10 years of age. Although the number of cases is small and the follow-up is only about 5 years, I've had very good results.

Lehman (New York City): Another similar procedure is a decancellation of the cuboid, the talus, and the calcaneus. The bones are squashed, the foot put into the desired position, and is held in that position for several weeks. A week or two later, the foot is remolded again. It will ultimately be stiff, but is a nice looking, functional foot.

Brown (Halifax, Nova Scotia): In his original paper, Dillwyn Evans transferred the tibialis anterior but he stopped doing that.

Turco: As described by Dillwyn Evans, his procedure consists of a complete soft tissue release plus a calcaneocuboid fusion but without a tendon transfer. I think this is the generally accepted view of Dillwyn Evans' procedure, although surgeons erroneously refer to it as only a calcaneocuboid fusion.

Stuart (Nairobi): The Dillwyn Evans procedure was described for the *relapsed* clubfoot. The average age of the patient at the time of surgery was 7 or 8 years.

Lehman: I have been doing the Ilizarov procedure for the relapsed CTEV. I can assure you, this procedure when used on the clubfoot has a number of problems associated with it. One is getting the correction. The other is maintaining the correction. Two separate efforts have to be made. First, to obtain correction, one must determine whether there is deformity that requires only osteotomy, as opposed to the foot that requires long-term retention of the correction but does not require osteotomy. Second, to be able to keep the correction once it is obtained, one must determine whether there is muscle imbalance in the foot and thus, the need for tendon transfer. However, this technique presents an opportunity to salvage feet that would require considerable shortening if a triple arthrodesis were performed.

Turco: We have not discussed the triple arthrodesis. I would like to ask if there is a place for triple arthrodesis and if so, what are the problems with the triple arthrodesis in the clubfoot?

Lehman: I use triple arthrodesis. I believe it's a great salvage procedure, but I've never seen a happy patient with a triple arthrodesis. The stiffness causes them to walk in an awkward manner. It's not a pleasing operation and should be saved as a final step. We have done many of them in neglected clubfeet at 30 or 40 years of age. Bedouin Arabs can't get married unless they have a plantar grade foot, so we have given them plantar grade feet. They ran and played and climbed ladders with their neglected clubfoot. After their triple arthrodesis, they looked better but didn't function as well.

Goldner: First of all, the results of a triple arthrodesis depend upon the ankle joint. If one has a good ankle joint, one is likely to get a good result. If there is rocker-bottom or cavus deformities that aren't corrected when the triple arthrodesis is performed, one will have a poor result.

I now use it primarily in patients who have had two or three extensive soft tissue procedures. Their foot is in good position but they have pain and may have developed degenerative arthritis as young as 12 to 15 years of age. That's the reason I believe that follow-up must be at least 15 years. Instead of talectomy, I use a triple arthrodesis or a pantalar arthrodesis when the ankle is also involved, and put the feet at a right angle, correct the cavus, line it up with the knee joint. These feet do very well.

Stuart: I still find a place for Whitman's talectomy in the badly neglected clubfoot. I also feel there is a place for it in cases where very early surgery was done badly. I'm still trying to work out the indications.

Kuo (Chicago): The oldest soft tissue procedure I have done on a relapsed clubfoot was in a patient 8 years of age; the oldest bony surgery on a neglected clubfoot I did was in a patient 15 years of age. In the latter case, I was able to correct the foot deformity with a combination of soft tissue and bony procedures. I really don't think talectomy is a procedure to be used for the idiopathic clubfoot. The only patients who need talectomy, in my opinion, are those with very rigid neurological problems, such as arthrogryposis. One thing about talectomy, even in arthrogryposis: after the talus is removed, the lateral column must be shortened because it becomes too long.

Turco: To do a talectomy, one must remove all of the talus. One must also displace the foot posteriorly. I would suggest that a pin be driven right up into the tibia to make sure it is held there, otherwise one will be dissatisfied. There is rarely an indication for doing a talectomy.

Watts (Los Angeles): Dr. Lehman, your comment about the Bedouins not being able to get married until their feet are plantar grade raises another issue. If you've dealt with the Bedouin Arabs as I have, then you know that we are talking about a totally different population. A person who has been walking on the dorsum of his feet for 15 or 20 years and who is very un-

happy with his triple arthrodesis is not comparable to the patient that we see in this country. I think the same can be said if one is comparing talectomies. We're really talking about a totally different type of patient and quality of life. I can tell you that many Bedouins who have had their deformed feet straightened look much better but have a painful foot. Many of them end up with a Syme's amputation, then walk as well as they did before they had their surgery.

Editor's Comments

Lehman et al. report a 22% incidence of talocalcaneal bars in their CTEV requiring previous surgery. These were attributed to bars overlooked at the initial surgery or iatrogenically caused by trauma of the original surgery. In our early cases, we frequently found what we thought were bars at the medial anterior aspect of the subtalar joint. However, with further experience we came to realize that dissection in this area is extremely difficult at times and that one may cut through the cartilaginous portion of the sustentaculum tali, rather than dissecting into the true subtalar joint at this level. Therefore, I would disagree with the authors that there is a significant rate of bars that were probably overlooked at the initial surgery. However, in the case of the arthrogrypotic foot a true bar is often present in this area.

These authors also reiterate a commonly held view that a frequent cause of overcorrection of the heel (valgus) is the apparent lack of integrity of the interosseous ligament, as it plays an important role in the prevention of hindfoot valgus. As far as the editor is aware, there is very little, if any, documented evidence to verify this view. In reviewing our cases retrospectively (documented with preoperative, interoperative, and postoperative radiographs), it was determined that the great majority of feet that subsequently were found to be in valgus when the navicular eventually ossified were, in fact, in valgus at the time the foot was pinned (see Chapter 15, Editor's Comments). A second cause of valgus is the failure to identify and treat calcaneocuboid subluxation (see **Thometz and Simons**, Chapter 8). When the navicular is reduced, it pushes the cuboid laterally, which, in turn, pushes the calcaneus laterally. If the talonavicular joint is overreduced, the calcaneus will be also.

Finally, a small percentage of patients (less than 10%) had normal reduction and pinning, but did gradually drift into valgus over a 1- to 2-year period. I believe that ligamentous laxity may have been responsible in those cases. Once we identified one of the causes as a technical error rather than as an error of omission, we were able to develop clinical and radiographic parameters to prevent this problem, which subsequently resulted in a significantly reduced incidence of this complication.[1,2]

The editor must agree with the comments of **Goldner**, **Kuo**, and **Turco** (in the Discussion section) regarding the indications for talectomy. I look upon the talus as the keystone of the foot. Once this is removed, it is very difficult to maintain the foot in good functional alignment with both the lower leg and the floor. The foot tends to rotate as well as to invert, and may become unstable and painful. Therefore, results can be very poor following this procedure and there is no satisfactory "salvage" procedure available other than to arthrodese the calcaneus to the tibia. Rather than talectomy, I prefer to "work around" the talus, e.g., in the older child with a flattop talus, in which the hindfoot is in calcaneus, valgus, or abnormal position, the U osteotomy described by **Paley** (Chapter 11) would be a more satisfactory solution than talectomy.

References

1. Simons, G.W.: Lateral talo-navicular subluxation—A complication of extensive soft tissue release for club feet. *Orthop. Trans.*, 8:448, 1984.
2. Thometz, J.G. and Simons, G.W.: Deformity of the calcaneocuboid joint in patients who have talipes equinovarus. *J. Bone Joint Surg.*, 75A:190–195, 1993.

Summary of the First International Congress on Clubfeet

S.S. Coleman

When George Simons asked me to summarize this congress, I found that he is very difficult to refuse; on the other hand, I knew the minute I hung up the phone that I was probably dealing with an impossible task. I wondered how anybody could summarize a group of papers presented by a large number of type A personalities to an equal number of class A personalities whose minds have already been made up, and who are going to say, "Well, I'm going to do it my way no matter what." Nonetheless, I would like to tell you what I have learned.

First, the discussion about *etiology* was very important. It was rather impressive to me that there is something basically wrong with the clubfoot musculature, namely type 1 fiber predominance and type 2 fiber deficiency. In addition, cast immobilization has no effect upon these findings. Therefore, the etiology of CTEV must be a genetic or a congenital phenomenon.

Second, I thought the theory of the *vascular etiology* was extremely important, because it explains some of the problems that we run into. Dr. Goldner has already mentioned several cases with vascular complications, and I have been asked my opinion about a case where the great toe was lost. We heard cases presented that show that we need to be consistently aware of the tremendous variation in the vasculature of the clubfoot. Although most of us knew that, it nevertheless imposes upon us a responsibility to be aware that there are potential problems every time we operate on a clubfoot. The question of the epidural anesthetic is something that we should really take a strong stand on, because if it is dangerous, I think we ought to go to our anesthesiologists and tell them that it isn't safe. I thought that was a contribution.

We discussed the *evaluation* of CTEV. My first committee appointment by the American Academy of Orthopedic Surgeons was on a result evaluation committee. We met for 2 years and finally came to the conclusion that, unless there is a very good, well-proven, and agreed upon preoperative evaluation, a postoperative evaluation is useless. So, I think what you were talking about earlier, Dr. Watts, is that we must decide which criteria are important and determine standards for their measurement. There are tremendous variations in TEV that must be classified and evaluated.

We all agreed that preoperative *radiographs* are important, but there was a great deal of controversy about intraoperative radiographs. Many questions were unresolved: Does the potential parallax problem reduce their helpfulness? How can we standardize the way the films are being taken? Who is going to risk his hands holding the films? Who is going to measure the films? Watts claims that there is as much as 15% variability in his cases, which means a 30% variability in a measurement that is crucial in deciding whether or not to perform surgery. It was agreed that it is helpful to take postoperative radiographs to evaluate what we've done.

Vascular monitoring using the Doppler and the oxygen pulsimeter was discussed by Crider and his colleagues and by Stanitski, but the question of whether the findings indicate any-

thing more than the efficiency of capillary refill or the vascular appearance of the foot was left unanswered. There was a great controversy about the need for routine vascular monitoring.

We spent very little time on *nonoperative treatment*, which I think might have some meaning. Dr. Zimbler said that he was able to correct only 10% of his CTEV nonoperatively. I know Lovell and Kite would probably have indigestion if they heard those comments. Kite felt it was an admission of total failure if one had to operate on a clubfoot. I think that there may be a place for nonoperative treatment, but no conclusion was reached about this.

We didn't spend much time speaking about *postoperative management*. We talked in vague generalities of physical therapy, manipulations, and observation but we didn't talk about whether patients should have bracing or splintage. If immobilization is used, for how long should one use it and what criteria should one use? I think it's almost as important an issue as the surgical procedure itself, and that brings us to the surgical issues.

We gave Dr. Crawford great credit for popularizing Giannestras' *Cincinnati incision*. A poll taken of the audience was four to one in favor of the Cincinnati approach. However, as Crawford appropriately pointed out, the incision is not as important as what you do when you get in there.

I think there is a lot to be said for the learning curve that we experience when treating clubfeet. I treat clubfeet differently now than when I started, not because I use a different incision, but because of new information that came along around 1988, the meaning and historical importance of which Crawford beautifully reviewed for us. For many years, the importance of the lateral corner and the lateral side of the foot was ignored, or at least not well known. Did we go through the same learning curve years ago with the Turco procedure and are we now going through it with the Cincinnati approach, only with a different incision? I think I'm doing the same releases that Dr. Crawford does. I just do them with a different incision. I would be willing to put my results up against his, but I would hate to compare my results in 1980 with his results in 1990. So I think the learning curve is an important consideration.

Dr. Grant discussed *wound closure* and *wound healing*. He stated that skin expanders are needed only in rare cases, and in very difficult cases some surgeons even leave the wound open. However, I think if you can't close a wound, you can get help with the cosmetic appearance. Plastic surgery might be considered in difficult cases where there is a good possibility of subsequent surgery.

The importance of the *calcaneocuboid joint* was discussed by Malan, Thometz, and Simons. Although Simons has brought our attention to its importance in the first few months of life, I had difficulty accepting this, because it seemed a problem only in older children. I think most of us agree that the decision to excise a capsule and push the foot over, or to shorten the calcaneus, or to shorten the cuboid can have a tremendous impact in the older child. But in the younger patient it is not really that crucial. The important thing is that we recognize that the calcaneocuboid joint is a major component; how we handle it is an individual decision.

We discussed *talar neck osteotomy*. Ozeki said he was thinking about discontinuing its use as have Roberts and others who have used and abandoned it. So, apparently the talar neck osteotomy, which was performed to correct the deviation of the talar neck (described by Irani, Sherman, and Settle) is no longer widely used. It is arguable whether angulation of the talar neck is primary or secondary, but trying to correct this angulation creates a high risk of pressure necrosis. Some surgeons feel it's not worth the risk. A significantly high percentage of avascular necrosis, which was anticipated by Ozeki and his colleagues, was not found. Dr. Hitachi does not think that deformity of the talar neck is a major factor in the presence of the adduction deformity of the foot.

I thought that some of the *new procedures* were provocative, although I may not be convinced enough to try them, particularly widening of the tibia to correct circumference discrepancy of the calf. I still also have reservations about correcting leg length inequalities while simultaneously correcting the clubfoot and widening the bone, especially when as much as 1,000 cc of blood can be lost in one operation.

Transfer of the anterior tibial tendon is a procedure that I have used often in older children for supination and for inversion deformity, which appears to be due to muscle imbalance. I was pleased to see that the transfer of the

anterior tibial tendon is considered an acceptable procedure with the proper indications, and I was very delighted to hear two or three of the authors agree that there is a place for this. I think it is now our job to find its indications.

Malan believes that *lengthening the anterior tibial tendon* is an important factor in persisting clubfoot or in prevention of correction. I have had to lengthen the anterior tibial tendon two or three times. When I reflect on at least 1,000 clubfoot procedures that I've done, I don't think that I have lengthened it very often and wonder if I should have done it more often.

Barnett's *separation of the medial and lateral columns* for dorsal subluxation of the navicular to reduce the subluxation without tension seems very logical and may turn out to be a significant contribution. I am going to learn more about that because we all have either produced a dorsal talonavicular subluxation or inherited one.

Kuo described his so-called *reverse Jones (dorsal bunion)* operation, which is not truly a "reverse" Jones procedure because the IP joint is not fused, whereas the IP joint is fused in the Jones procedure; however I think the principle is the same.

The complications of *valgus, calcaneus, and cavus* were discussed. Weiner's procedure is not a primary clubfoot procedure, but is a salvage procedure for cavus deformity in a patient who has a corrected hindfoot. That's important to emphasize, because one cannot correct the hindfoot with a midfoot procedure.

The *release of the medial insertion of the anterior tibial tendon insertion* from the 1st metatarsal was described by Abberton for nonfixed supination deformity. The *Heyman-Herndon procedure* with *osteotomy of the base of the 2nd metatarsal* was suggested by Smith and Weiner as a means of mobilizing the forefoot more easily in the fixed deformity. I stopped performing Heyman-Herndon capsulotomies years ago, but the addition of the 2nd metatarsal osteotomy may be useful with these capsulotomies. We all agreed that the cuneiform osteotomy is a well-established operation that corrects that peculiar angular deformity of the tarsometatarsal joint. If this is accompanied by a closing lateral wedge of the cuboid and the wedge is put into the first cuneiform, this seems to give good correction to the forefoot. Goldner should be given credit for these *combined midfoot osteotomies*.

I've had a *compartment syndrome* in the foot and learned that it can be disastrous not to recognize and release those compartments in the foot (not in the calf, but in the foot). It's all a matter of early recognition, because if you recognize it, then the foot can be salvaged, although some feet and some portions of feet may not be able to be saved in very bizarre neurovascular situations. The issue of *epidural blocks* in clubfeet surgery must be investigated further.

Dr. Szabo explained *variations of the ossification centers* and their relationships to the soft tissues. Turco discussed a large series of *failures of primary surgery* and some of the reasons for these failures.

There does not seem to be a good solution for the *flattop talus*. The only solution is prevention, but even though it may occur, it does not seem to present a big problem.

I had difficulty in putting the *comparative evaluations of different surgical procedures* into perspective. It has to do with experience, how skilled one is at reaching difficult places, and how one respects different tissues.

I would like to mention several areas that should be considered if another international clubfoot congress is held. We touched on the issue of *internal tibial torsion* and whether or not it exists. If it does exist, how do we assess it? What do we do about it? At what age should it require treatment? We didn't talk about the *teratologic foot*, but should discuss it in detail because we no doubt share terrible problems with the teratologic clubfoot because of recurrences, and we need to discuss measures for averting this. Why do I have a marvelous result on patients at ages 2 or 3, and at the age of 6 the patient returns with bad recurrence? I cannot understand what has happened. We must try to find out why *recurrences* take place.

Dr. Simons, again, thank you for the opportunity to summarize this congress and to tell you what I have learned. I hope it reflects what the rest of you have learned and what you'll take home with you.

17
Additional Papers

Introduction

As with any gathering that is global in both scope and attendance, time put strict limits on the number of papers that could be presented at the First International Congress on Clubfeet. Well over 100 abstracts were received, 86 of which we were able to present when the meeting was extended from one day to a day and a half. Several papers that were submitted but not presented due to limitations of time or content, or not received prior to the congress, are presented in this chapter.

In the first paper, **Fahmy** and **Fahmy** distill data that they derived from the abstracts presented at the congress and formulate it into algorithms for practical application as a tool for clinical decision-making by means of artificial intelligence. They therefore synthesize a very large body of knowledge, necessarily simplifying some information, in order to systematize it for programming into a computer for easy storage and retrieval. As with any surgical tool or method, such as the use of an intraoperative radiograph or of a Cincinnati incision, individual surgeons are free to adopt, modify, or disregard this algorithmic approach to arriving at the best treatment solution. The reader is reminded that this is a retrospective paper and that some material in the expanded papers written since the congress was not available to these authors.

Kinoshita, **Onomura**, and **Okuda** are as yet unable to report final results of their modified Morita's therapeutic system because their cases have a short follow-up. However, they report good clinical appearance, radiographic findings, and function to date.

Redon and **Mendoza** provide the results of their small series in a study evaluating a treatment protocol established at their institution in 1989. The value of these results, unfortunately, cannot be properly assessed since the criteria for evaluation consist of parameters that have not been generally agreed upon by a majority of individuals prominent in this field.

Abberton describes a very specialized procedure (posterolateral release) for revision surgery on a small number of patients and notes that "the operation is limited in its indications, making evaluation in other than anecdotal terms impossible."

Sengupta and **Gupta**, using subcutaneous tenotomies and subcutaneous plantar releases, base the results of their method of management of CTEV on three main points: (a) cosmetic appearance and acceptance by the patient, (b) gait, and (c) squatting. They provide the perspective of treating clubfoot deformity in developing Third World countries, without many of the technical advantages of modern surgical practice. As the authors observe, the burgeoning population in these countries makes inexpensive and readily available treatment methods a pressing need for the future.

In the final paper, **Hitachi** describes his detailed approach for the conservative treatment

of clubfoot and the anatomical studies carried out early in the course of his 30 years of practice. Some ideas vary with those currently held by many authors, yet others have been generally established (see page 565). Unfortunately, **Hitachi** has not provided scientific documentation in support of some of his more provocative conclusions.

Preparing the Findings of the First International Congress on Clubfeet for Computer-Assisted Decision-Making

W.M. Fahmy and H. Fahmy

The First International Congress on Clubfeet has provided a forum to update facts derived from the abstracts of this congress.* The following general trends were deduced:

Growing interest in the clinical implication of the vascular and neurogenic theories of etiology
Age, stiffness, location of the deformity, and socioeconomic environment as determining factors in almost all treatment methods
Awareness of the need to develop quantitative evaluation systems
Increasing interest in forefoot and midfoot deformities and in lateral column procedures
Sporadic attempts to improve the cosmetic appearance of thin calf in clubfoot patients
Occasional reliance on documented algorithms, but rare use of the computer as a tool for clinical analysis.

This paper discusses how the abundant information in the findings of this congress can be formulated into conditional statements and then into algorithms, which are the initial phase in customizing a computer-assisted decision support system (CDSS).

*For the reader's convenience, we have indicated the author's name and chapter number for each paper in this monograph (e.g., "Kuo:7"). A Glossary is provided at the end of this paper.—ED.

Orthopedic Applications of Artificial Intelligence

Traditionally, an *expert system* (ES) copies declarative and procedural expertise, whereas a CDSS models the problems by quantifiable attributes. Both can rationalize decision by utilizing *conditional rules* (CR). In clinical applications, a CDSS supports human judgment interactively by the processing and storing capabilities of the computer.[6]

The most common orthopedic applications of artificial intelligence are in the fields of informatics and imaging, whereas ES and CDSS are largely neglected and robotic applications are restricted to a few trials of handling microsurgical equipment.[2] *Imaging applications* involve finite analysis of computer graphics (pixels), such as Rab's three-dimensional biomechanical model of a clubfoot (Rab:2), and *informatic processing* involves the retrieval of selective data[5].

The CR is formed by a sequence consisting of an antecedent condition that is governed by an IF factor, the premises of which are controlled by relation operators "<" and ">" and a consequent action or rule that is governed by a THEN statement. The function of each CR depends on its sequence within the hierarchy of the computer program. For instance, *procedural rules* are usually found at the beginning of the program as an "inference

mechanism" (e.g., see Table 17.2). The sequence of these procedural rules constitutes the "algorithm" of the management steps.[1] *Production rules* are located toward the end of the program and synthesize specific information from a corpus of knowledge (e.g., see Tables 17.4–17.7).

Computer Programming Techniques

The method by which a computer program is written is determined by the predominant type of knowledge in the corpus (technical, mathematical, statistical, or in-rules) and by the nature of the problem (diagnostic, prognostic, or therapeutic). We formulate a mathematical equation using statistical factors derived from a *statistics base* as described in the Discussion section. These statistical factors are multiplied by specific x-ray parameters, such as those for the prognostication of "early" and "intermediate" stages of CTEV (Yamamoto:4). We also model the later stages of CTEV by a mathematics base that quantifies the involved structures from a matrix i.e., a table (Carroll:3). A readily structured rule base is provided in Table 17.1B (Carroll:3), which is comprised of production rules for alternative therapeutic measures.

TABLE 17.1A. Early management of CTEV based on Carroll's clinical categories.

Freedom of movement (*fm*) Deformity (*df*)	A	B	C	D	E
Fixed forefoot supination	1	0	0	0	0
No midtarsal mobility	1	0	0	0	0
Medial/posterior skin creases	1	0	0	0	0
Curved lateral border	1	0	0	0	0
Cavus	1	1	0	0	0
Navicular fixed to the medial malleoli	1	1	1	0	0
Os calcis fixed to the fibula	1	1	1	1	0
Fixed equinus	1	1	1	1	1
Calf atrophy	1	1	1	1	0
Posteriorly displaced lateral malleolus	1	1	1	1	0
Severity of contracture scores	10	6	5	4	1

Clinical Classification Systems

The basis for both information processing and digital imaging is classification. Stated very simply, every bit of information is given a label to make it available for processing. The processing itself is carried out by means of digital (binary, or "on" or "off") electronic signals to the computer's microprocessor and control units by which "yes-no" and "if-then" gates are controlled.

Medical descriptions in general, and orthopedic problems in particular, are characteristically systematic; i.e., there are common and regular features that form patterns, the basis for medical informatics.[1] These regular features allow us to record, communicate, and model the clinical features of the pathology (deformity) by using clinical evaluation/classification grading systems, such as those presented in Chapter 3.

TABLE 17.1B. Algorithms for releases according to category of contractures (following manipulation).

IF	Clinical category (Ag < 6)	Repeated cast and manipulations	THEN Goto	Type of release
"	A	"	→	Lateral column + plantar + medial + posterior
"	B	"	→	Plantar + talar + calcaneal + fibular + posterior
"	C	"	→	Medial + posterior
"	D	"	→	Talocalcaneofibular + posterior
"	E	"	→	? No release

TABLE 17.2. Algorithms for lateral column (calcaneocuboid joint) release by radiological grade according to Thometz and Simons.

IF	Radiological grade	*df/fn*	THEN Gosub	Procedural rules to subsets of production rules
"	0 & 1	3	→	No operation
"	2	2	→	Capsulotomy, resection, manipulation, and pinning
"	3	1 & 0	→	Bone procedure and retention

TABLE 17.3. Algorithms for early management and internal fixation.

IF	*fm* > 1 and	THEN Goto	Procedural rule
			Manipulation:
"	*ag* < 6	→	2/d by parents
	SEP > 111		
			Internal retainers:
"	*ag* < 4	→	Lever by K wire post. lat. talus. K wire or Steinman pin 6 to 8 weeks
	SEP < 111		Permanent suture fib. to 5th metatarsal
			External retainers:
"	*ag* < 6	→	Holding cast
	ag > 6		Wire traction cast
	SEP > 111		Articulated splint

TABLE 17.4. Algorithms for late management of adduction and supination deformities.

IF	Condition	THEN Goto	Production rule
	1–2 years old		Soft tissue procedures:
"	*df* = 2 and *SEP* < 221	→	Anteromedial release, y-y tendo Achilles, tendon tract capsulotomy
	df < 2 and *SEP* > 111		Ilizarov
	2–5 years old		Soft tissue + bone procedures:
"	*df* = 2 and *SEP* < 22	→	Tarsometatarsal release + tendo Achilles + 5th metatarsal base osteotomy
	df < 2 and *SEP* < 22		Evans procedure
	df < 2 and *SEP* > 111		Ilizarov closed
	5–9 years		Bony procedures:
"	*df* = 2 and *SEP* < 22	→	Cuneiform opening wedge
	df < 2 and *SEP* < 22		Cuboid closed wedge + opening m. cuneiform + talar neck osteotomy + bone graft
	df < 2 and *SEP* > 111		Skin expander

TABLE 17.5. Algorithms for late management of cavus deformity.*

IF	Condition	THEN Goto	Production rule
"	$df = 1 = \leq 40°$ and $ag > 9$ m	→	Tarsometatarsal → > 6 wks posterior release ± tibialis anterior trans. to lat. axis
"	$df = 0 = < 40°$ and $ag > 36$ m	→	Osteotomy 2nd metatarsal base
"	$df = 0 = < 40°$ and $ag > 72$ m	→	Oblique osteotomy + release abductor quinti + adductor hallucis
"	$df = 0 = < 40°$ and $ag > 72$ m	→	Akron dome osteotomy
"	$df = 0 = < 40°$ and $SEP =$ 112 (psy-cosmetic)	→	Akron dome osteotomy + claw toe correction

*Variable df = Meary's angle ± 40°.

TABLE 17.6. Algorithms for late management of equinus, thin calf, or tibial torsion.

IF	Condition	THEN Goto	Production rule
"	Equinovarus $[df_{(1,8)}]$ and 5–9 yrs	→	Triple fusion or V osteotomy + Ilizarov
"	Pain = claudic'n $p > 1$	→	Compartment syndrome → decompress
"	Tibial torsion $[df_{(1,7)}] < 2$ and 1–3 yrs and $SEP > 111$	→	Ilizarov
"	Tibial torsion and 3–9 yrs and $SEP > 111$	→	Ilizarov + osteotomy
"	Thin calf $[df_{(2,6)}] < 1$ and 3–5 yrs and $SEP > 112$	→	Resect fascial envelope (deep and superficial)
"	Thin calf and 5–9 yrs and $SEP > 221$	→	Ilizarov longitudinal split tibia and fibula

TABLE 17.7. Algorithms for late management of valgus deformity.

IF	Condition	THEN Goto	Production rule
"	Dorsal bunion $(df_{(1,12-13)} < 3]$ and $ag > 36$ m	→	Reverse Jones
"	Dorsal talonaviculocuneiform subluxation $[df_{(2,10-11)} < 3]$ and $ag > 36$ m	→	Reassemble medial column of midfoot and forefoot (Barnett)

Preparing Data for Computation

To use the computer's "if-then" analytical ability to solve clinical orthopedic problems, the first step is to determine the weight of significance, the clinical types, and the dimensions of the attributes of signs that are used in diagnostic modeling. The next step is to develop premises for the attributes in the condition rules (CR). An example of a CR can be found in the oldest medical document in the world, the Edwin Smith papyrus: "if there is blood issuing from the ear" (condition) "and the neck is stiff" (condition), "this I cannot treat" (con-

sequent statement).[3] In modern literature a CR may not be readily apparent. It is often necessary to look for such terms and grammatical signals as "when" and "since" as the *if* clause of a condition and conclusive terms such as "therefore," "thus," etc., as well as colons, semicolons, and commas as the *then* consequent component.

Instrumental Signs for Computation

The deformity of congenital talipes equinovarus (CTEV) involves many interrelated factors such as stiffness, site of lesion, and the like, with consideration for age and economic status. The attributes of these criteria constitute the conditional premises of the CR. Almost all descriptive terms can be translated to measurable units. The number of these units should be restricted to alternative consequents (e.g., solutions). Normalization of heterogeneous measuring units is only required in comparative decision analysis. This may be achieved by mathematical conversion or functional conversion using either (x,y) vector or linear scale transformation.[4] The defective function of *deformity* variable (*df*) is estimated from a matrix of the involved structures, represented by $df_{y,x}$. The subscript $_{(y1-3)}$ represents dorsal, plantar, and lateral functional units of the foot and ankle, respectively, whereas subscript $_{(\times 6-13)}$ represents proximal $_{(\times 6)}$, distal tibiofibular $_{(\times 7)}$, ankle $_{(\times 8)}$, subtalar $_{(\times 9)}$, midtarsal $_{(\times 10)}$, tarsometatarsal $_{(\times 11)}$ metatarsophalangeal $_{(\times 12)}$, and toe segments with its skin envelope. The direction of deformity is estimated by mathematical function from vectors of the involved and adjacent segments of deformity variables; in newborns, the direction is determined by skin creases. The range of *freedom of movement* (*fm*) is measured as a percentage of the reducibility of either the hindfoot or the forefoot (Dimeglio:3); from this percentage a range from normal of 0 to 3 is deduced. It is customary to correlate *function* (*fn*) with (*fm*).

The factor of *age* (*ag*) is conventionally the key to algorithmic management, which reflects a relationship between soft tissue and bone structures. "Early" as a subfactor of age indicates newborn and infants before 8 months of age; "intermediate" indicates children 8 to 18 months of age; and "late" indicates children up to 8 years of age. After 8 months of age, radiological parameters can be used to evaluate progress precisely.

A compound variable for *social*, *economic*, and *psychoaesthetic* (*SEP*) factors is represented in its average normal status by 111, or "one" for each of the three component factors. In unbalanced situations, we either add or subtract "one" from the respective components of this variable. The following CR illustrates this variable:

IF only socioeconomic conditions are low ($SEP = 001$), or when continuous physiotherapy is available ($SEP = 121$) (Bensahel:7), THEN mini procedures and percutaneous tenotomy are justified (Sengupta:17).

Etiology

The neurogenic hypothesis of the etiology of CTEV is supported by morphometric and enzyme specific histochemical staining, which shows a predominance of type 1 fiber and deficiency of type 2B fiber in intrinsic muscles, pointing to abnormal muscle development (Mellerowicz:1). These changes may be due to transient neuronal compromise (Kojima:1). Slow-twitch type 1 fibers are a feature of Charcot-Marie-Tooth disease, cerebral palsy, and lumbosacral agenesis (Shimizu:1, Handelsman:1). In 14% of cases, muscle anomalies are found in the form of accessory soleus and flexor digitorum accessorius of Turner (Sodre:1). There are electromyogram (EMG) changes in 75% of cases in the form of reduced extensor digitorum brevis motor unit counts and motor conduction amplitudes, but nerve conduction velocity is normal (Martin:1).

The vascular etiology is supported by evidence of abnormal arterial angiography in 90% of cases studied (Hootnick:1). This observation is confirmed in 50% of cases studied by color Doppler imaging (Schwartz:1). The finding of reduced midline metatarsals points to the occurrence of the lesion after the "specification" phase when the response for bone and soft tissue has terminated (Hootnick:1). Furthermore, 20% of clubfeet showed retarda-

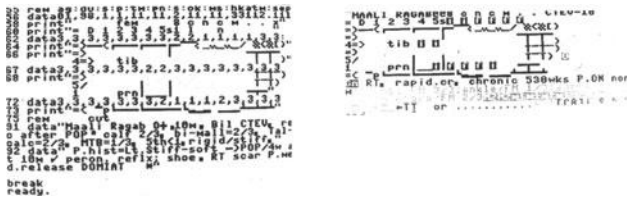


FIGURE 17.1. A matrix showing a three-dimensional composition of the foot. The top row denoting the big toe and its nail shading represents the dorsal functional side; the middle row represents the plantar surface; and the third row represents the lateral side and intrinsic action. This figure is an example of how deformities can be generalized from descriptive terms to functional values. Input requirements are met by factoring in the weights for the defective function of deformity variable *(df)* and all related signs in the uppermost row of the matrix.

tion of tarsal ossification in the form of (a) flattening of the trochlea; (b) flattening of the talar neck; (c) development of multiple ossification centers of the navicular, os tibiale externum, and os trigonum; and (d) development of navicular necrosis (Szabo:14; "Effects of Soft Tissue . . .").

This balanced emphasis on the neurogenic and vascular etiologies inspired our developing a three-dimensional characterized matrix model of the dorsal, plantar, and lateral aspects of the leg and foot in the form of arrays as a clinical acquisition frame on the computer screen. Functional deficits rather than anatomic deformities are displayed (Figure 17.1).

Early Clubfoot Management (Birth to 8 Months)

Clinical Categories

There are four traditional clinical categories ("valgus" as the result of overcorrection has recently been added as a fifth category) that model pathological subtypes to outline the management and outcome of the treatment of CTEV. Here are the *conditional rules* derived from these categories:

IF there is an anterior crease $[df_{(3,8)} < 3]$, THEN this is a resolving (postural, reducible) type.

IF there is a posterior crease $[df_{(1,8)} < 3]$ *and* stiffness (i.e., the forefoot is 60% reducible in both the horizontal and sagittal planes $[fm = 22]$), THEN it is a fibrous tendon type. The following statements apply:

It is generally accepted that manipulation may be effective until 8 months of age.
Only selective release is advocated because of the risk of overcorrection.
A satisfactory result can be expected in 95% of the cases.

IF there is a supinated forefoot $[df_{(3,9-10)} < 3]$, i.e., peroneus longus function, *and* stiffness (i.e., less than 60% reducible in both the horizontal and sagittal planes $[fm = 7711]$) of two segments, *or* a rigid posterior $[fm = 01]$ *and* medial crease $[fm = 01]$, THEN it is of the contracted, resilient, fibrous (stiff-soft) type, which occurs in 30% of cases. It is managed by tailored releases according to contractures (Table 17.1A,B) and has a 95% satisfactory result.

IF there is bilateral involvement $[si > 1]$ *and* stiffness with less than 30% reducibility *and* shortness $[df_{(7-10)} = 0]$, THEN it is of the teratogenic type, which occurs in 9% of cases. More than one procedure is needed in 40% of cases with a 50% satisfactory result (Dimeglio:3).

IF there is stiffness $[fm = 1]$ with pronated forefoot $[df_{(1,10-11} < 3]$ *and* hammertoe $[df_{(1,12)} < 3]$ $[df_{(1,13)} < 3]$ (Catterall:3), THEN it is a sequela of false correction.

Management Algorithm

Early management CRs are provided in a matrix of 10 physical signs with a scale of scoring

units from A to E (Carroll:3). Four of these rules are elective release procedures. Attributes of these 10 signs are shown in Table 17.1A,B. Recurrent cases not accounted for by Carroll's scoring system are covered by the following CR:

IF the child is 10 to 12 months of age [$ag > 10$ and $ag < 12$] *and* there is stiffness [$fm = 2$] *or* relapsing course [$cr > 2$], THEN complete subtalar release is needed (Thometz:8). The following technical statements also apply:

Vascular deficiency of the anterior tibial arterial system is present in 90% of cases (Hootnick:1,14).

The Cincinnati incision is suitable as a secondary approach with poorly healed scars (Sodre:7).

It is advisable to preserve the talocalcaneal interosseous ligament (Yamamoto:4; "Modified Posteromedial Release").

It is recommended during z-lengthening of the flexor hallucis longus and the tibialis posterior tendon to keep above the malleoli to preserve the pulley mechanism (Handelsman:1; Pandey:16).

To achieve accurate reduction of the subtalar joint, the sustentaculum tali must be located in the middle third of the plantar surface of the talus (Barnett:7).

The objective of delayed release after 10 to 12 months is to avoid operative scarring (Kinoshita:17).

Conditional Rules for Manipulative Treatment

The methods of treatment are governed primarily by the variables of *age* (*ag*) and *freedom of movement* (*fm*). Here are the conditional rules:

IF the child is under 3 months of age [$ag < 3$], THEN the consensus is treatment by manual manipulation and holding casts. In certain socioeconomic conditions [$SEP = 001$], the parents perform manipulation and exercises on the child twice daily (Redon:17). It is also claimed that repeated elective manipulations can control severe deformities by gradual correction with leverage Kirschner wire traction casts (Hitachi:17).

Retention of Correction

It is difficult to construct an algorithmic schematic from these diverse methods of management. However, the main governing factors are soft or stiff, i.e., freedom of movement (*fm*), age (*ag*), and socioeconomic variables (*SEP*). External supports range from casts to various types of orthotic devices, including a hinged articulated splint (Seringe:6). The following statements apply to retaining correction:

Kirschner wire is used as a lever in the posterolateral aspect of the talus to derotate the talus in the mortise (Carroll:8).

A Kirschner wire retainer is used for 8 weeks, followed by immobilization in long leg casts (Yamamoto:4; "The Relationship Between . . .").

A Steinman pin is also used for 6 weeks, casting for 10 weeks, and a brace for 6 months.

Where there is no regular follow-up with low socioeconomic [$SEP = 001$] factors or the patient must travel a long distance, an internal cord retainer of 2 = 0 Mersilene Ethicon (a subsidiary of Johnson & Johnson Company) thread is tied from the fibula to the base of the 5th metatarsal. The tensile strength is doubled above the age of 12 months (Fahmy:personal communication).

Alternative procedures for internal fixation are shown in Table 17.3.

Intermediate Clubfoot Management (8 to 36 Months)

Conditional Rules for Calcaneocuboid Malalignment

In infants, radiological evaluation supports goniometric measurement of malalignment of the outer border of the foot. There is a linear correlation between *function* (*fn*), freedom of movement (*fm*), and deformation (*df*) (Yamamoto:4; "The Relationship Between . . ."). The attributes of (the variable for) radiological grades (*Gr*) range from 0 to 4 and direct the program's procedural rules to three management alternatives (Table 17.2). Here are the conditional rules:

IF the calcaneocuboid joint is $df > 2$ or radiological grade $Gr < 2$, THEN no procedure is done.

IF $df = 2$ or $Gr = 2$, THEN surgical release is used.

IF $df < 2$ or $Gr > 2$, THEN bone surgery is indicated (Thometz:8)

A lateral release is performed either through a Cincinnati approach (Crawford:7), a lateral approach (Howard:7; Malan:8), or Carroll's posteromedial approach (Porat:15).

Algorithms for early lateral column (calcaneocuboid joint) release are shown in Table 17.2.

Prognostication of Results (Birth to 36 Months)

Production rules concerning prognosis are heavily influenced by the factor of age (*ag*). A multiple regression model is used to analyze the relationship between functional results and radiographic angles: $Y = [1.37 \times (x1) - (0.46 \times (x2)] + 0.44 \times (x3) - 1.11 \times (x4) - 0.33 \times (x5) + 0.12 \times (x6) + 137.93$, where Y is the score, $(x1)$ is the metatarsal bimalleolar (MTB) angle, $(x2)$ is the bimalleolar angle, $(x3)$ is the anteroposterior angle, $(x4)$ is the tibiocalcaneal angle, $(x5)$ is the lateral talocalcaneal angle, and $(x6)$ is the 1st metatarsal angle. The regression coefficient is high when there are changes in the $_{\times 1}$ (MTB) and $_{\times 2}$ (bimalleolar) angles (Yamamoto:4; "The Relationship Between . . .").

The following CRs apply to three possible results with respect to range of *freedom of movement* (*fm*) of a joint segment:

IF there is a stiff hindfoot [$fm > 1$] with a posterior crease [$df_{(1,8)} < 3$] and soft forefoot [$fm > 2$] (more than 60% reducible), THEN results are satisfactory in 95% of cases.

IF there is a rigid hindfoot [$fm < 1$] with a posterior [$df_{(1,8)} < 3$] *or* medial [$df_{(2,9)} < 3$] crease *and* stiff [$fm > 1$] supinated forefoot [$df_{(2,10)} < 3$], THEN there is possible recurrence, and two operations may be needed with a limited number of satisfactory results.

IF the foot is rigid (less than 30% reducible) [$fm < 1$] *and* short [$df < 2$] in all segments *or* bilateral [$si = 2$], THEN there is an 80% chance of vascular compromise, more than one operation may be needed, and satisfactory results are achieved in 50% of cases (Dimeglio:15).

IF the intraoperative lateral talocalcaneal angle is less than 30° [$df_{(2,10)} < 3$], THEN further operation may be needed (Stevens:4).

IF a posteromedial release is performed at less than 6 months of age [$ag < 6$], THEN more surgical interventions will be required (Kuo:7).

IF the child is less than 6 months of age [$ag < 6$], THEN complete initial posteromedial release is better than a limited release (Kuo:7).

Late Clubfoot Management (36 Months to 8 Years)

Conditional Rules for Adduction and Supination

The structural segments of these deformities are represented by the variables $df_{(1,10)}$ (adduction) and $df_{(1,11)}$ (supination).

These deformities are assessed by the anteroposterior (AP) talar–1st metatarsal angle (Simons[7]) or the angle between the 1st metatarsal axis and a line along the base of the metatarsals, normally 55° to 65° (Barriolhet:4). For computation analysis, a range of deviation from normal of 0 to 3 is used. The metatarsal bimalleolar MTB angle is also used as an index for verifying correction of adduction.

Age *(ag)* remains the primary determinant in directing the computer program's procedural rules. The conditional rules for adduction and supination are:

IF the child is 1 to 2 years of age [$ag > 12$], THEN the choice is anteromedial release.

IF there is mild deformity [$df = 2$] and low socioeconomic factors [$SEP = 001$], THEN the choice is

Transpose medial insertion (strongest) of tibialis anterior from the medial and plantar aspects of the base of the 1st metatarsal and metatarsocuneiform joints *and*

Medial-dorsal-plantar capsulotomy of the metatarsocuneiform and naviculocuneiform joint (Abberton:13).

IF the child is 2 to 5 years of age ([$ag > 24$] and [$ag < 60$]), THEN the choice is soft tissue and bone procedures.

IF there is mild deformity [$df = 2$] and low socioeconomic factors [$SEP = 001$], THEN the choice is

Tarsometatarsal mobilization by soft tissue release (Heyman-Herndon-Strong technique)
Osteotomy of the base of the 5th metatarsal
Tibialis anterior tendon transfer lateral to the midline of the axis of the foot, which is satisfactory in 75% of cases (Smith:13).

IF there is severe deformity ([$df < 2$] *or* [$SEP = 222$]), THEN the choice is correction without osteotomy by Ilizarov external fixation apparatus (Grill:10).

IF the child is more than 5 years of age [$ag > 60$], THEN the choice is bone and skin procedures by one of the following:

IF $df = 2$, THEN perform an osteotomy at the area of maximum deformity at either the first cuneiform or talar neck and insert bone grafts (Ozeki:11).

IF $df < 2$, THEN a closing wedge osteotomy of the cuboid with opening wedge osteotomy of the medial cuneiform is performed (Schoenecker:13).

IF freedom of movement [$fm = 0$], i.e., teratogenic skin, THEN the choice is

Tissue expander
Weekly stretching
Local flap
Fascio or myocutaneous flap (Grant:8).

Algorithms for adduction supination deformity are shown in Table 17.4.

Conditional Rules for Late Cavus

IF the child is less than 9 years of age [$ag < 108$] *and* there is moderate equinocavus (i.e., a lateral talar–1st metatarsal angle [Meary's angle] of less than 40° [$df < 2$]), THEN the choice is hindfoot varus and equinus soft tissue revision.

IF there is severe cavus with a Meary's angle of more than 40°, THEN the choice is radical plantar release and 6 weeks later a posterior release is advised (Coleman:12).

IF the child is older than 9 years of age [$ag > 108$], THEN the procedure of choice is an Akron midtarsal dome osteotomy (Weiner:12).

Algorithms for late cavus deformity are shown in Table 17.5.

Conditional Rules for Late Equinus, Thin Calf, or Tibial Torsion

The location of these deformities is represented by these variables [$df_{(1,8)} < 3$] (equinus), [$df_{(2,6)} < 3$] (thin calf), and [$df_{(1,7)} < 3$] (tibial torsion). The conditional rules are:

IF there is equinovarus deformity [$df_{(1,8)} < 3$] in a child over 3 years of age [$ag > 36$], THEN the choice is a bone procedure with or without soft tissue release. Complex foot deformities may also be corrected by V osteotomy of the calcaneus and Ilizarov technique (Paley:11).

IF there is a thin calf syndrome [$df_{(2,6)} < 3$] before 3 years of age [$ag < 36$] and [$SEP = 112$], THEN the choice is fascial resection or no treatment. At a later age [$ag > 36$], the cosmetic problem can be managed by a longitudinal osteotomy of the tibia with lateral distraction by an Ilizarov external fixator and a similar procedure on the fibula (Paley:10, 11).

IF there is compartment syndrome, i.e., *pain* [$p > 1$] and *course* [$cr < 0$], THEN decompression of the compartments is indicated (Simons:14).

IF there is tibial torsion [$df_{(1,7)} < 3$] before 3 years of age [$ag > 36$], THEN the Ilizarov external fixator without osteotomy may be used. The constrained system uses fixed hinges to correct the deformity, whereas the unconstrained system uses the natural anatomical hinges (Paley:10, 11). At a later stage, osteotomy may be used above the physis.

Algorithms for late equinus, thin calf, or tibial torsion are shown in Table 17.6.

Conditional Rules for Late Valgus

The functionally defective segments of the medial column of the foot are represented by the variables [$df_{(2,10-11)}$] and [$df_{(2,12-13)}$] for the rays of the toe. The conditional rules for late valgus are:

IF there is a stiff [$fm = 2$], pronated [$df_{(2,10)} < 3$] forefoot [$df_{(2,12)} < 3$] *and* hammertoe [$df_{(2,13)} < 3$] [$df_{(1,12-13)} < 3$], THEN this results from false correction.

IF there is dorsal bunion following surgery [$df_{(1,12-13)} < 3$] and $SEP = 112$, THEN a reverse Jones procedure is required (Kuo:12).

IF there is dorsal talonavicular subluxation

$[df_{(2,10)} < 3]$ and naviculocuneiform $[df_{(2,11)} < 3]$, THEN reconstruction by separation of the medial and lateral column to reassemble the medial column is required (Barnett:9).

Algorithms for late valgus foot deformity are shown in Table 17.7.

Discussion

Multiplying all of the possible attributes of deformity combinations yields a total of 1701 pathological conditions: 3 (functional columns) × 7 (*fn*) segments × 3 (range values) × 3 (*fm*) units × 3 (*ag*) categories × 3 (*SEP*) factors. To date, we have approximately 144 control measures of CTEV. The suitable course of action is selected from the program corpus of knowledge by procedural rules that are arranged in a hierarchical order resembling branches of a tree. Production rules, on the other hand, produce treatment outlines, technical guidelines, and prognosis forecasts.

Statistical data reflect some certainty on the decisions given by CDSS. The following statements form an example of such a statistics knowledge base:

Atypical (teratogenic) clubfoot occurs in 9% of cases (Dimeglio:3). Only 10% of the typical cases can be corrected nonoperatively (Zimbler:6), with 91% being either the typical or resolving form. About 95% of patients with clinically absent peroneal reflex preoperatively had this function return postoperatively (Kuo: 7). There is better correction by opening the subtalar joint (Dimeglio:15). Calcaneocuboid joint release in cases of stiff-stiff and stiff-soft feet is indicated in 40% of procedures (Dimeglio:15). Adjunct lateral column (calcaneocuboid joint) release raises the satisfactory results to 98% (Howard:7, Malan:8).

The consensus of opinion is that the technical aspect of management is as taxing as the decision-making because

Modern procedures are technically demanding and require a great deal of practice,
Releases are now performed earlier than walking age,
Releases are quantitatively checked to avoid excessive release with overcorrection,
Total subtalar release is particularly indicated in secondary procedures (Seringe:15),
Use of the Cincinnati incision makes releasing the posterolateral knot easier and improves the bimalleolar angle (Klaue:7). This incision is now used more widely than Carroll's posterolateral approach or Turco's posteromedial approach (Porat:15). A comparative review of surgical treatment of the lateral column by Carroll, subtalar release by McKay, and posteromedial release by Turco showed no significant difference in results (Magone:15).†

Such statements within the corpus of knowledge are conveyed by relevant production rules. Clearly, selecting the correct course of treatment becomes easier with a decision-support diagnostic tool.

Conclusion

Conditional rules and statements form the corpus of a computer-assisted decision support system for the management of CTEV. The premises of program procedural rules are quantifiable attributes of age, position of deficit or deformity within a matrix, a three-rating scale of function, three ranges of movement, and socioeconomic and aesthetic factors.

These measurable attributes direct the computer program to these subsets of production rules and statements for management:

1. Age classifications of "early" (less than 8 months), "intermediate" (8 to 36 months), and "late" (36 months to 8 years), determine whether a soft tissue or bone procedure should be used.
2. Location of defective functional units in the deformity is calculated from a matrix of nine columns representing segments of the foot and leg and three rows representing dorsal, lateral, and plantar function. The summation of the values of deficits points to a prognosis from a statistic base.
3. Ranges of freedom of movement help determine a prognosis.
4. Socioeconomic-psychoaesthetic attributes, among other secondary factors, govern the length and technical details of treatment required; this includes reconstruction for cosmetic purposes.

†This conclusion is refuted in the Editor's Comments section of Chapter 15.—Ed.

Since conversion of textual information into conditional statements is an essential phase in decision processing, it would be advantageous if authors would provide this in scientific communications to enhance the message and reduce the chances of misinterpretation. If needed, a conditional statement could then be readily converted (formatted) into conditional rules for CDSS programming.

Summary

International forums help provide a wide view of standard practices and knowledge dealing with the treatment of clubfoot. This paper has been an attempt to convert this standard body of knowledge into algorithms for computer-assisted clinical orthopedic analysis and for the planning of treatment procedures.

Glossary

***(ag)*:** age; a variable representing a stage of chronological maturation, usually expressed in months.
algorithm: a computational procedure that consists of hierarchically arranged steps or rules whose function is defined by their position within the order of a computer program (i.e. procedural rules at the beginning establish conditions for the program, whereas production rules are the outcome or result of the decision-making process).
acquisition frame: a checklist, often in table or matrix form, to visually organize information on the computer monitor screen for later steps in a computer program.
attribute: a clinical characteristic featuring a range or unit of measurement, either real or arbitrary, that can be assigned a given significance and weight.
(CDSS): computer-assisted decision support system; a customized set of instructions to the computer as a means to model a problem prior to analysis.
condition: a modifying factor that governs the "do" or "not do" series of decisions made by the computer according to its program.
conditional statement: a sentence found in the text before translation to computer language; this is also called an "IF factor" and starts with the words "if" or "unless."
consequent statement: a textual sentence before translation to computer language; this sentence is also called a "THEN factor" and follows the grammatical transition after the "if" or "unless" part of the sentence.
***(cr)*:** course; a variable representing the stages of a medical condition, i.e., regressive, progressive, recurrent.
***(CR)*:** conditional rule; a sequence expressed in the form of an "IF-THEN" statement, consisting of an antecedent condition, which is usually followed by the signs "<" and ">" and by a consequent action or rule.
***(df)*:** deformity; a variable representing deficiency in functioning, expressed as units measured against a standard or normal condition.
***(ES)*:** expert system; a set of customized instructions as a means to copy in a computer declarative and procedural statements from a body of specialized knowledge.
***(fm)*:** freedom of movement; a variable representing the range of motion that exists in a joint, expressed as arbitrary units.
factor: derived from a fact; part of the premise that precedes a condition; it is ranked higher than an attribute.
***(fn)*:** function; a variable representing a level of physical orthopedic performance, expressed as assigned weights.
gosub: a BASIC computer program instruction that directs a branching process toward a specified area, or line number, within the program.
***(Gr)*:** grade; a variable representing a stage or degree of a process as signified within a scaling system.
imaging (digital): electronic gradations of energy (pixels) represented on a screen matrix to permit adjustment and manipulation of a graphic display or projection.
informatics: a field of artificial intelligence that manipulates data without attempting the additional process of conditional reasoning or decision-making.
knowledge base: a body of miscellaneous information or data consisting of statistical, mathematical, or technical expertise from which production rules are formed.
linear scale transformation: the conversion of measuring units to functional units by means of x and y coordinates.
mathematics base: a body of data containing a set of formulas consisting of numbers that deal with specific functions.

normalization: the conversion of heterogeneous measurement units to homogeneous functional units by $fn_{(x,y)}$ calculus or tracing.
premise: the beginning part of the proposition that comprises a condition; it is governed by attributes.
procedural rule: the driving force of the program inference mechanism; the part of the algorithmic sequence at the beginning of the computer program that directs the decision-making process through a hierarchical order of steps that branch like a tree.
production rule: the course of action reached by a serial decision-making process from an initial set of conditional rules; also termed a "program procedure," "consequent statement," and "THEN statement."
rule base: a body of knowledge expressed in the form of conditional rules.
(*SEP*): socioeconomic-psychoaesthetic; a variable representing the social, economic, and psychological-aesthetic considerations (cosmetic appearance or satisfaction with function) that influence treatment decisions.
(*si*): lesion site; a variable representing the location of a lesion with respect to the axis of the body, i.e., right, left, multiple.
statistics base: a corpus of data; the collection, organization, and interpretation of numerical data expressed mathematically.
vector scale transformation: the linear conversion of quantities completely specified by a magnitude and direction from an x scale to a y scale for mathematical functional analysis.

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A Method for the Treatment of Congenital Clubfeet in Infants

M. Kinoshita, T. Onomura, and R. Okuda

We have systematically treated congenital clubfeet by our therapeutic system starting in the early neonatal period. The system[2] involves manual correction, taping, application of plaster casts, Morita's operation,[5] use of an orthosis, and a program of clubfoot exercises (Table 17.8).[3] Each of these components has been specially modified and differs from those previously reported. Cases in which cast correction was insufficient or cases that were referred to our clinic because of relapse (i.e., cases that were previously treated by procedures different from ours) are sometimes treated by posteromedial release operation at our clinic, although they are exceptional cases.

TABLE 17.8. Our method for treatment of congenital clubfoot.

Birth	Infancy	1 year (age of ambulation)
Manual correction with serial casts	AFO for infant (Figure 17.2E)	Improved Wisbrun's high lateral arch support (days) and AFO (nights) (Figure 17.3)
Stretching exercises (twice within 14 days, then weekly)	Stretching exercises at home	Specialized stretching and strengthening exercises (Figure 17.4)
No surgery	Tibiocalcaneal angle > 75° gradual leverage-wire traction/ correction (Morita)	Posteromedial release for relapsed cases (referred to our clinic or failed cast correction)

Method

Manual correction is attempted first in all cases. Equinus, inversion, and adduction deformities of the hindfoot are corrected simultaneously around the axis of the subtalar joint. To preserve the correction achieved manually, the foot is fixed with adhesive tape covered with a thin below-knee cast (holding cast). This procedure is repeated twice a week for the first 2 weeks, and once a week thereafter. Satisfactory correction can usually be achieved by repeating this procedure 5 to 10 times (Figure 17.2A–D). Severe cases of congenital clubfeet may also frequently be corrected by this procedure and require no surgical treatment.

After deformities have been corrected by stretching exercises and serial casts, additional treatment is performed. Before the infant begins to walk a plaster splint or ankle-foot orthosis (AFO) is used (Figure 17.2E), accompanied by daily stretching exercises by a trained family member. This orthosis prevents supination contracture of the foot and improves the muscle balance of the ankle. When the patient starts to walk, an arch support is used during the daytime and is replaced by another type of AFO at night. The arch support is made of low-density polyethylene that is 3 mm thick. Of the three foot arches, the lateral arch is highest. This corrects foot deformity and improves muscle balance of the leg and foot (Figure 17.3). It has been reported electrophysiologically, radiographically, and biomechanically that our arch support has both static and dynamic corrective effects.[4]

Clubfoot exercises are started when the patient is old enough to understand our instructions. These exercises, which incorporate bamboo-stepping exercises, classic ballet plie movements, etc., are aimed at stretching the gastrocnemius and supinator and reinforcing the pronators (Figure 17.4).

In most cases when the initial therapy has not resulted in sufficient correction, Morita's operation is used. Persistence of hindfoot deformity is the indication for Morita's operation, i.e., the tibiocalcaneal angle is over 75° on the lateral radiograph with the ankle joint maximally dorsiflexed.

Technique

Morita's operation is performed as follows:

1. The proximal and distal halves of the Achilles tendon are incised transversely and the superficial half of the Achilles tendon is cut longitudinally, leaving the other fibers intact. The posterior ankle joint capsule is incised. (When gradual correction with leverage wire is used, a z-lengthening of the Achilles tendon can be performed while retaining some connection of the tendon fibers. We obtain the appropriate lengthening of the Achilles tendon, and the function of the gastrocnemius muscle is not disturbed. The posterior ankle capsule can be incised without incising the Achilles fibers.)
2. A Kirschner wire (1.5 mm in diameter) is inserted through the posterior part of the calcaneus, with care being taken to protect the nerves and vessels behind the medial malleolus. Two sleeves with set screws attached to wires are fixed to the Kirschner wire. Next, the wooden foot plate is placed on the pad of gauze, which is beneath the region of the calcaneocuboid joint. The foot and foot plate are then connected with attached wires.
3. The surgeon holds the heel in one hand, utilizing the Kirschner wire to gain a firm grip



A



B



C

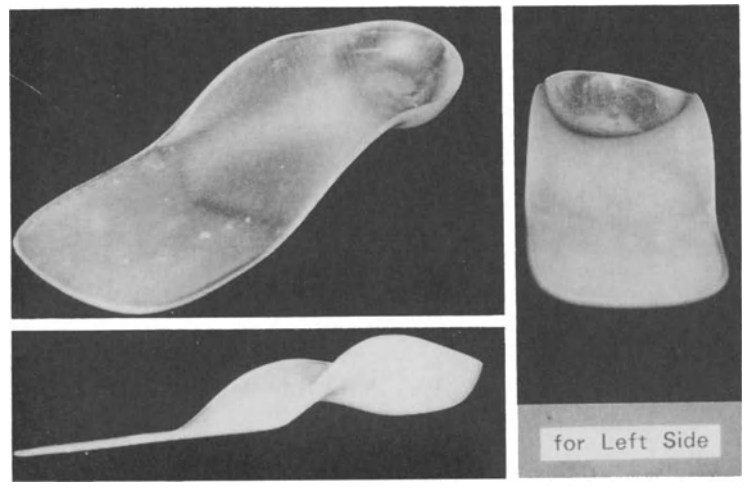


D



E

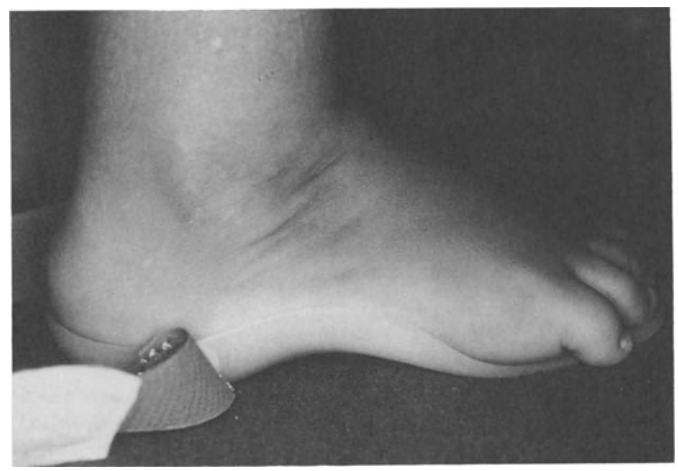
FIGURE 17.2. A: A neonatal female 10 days after birth with severe congenital clubfeet. B: Holding casts applied over adhesive taping after manual correction. C: Holding cast without tape. Since the cast is below the knee, it is possible to prevent contracture of the gastrocnemius muscle by stretching exercises. D: Correction was obtained 7 weeks after starting conservative treatment. E: Ankle-foot orthoses for the infant are applied to hold the corrected position before the child walks.



A



B



C

FIGURE 17.3. A: Our arch support. B: This arch support is used when the patient starts to walk. Lateral view. C: Medial view.

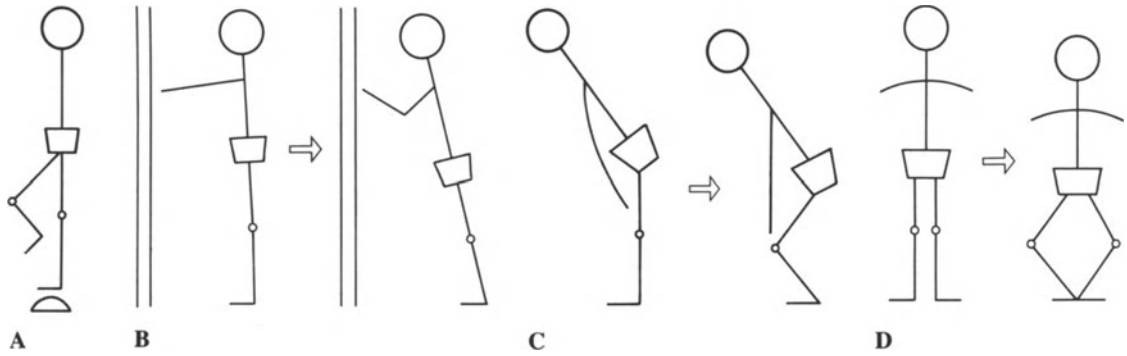


FIGURE 17.4. A–D: Schematic drawings of exercises for clubfeet.

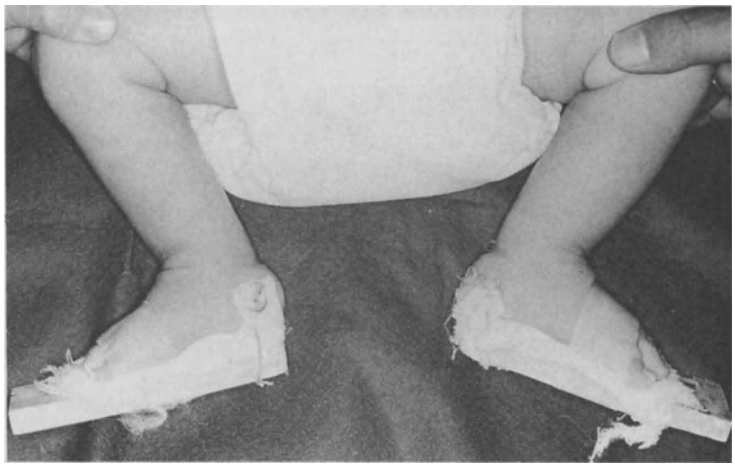


FIGURE 17.5. Photograph of patient's feet 1 week after Morita's operation.

on the heel, and holds the anterior part of the foot plate in the other hand. The heel is now pulled downward and rotated outward slowly, and the forepart of the foot is pushed upward. Additional manipulations are carried out several times.

4. When satisfactory correction, or as much correction as possible, has been achieved, the tendon is sutured with two interrupted sutures, the skin is closed, and the cast is applied (Figure 17.5). Four weeks after the operation, the cast is removed and an orthosis is used.

Results

Morita[5] reported the results of this procedure in 52 feet (37 patients) from 1949 to 1957. The average age of the children at the start of treatment was 1 year 10 months. Twenty-two of the 37 patients were followed, with an average follow-up period of 4 years 2 months (range 2 to 10 years). Morita's results at the time of follow-up were 9 "excellent," 13 "good," 6 "fair," and 7 "poor."

Of the 56 CTEV (44 patients) treated at our clinic since 1975, 30 feet (19 patients) required this procedure. *As there are some cases with a short follow-up the final results cannot be reported, but the clinical appearance, the radiographs, and the function of the feet are good at present.*

The passive dorsiflexion motion was 15° (mean) and plantar flexion was 51° (mean). The position of the heel when standing showed neutral position or valgus in all cases. Only four cases showed toeing-in gait, but no patients complained of pain on motion.

The postoperative talocalcaneal index (Beat-

son and Pearson[1]) was 51.3° (4° to 60°), which is the sum of the anteroposterior and lateral talocalcaneal angles measured on the roentgenograms with the patient standing.

Discussion

Conservative treatment for congenital clubfoot must be initiated at an early age, but surgical treatment should be undertaken if the manual correction and casts cannot achieve satisfactory results. It is important to perform surgery with great care in infants to minimize scar formation. Radical release operations performed at an early age may cause the formation of excessive scar tissue, which can result in the recurrence of deformity, even though microsurgical techniques are used.

Our operative method (Morita's operation) has some advantages as a surgical procedure for infants because maximal correction can be obtained by minimal soft tissue release. We have used this procedure both in infancy and later. It is most effective when performed in infants. The systematic pre- and postoperative management mentioned above is needed to achieve the best results.

Bone lengthening by the Ilizarov method produces soft tissue lengthening without the need for soft tissue release.[5] With Morita's operation, contracted soft tissues can be gradually corrected with leverage wire traction. Hence, Morita's operation has some similarities to the Ilizarov method.[5,6] Tissue release during Morita's operation causes minimal tissue damage. Thus, this is a safe and efficient surgical procedure.

Summary

The authors' method for the treatment of congenital clubfeet for gradual correction of resistant foot deformity is described. The procedure utilizes the principle of the lever, first reported by Morita in 1962. It is useful for infants because maximal corrective effect can be obtained by minimal tissue release.

We have developed a therapeutic system by modifying both Morita's operation and the methods of manual correction, as well as by devising an orthosis and special exercises for clubfeet. This is a preliminary report as follow-up is too recent to report results.

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Rationale for Planning the Initial Treatment of Clubfoot

A.T. Redon and R.R. Mendoza

Experience has demonstrated that typical congenital talipes equinovarus (CTEV) is a severe dysplastic deformity that has a natural tendency to persist if no treatment is given.[9] However, as a result of determined efforts by surgeons to correct this defect, the multiple techniques that have been developed include extremely prolonged conservative methods as well as early extensive (often excessive) surgery, with unsuccessful results.

The rationale for planning the initial treatment of clubfoot has developed from our treatment of clubfeet over the last 5 years. The purpose of this paper is to present and discuss the pitfalls of our surgery, which resulted in either lack of correction or in overcorrection of the foot.

This series also constitutes a justification for the clubfoot treatment protocol now used at the pediatric orthopedic department of the Military Central Hospital of Mexico in Mexico City, although this new protocol has been established only since 1989 and results are not yet available.

Method Recommended

The method for planning the initial treatment of clubfoot consists of 2 to 3 months of serial casts. All components of the deformed foot are simultaneously corrected to a neutral position. Varus of the hindfoot is corrected while forefoot adduction is corrected, since this is the most difficult part of the deformity. Overcorrection of varus and equinus must not be allowed.

After this initial period of cast applications, immobilization is eliminated and home exercises are started twice daily. Exercises are performed with the help of the parents, who are trained and supervised by the orthopedic surgeon every 4 to 6 weeks. This program allows active muscle function with improved circulation to the muscles.[7] At approximately 10 to 12 months of age, as determined by the lack of dorsiflexion and by resting the foot on its lateral border, a posteromedial posterior release (PMPR) is performed through a longitudinal incision. The incision permits lengthening of the Achilles tendon, the flexor hallucis longus, the flexor digitorum longus, and the posterior tibial tendon, as well as posterior capsulotomies of the ankle and subtalar joints. This incision must not cross the skin grooves of the medial aspect of the hindfoot.

Postoperatively, a long leg cast is applied with the hindfoot in neutral position and the knee at 35° of flexion. This positioning of the knee within the cast permits the child to stand, and walking is encouraged. The ankle is placed at 90° and the foot at 20° to 25° of external rotation. The cast is retained for 6 to 8 weeks (Figure 17.6). Exercises are then started. This program avoids the prolonged use of casts and prevents an overcorrected valgus foot as well as severe peroneal muscle atrophy. A polypropylene orthotic, which is inserted into a straight last shoe, is used along with an external rotation bar at night.

Materials and Methods

During the 5-year period of January 1985 through December 1989, 49 patients with clubfeet (CTEV) were treated at the orthopedic department of the Military Central Hospital. Each of these patients was examined by the senior author (A.T.R.). However, only 19 of the 49 patients were included in our study, as the purpose of the study was to evaluate the results of our former treatment method.

These 19 patients were included because they were first treated in our hospital between birth and 3 years of age. They were classified as type I (typical). There were 8 patients with bilateral clubfeet and 11 with unilateral. Sex distribution was 15 males and 4 females (a ratio of 3.8:1).

Patients excluded from the study were (a) children over 5 years of age (as it is our belief



FIGURE 17.6. A long leg cast is applied for 6 to 8 weeks.

that surgical indications and procedures are different after this age), (b) patients who had reached adulthood, (c) patients who had a relapsing rigid deformity after having a classic posteromedial release[10] elsewhere, and (d) patients whose clubfoot was a part of congenital severe systemic disorders, classified as type II (dysplastic).

The method of assessment consisted of a clinical evaluation of the alignment of the foot while standing and alignment of both feet while walking. Range of motion of the foot was evaluated in passive and active flexion-extension of the ankle. The varus-valgus of the hindfoot and the alignment of the forefoot were also evaluated. Results were considered "excellent" when the operated foot had a normal appearance, with normal walking alignment, normal range of motion, and normal muscular strength. Results were "good" when there was gross alignment of the foot and gait with no hypercorrection, plantar contact with the floor, a functional range of motion, and good muscular strength. Results were "fair" when there was a partial flexible recurrence of deformity, decreased range of motion, and loss of the alignment of the foot in stance or gait. These feet required a second procedure (either surgical or conservative) to correct the alignment. Results were considered "poor" when there was either no correction or overcorrection, thus requiring a reconstructive surgical procedure.

Results

In this study, 5 of the 24 feet did not require surgical correction, since they had good correction with conservative treatment (2 to 4 months of serial casts), which started between the ages of 1 to 3 months. Two of these patients had good correction at 18 months and one at 10 months after treatment.

Of the 24 operated feet (16 patients), only one foot had an "excellent" result. This patient was operated on at the age of 15 months after 2 months in casts. Postoperative follow-up was 16 months. Thirteen feet had "good" results. They were operated on after a period of preoperative cast treatment that averaged 5.9 months (range 0 to 12 months). Postoperative follow-up of this group averaged 12 months (range 6 to 37 months). The age at the time of surgery of the patients with "excellent" and "good" results averaged 15.3 months (range 7 to 38 months).

Five feet had "fair" results. Three feet (two patients) had recurrence of deformity at 10 and 23 months postoperatively. Both patients required revision surgery—a second PMPR. These patients had satisfactory alignment 8 to 15 months after the second surgery. One additional foot relapsed into forefoot adductus at 18 months postoperatively and required an additional period of 2 months of cast treatment with final recovery of alignment when examined 8 months later. Finally, one foot had recurrence of forefoot adduction and will require surgery in the future. Preoperative cast

TABLE 17.9. Results of prolonged preoperative cast treatment followed by posteromedial posterior release (PMPR).

Duration of cast (months)	Age at surgery (months)	Additional medial approach	Second treatment	Follow-up final op. (months)	Final result
6	20		2nd PMRP	8	Fair (R)
6	21			37	Good (L)
6	11		2nd PMRP	15	Fair (L)
			2nd PMRP		Fair (R)
7	11			35	Good (L)
					Good (R)
10	11			39	Overcorrected (L)
			Grice (R)	9	Partial correction (R)
11	15	Yes		28	Good (L)
			Casts (R)	10	Fair (R)
2	38			13	Good (R)
5	11	Yes		18	Overcorrected (L)
7	14			15	Overcorrected (L)
2	15			16	Excellent (R)
7	8			15	Relapsing (L)
				15	Good (R)
5	7			19	Good (L)
				19	Good (R)
7	14			10	Good (R)
12	15			10	Fair (L)
				10	Good (R)
No	26			6	Good (L)
4	14			7	Good (L)
				7	Good (R)

immobilization averaged 8.2 months (range 6 to 12 months). The average age of the patients at the time of surgery was 14.4 months (range 11 to 20 months).

Five feet had "poor" results. One child developed overcorrection of both feet at 30 months postoperatively. A Grice procedure was performed on one foot. The final result after 10 months showed good alignment of the hindfoot, but the forefoot was in adductus; the other foot remains overcorrected. Two feet operated on after 5 and 7 months of cast treatment remained overcorrected at 18 and 15 months postoperatively. The cast slipped badly in one foot in the postoperative period and the deformities completely relapsed. These five patients were operated on after an average of 7.8 months (range 5 to 10 months) of preoperative cast treatment. The average age of patients at the time of surgery was 11 months (range 8 to 14 months) (Table 17.9).

The overall results of surgical treatment were 4% "excellent," 54% "good," 21% "fair," and 21% "poor."

Discussion

Although the number of patients in this series is small, the best results were obtained when surgery was performed after a short period of preoperative cast applications and at an older age. The worst results occurred when preoperative casting was prolonged and surgery was performed at an earlier age. However, these figures were not statistically significant.

The three nonoperated patients (five clubfeet) who had cast immobilization from 2 to 4 months as well as the patients with "good" results demonstrate that prolonged immobilization is not needed.

A small number of children with gross deformities can be corrected by a short period of treatment initially. Primary cast treatment is almost always indicated.

Experience has shown that a number of feet treated surgically by the classic posteromedial release[10] will undergo severe relapsing deformity. Adhesions can develop when the ten-

don sheaths behind and below the medial malleolus are opened and z-lengthenings of the posterior tibial and the flexor hallucis longus tendons are performed within the sheath. Therefore, tendon lengthening within the sheath must be avoided to prevent adhesions and loss of mobility; this occurred in 3 of the 49 patients mentioned above who developed a severe relapsing deformity following PMR performed elsewhere.

The question of whether the talocalcaneal joint must be released remains unanswered. In our patients who developed overcorrection, the hindfoot was placed in a valgus position and the forefoot was placed in an abductus position in order to ensure correction. Nevertheless, overcorrection occurred even without a medial release of the talocalcaneal joint. This suggests that the medial side of the joint must be left untouched both by the surgery and by the preoperative and postoperative cast treatment.[1,4,10]

True dysplasia[5,8] of the talus, the navicular, the posterior tibial, and gastrocnemius muscles suggests that the problem is far from solved.

The old recommendation of starting cast treatment as soon after birth as possible does not seem to have great value, as early immobilization may prolong cast treatment. As demonstrated in this study, prolonged cast treatment either pre- or postoperatively (in this series up to 15 months) was associated with a significant number of fair and poor final results.[2,3]

When the proper alignment of the foot has been obtained, usually after 2 months of serial casts, there is no reason to continue cast treatment, since muscular atrophy will become worse. However, if surgery is performed long before the child starts to walk (assuming that walking helps to prevent recurrence), there is a postoperative nonambulatory period that makes early surgery unnecessary; there is no satisfactory reason to perform an operation on feet that will not be used until several months later. Early operation increases the possibility of recurrence, the need for orthotic protection, and the eventual need for further surgical treatment. The real advantage of our technique is that the child is ready to walk when his casts are removed.

The results of treatment of CTEV at our institution indicate that the *optimal results are associated with avoidance of*

1. prolonged preoperative cast treatment,
2. early surgery (as a number of patients will not need it),
3. surgical procedures within tendon sheaths, and
4. overcorrection of the medial aspect of the talocalcaneal joint preoperatively and postoperatively.[6]

Summary

The results of 19 patients 1 to 3 years of age with 24 clubfeet treated by posteromedial posterior release (PMPR) after a period of unsuccessful conservative treatment are presented. Lengthening of the Achilles, posterior tibial, flexor hallucis longus, and flexor digitorum longus tendons, as well as posterior capsulotomy of the ankle and subtalar joint was performed by a posterior approach without crossing the posteromedial skin grooves of the hindfoot.

Results were 1 "excellent," 13 "good," 5 "fair," and 5 "poor." The poor results were due to relapse or overcorrection. Excellent and good results (58%) were obtained after a period of cast treatment that averaged 5.9 months (average age at the time of surgery 15.3 months). Results were fair and poor (42%) after cast treatment that averaged 8.2 months (average age at the time of surgery 14.4 months). There was no significant difference in this small series. The results justify a modification in the plan of treatment by shortening the preoperative period of cast treatment and avoiding overcorrection of the hindfoot.

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Persistent and Relapsed Internal Rotation of the Foot After Soft Tissue Release

M.J. Abberton

Persistent internal rotation of the foot, with or without supination, is a major cause of dissatisfaction after soft tissue surgery in clubfeet. It may occur in the hindfoot, midfoot, forefoot, or in any combination of these.

It is not uncommon to discover a child with a foot that can be placed plantar grade and appears flexible, yet assumes a position of internal rotation when the child walks or runs. The degree of this overlooked rotation is often very great.

It is important to consider the full torsional profile of the child's limbs, noting the angle of the feet to the line of progression, any retained femoral neck anteversion, and tibial shaft torsion. More important guidelines are the attitude of the heel in terms of valgus and varus, the relation of the point of the heel to the malleoli, the axes of rotation of the knee and ankle, the alignment of the first and fifth rays, and the degree of supination of the forefoot in respect to the neutral heel.

Some of the children with an internally rotated gait will prove to have feet in which many or all of the aspects of the initial deformity of CTEV have been inadequately corrected or have relapsed. It may be possible to revise the soft tissue correction, but often such a child is in need of a total salvage procedure.

In this paper I shall describe a procedure of less magnitude that can be beneficial when there is a particular, circumscribed deformity.

Certain feet appear to be reasonably well-corrected when the patient is standing. However, the child walks with an internally rotated gait. Such feet appear simply to be internally rotated at the ankle and to have apparent posterior displacement of the lateral malleolus. In these cases, I believe that a posterolateral release (PLR) is indicated.

Procedure

The child is placed prone on the operating table, draped so that the knee can be clearly seen and can be fully flexed. Only in this way may the axis of the limb be continuously reviewed. In cases where only one side is to be operated upon, it is useful to prepare the skin and drape the contralateral (normal) limb in the same fashion so that comparisons can be made. Bilateral indelible markers are used for the patella, tibial tubercle, and malleoli. If the contralateral side is abnormal, it is best draped to exclude it from view.

Partial exsanguination should be used. A J-shaped (modified Cincinnati type) incision is

made around the lateral malleolus extending to the calcaneocuboid joint. The sural nerve should be identified and retracted.

The underlying fascia is usually thick and can be distinguished from the superior limb of the peroneal retinaculum. It is divided separately in the line of the incision with the division of the retinaculum more posterior to preserve the peroneal sheaths. This will allow some correction, and a gap up to about $\frac{1}{8}$ inch may be seen. In some cases, this is virgin surgical tissue, but often there is cicatricial thickening in these layers. Because all of these children have undergone previous surgery, there is often cicatricial contracture extending from the tibia to the posterolateral aspect of the calcaneus that must be released.

Deeper dissection will demarcate the calcaneofibular ligament. This must be divided from its calcaneal insertion as far posteriorly as possible. The posterior talofibular ligament may also need to be released.

It is possible at this stage to assess the correction obtainable. Attention should be paid to the attitude of the plantar grade foot in relation to the malleoli and the axis of knee flexion.

In the corrected position, the degree of laxity of the peronei may be assessed. Appropriate plication of these is performed between the lateral malleolus and the musculotendinous junction. It is desirable to preserve the paratendinous tissue between the peroneus longus and brevis and to make the plications at different levels, but this is not always possible. When the plication is complete, the foot should have a full range of passive movement at the ankle without internal rotation.

If this procedure is to be combined with an anteromedial release of tibialis anterior for forefoot supination, plication of the peroneus longus should be delayed until the anteromedial release has been carried out in order to maximize the effect of the plication.

The limbs are maintained in full correction in long leg casts for 6 weeks. Night splints and special footwear are not used thereafter.

Indications and Contraindications

The prime indication for this limited procedure (PLR) is internally rotated feet in which the subtalar joint is satisfactorily corrected.

On clinical evaluation, the heel can be brought to a neutral position without either varus or valgus, but the posterior prominence of the heel is lateral in relation to the malleoli.[1] Dorsiflexion of the ankle is satisfactory, but plantar flexion is limited to the plantar grade position. The APTC angle is narrow but within normal limits. These feet show satisfactory posterior reduction of the talus under the tibia on the lateral radiograph.

Reasonable flexibility of a well-corrected midtarsus is a prerequisite.

The procedure may be combined with anteromedial release of the anterior tibialis tendon for correction of forefoot adduction and supination, provided that the midtarsal joint (talonavicular and calcaneocuboid) correction is satisfactory.

The approach permits exploration of the posterior aspect of the ankle joint and revision of the posterior ankle capsulotomy, the posterior subtalar capsulotomy, and elongation of the Achilles tendon. However, extending the procedure in these ways diminishes the satisfaction with the procedure in proportion to the degree that it is extended—as these requirements all represent relative contraindications. This is particularly true if exploration of the calcaneocuboid joint is added; the need for such a revision indicates poor midfoot correction at the calcaneocuboid joint and possibly the talonavicular joint as well. The procedure may be combined, however, with anterior calcaneal osteotomy.

Poor hindfoot and midfoot correction and rigidity of the foot are major contraindications. Another contraindication is TEV deformity due to neurological disorders.

Results

Over the past 5 years this procedure (PLR) has been performed 23 times as a revision procedure after soft tissue release in CTEV. The children treated during this time ranged in age from 19 months to 11 years.

Peroneal plication was not performed in the earlier cases, but is now a standard part of the procedure.

Apart from the small numbers, the fact that the operation is limited in its indications makes evaluation in other than anecdotal terms impossible.

Thus, I was able to assess the value of the

procedure only in the broadest terms in regard to the expectations of the parents, the child, and the surgeon. The surgeon's assessment should be more critical than that of the parents, for he is more knowledgeable in points of a technical nature.

All are revision cases, and thus I feel that no foot should be described as "excellent." The parents are specifically counseled against having any such expectation. The four grades of satisfaction are "good," "improved," "no change," and "worse."

In these terms, the parent's assessment was "good" in 12, "improved" in 5, "no change" in 4, and "worse" in 2. The surgeon's assessment was "good" in 10, "improved" in 6, "no change" in 4, and "worse" in 3.

There was good correlation between the surgeon's and parent's assessment. The children who were "worse" on the surgeon's assessment were all subsequently found to have a neurological problem.

There were no complications. Of the "no change" group, one child underwent a repeat procedure and subsequently achieved a "good" rating in both the parental and surgeon's scales.

It is not possible to be definite, as neither the numbers nor the length of follow-up permits a stronger statement, but my impression is that peroneal plication has improved the results of this procedure.

In conclusion, this procedure is recommended with very limited indications for the management of CTEV.

Summary

Persistent internal rotation of the foot is a major cause of dissatisfaction after soft tissue corrective surgery in the clubfoot. The site of residual deformity may be in the hindfoot, midfoot, forefoot, or in any combination. The foot with rotational deformity, and especially a foot with significant failure of correction of talocalcaneal rotation, requires total revision. This is difficult and success is rare, even if the decision to offer it can be made early. There is some scope for a limited procedure which will address those feet in which there is partial failure of correction.

Posterolateral release is indicated in those feet with internal rotation deformity in which the subtalar joint is acceptably corrected. Such feet will have a reasonable appearance with acceptable medial and lateral borders but, when viewed critically, are internally rotated with respect to the shin.

The essence of the procedure is the release of all tethering fascia and ligaments (especially the calcaneofibular) between the fibula and the posterior half of the calcaneus, and a surgical shortening of the peroneal tendons. Restricted extension of the ankle joint requires revision by elongation of the Achilles tendon and posterior release of the ankle capsule.

Such a procedure is designed to correct a failure of the initial surgery. No two procedures are exactly the same. Since salvage procedures have limited aims, compromises have to be accepted when restricted procedures are offered. Under these circumstances, no series of objective results can be offered.

In my hands, there has been significant parental acceptance of the results and a reduction in the need for specialized footwear.

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Follow-Up Study of a Method of Management of Congenital Talipes Equinovarus Deformities with Easily Available Surgical Facilities in Developing Countries

A. Sengupta and P. Gupta

In most of the developing countries, the majority of patients have very limited access to formal medical treatment. Common conditions in children with CTEV are often left untreated. The children grow up with severe cosmetic and psychological defects resulting in a grossly handicapped patient.[10,12,16]

In 1975, about three-fourths of the world's people were in the developing countries, but by the year 2000 this will grow to four-fifths. To properly serve the medical needs of this huge proportion of our population living in rural areas of developing countries, we must develop new treatment methods from a new perspective.

Since there is a lack of adequate transportation to the few treatment centers in the cities, the cost of transportation is often very high. In addition, the costs of the hospital stay and of medicine and supplies are often beyond the reach of the patient's family—including the loss of the wage earner's wages and labor. We must try to take the services to the rural areas, thus preventing the so-called inverted glass pyramid syndrome.[2,6,7,17]

A scheme for management of CTEV was presented to the Institute of Child Health in Calcutta in 1964, with a view to developing a socially acceptable and cost-effective method[11,13] that includes the growing child's access to regular supplies of orthotics.

Materials and Method

When the study was started, the primary aim was to obtain the best result with a minimal hospital stay, minimizing the number of visits, and using low-cost equipment. It was found that blind release of soft tissue contractures along with manipulation and cast applications could be undertaken as outpatient procedures. It was gratifying to see that the resulting pinpoint scars are very acceptable to the parents and help alleviate the fear of operations. The children were placed in one of four groups, depending on the age when first seen for examination and treatment, on the degree of correction possible without anesthesia, and the palpability and position of the calcaneus. Those in groups I and II, and most of those in group III, were deemed suitable for this general treatment plan; those in group IV required an individualized approach (Table 17.10).

The children were given a corrective cast without anesthesia on the day of reporting. This helped the parents to train themselves in caring for a child in plaster. The child had the minor operation 15 to 20 days later.

Subcutaneous Tenotomy

Availability of Instruments

Subcutaneous tenotomies have been extremely useful in correction of postpolio deformities in countries with only minimal surgical facilities. It was thus thought that blind elongation of the Achilles tendon (ETA) and blind medial release (MR) of the plantar fascia and abductor hallucis brevis in selected patients with CTEV would reduce expenditures and the length of hospital stay and be more cosmetically acceptable. The surgical instruments required are standard instruments and are readily available. The surgical equipment needed was a scalpel with a No. 11 blade (or a tenotomy knife), two hemostats, one dissecting forceps, and a pair of scissors. The necessary dressings, sheets, and a pair of gloves can all be easily sterilized in ordinary pressure cookers available for domestic use. Corrective shoes were shaped from easily available canvas shoes and wooden clogs common to most village cobblers.

TABLE 17.10. Group classification criteria.

Group I (early) 10%	Group II (average) 60%	Group III (late) 20%	Group IV (problematic) 10%
Age 10–90 days	90 days—walking age	Between walking and school age	After school age
40%–50% correction without general anesthesia	20%–40% correction without general anesthesia	Little correction without general anesthesia	No correction without general anesthesia
Calcaneus easily palpable	Calcaneus easily palpable	Calcaneus inverted	Arthrogrypotic and other conditions

TABLE 17.11. Criteria for evaluating results.

Excellent	Good	Fair	Poor
Normal appearance	Well-accepted appearance	Acceptable appearance	Unacceptable appearance
Walks normally	Walks well barefoot and with normal shoes (slight difficulty with chappals)	Can walk barefoot but prefers shoes (cannot use chappals)	Walks with difficulty
Squats easily	Leans forward to balance while squatting	Support needed in squatting	Cannot squat

Anatomical Considerations

The Achilles tendon is made up of two main components: a superficial part consisting of fibers from the gastrocsoleus and a deeper part with fibers from the soleus. The former part becomes tendinous almost at the middle at the leg and is easily separated from the relatively fleshy soleus. There is some rotation of the fibers near their insertion, the superficial fibers being posterolateral near its insertion. Here all important structures are separated by a pad of fat and lie far anteriorly, with relatively little chance of damage during tenotomy if done carefully.[3,4] The plantar fascia and the abductor hallucis brevis act as a bowstring to cause and/or exaggerate the varus deformity.

TABLE 17.12. Analysis of results*.

	Group I	Group II	Group III	Group IV
Excellent	85%	68%	53%	—
Good	10%	17%	32%	—
Fair†	3%	8%	5%	—
Poor†	2%	7%	10%	—

*Based on more than 5,000 cases (longest follow-up 25 years).
†Most of these patients did not or could not return for follow-up and often returned later by as much as 3 months.

Technique

Under general anesthesia and proper asepsis, the child is taken to surgery as a day patient. A tourniquet is applied (pieces of bicycle tubing are frequently used). The Achilles tendon is stretched and the distal end just above its insertion is palpated. A tenotomy knife or No. 11 blade is inserted into the center of the tendon near its insertion, in a slightly oblique direction. The deeper fibers occupying the anteromedial aspect of the tendon, which make up the soleus component, are gently divided. Keeping the tendon stretched, the knife is reinserted proximally about one-third the distance between the knee and the ankle, between the deep and the superficial fibers. Here the fibers mostly lie anteroposteriorly and the fibers of the gastrocsoleus are mostly tendinous. These tendinous fibers are now divided, thereby completing the step elongation of the Achilles tendon. The foot is gently dorsiflexed with an even, firm pressure. A snap is often felt and the superficial fibers slide on the deeper fibers as



FIGURE 17.7. Postoperative appearance of a child following the author's subcutaneous tenotomies. A: Front view. B: Back view. C: Medial view.

the Achilles tendon elongates. Full dorsiflexion (30° beyond a right angle) is obtained in about 80% of cases, just over a right angle in 15% of cases, and to a right angle in 5% of the cases.

The medial release is performed by a blind release of the plantar fascia and the abductor hallucis brevis by passing the knife deep to these structures and gently dividing them from inside out.

The tourniquet is released. Pressure is applied to the wounds in the leg and the foot for a minute, and the wounds are inspected for any undue hemorrhage. A crepe bandage and a long leg cast are applied, accepting the position of maximum correction where good circulation is present in the toes.

The cast is removed at 3 weeks, and a second cast is applied under sedation for another 3 to 4 weeks. The correction thus obtained is maintained in a suitable orthosis until the child starts to walk well and can use normal shoes. The orthosis found to be most useful was a simple pair of canvas shoes attached to wooden clogs.[14–16]

Results

The aim of correction of CTEV and the evaluation of various methods of management have received wide attention. It was decided to base the results of our method of management on 3 main points: (a) cosmetic appearance and acceptance by the patient, (b) gait, and (c) squatting (Table 17.11).

Based on these points, the results were graded as "excellent," "good," "fair," and "poor" (Table 17.12).

Discussion

Early operative treatment for correction of CTEV has gained considerable popularity. Because of its lower management cost, easier follow-up, and ease of providing orthotic devices, this technique of step elongation of the Achilles tendon and medial release of the plantar fascia and abductor hallucis by blind



FIGURE 17.8. Squatting is a normal daily function in developing countries. This child squats easily with no need of support following CTEV correction by subcutaneous tenotomy.

tenotomy is a suggested procedure, especially in developing countries.

Cost is minimized by (a) fewer visits for complete management, which reduces the lost wages and labor of the family wage earner; (b) a less extensive operative procedure, which minimizes bed occupancy and often allows correction to be carried out as an outpatient; and (c) minimized use of operating room materials and plaster casts.

The technique can be followed up in small, rural health centers, thus reaching out to the main proportion of the population.

Corrective orthoses constructed of canvas shoes and wooden clogs are easily available and can be repaired and replaced by the village cobbler.

Critical analysis of results suggests that the very inconspicuous scars produced by this method are cosmetically unparalleled, especially for girls who later wish to have ankles as normal and shapely as possible (Figures 17.7 and 17.8). The cosmesis is a definite advantage in countries where marriage often is necessary for economic survival. The percentage of correction achieved by this method is quite satisfactory when compared to other accepted criteria of successful treatment. This method of correction of CTEV should be assessed at other centers as an alternative to standard procedures.

Summary

We have developed a system of percutaneous release of soft tissue contractures for selected children with clubfeet. This system may be used in developing countries where the surgeon must deal with problems such as extremely limited access by most of the population to even basic surgical facilities, in addition to scarcity of orthotics, general economic handicaps, and attitudes of apathy and fear toward major surgical operations.

Since 1964, just over 6,000 cases have been treated by this system. Critical evaluation of cosmetic and functional results in over 5,000 cases (longest follow-up 25 years) suggests that the results are good enough to recommend this technique for countries with advanced facilities as well as for developing countries.

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Early Treatment of Severe Idiopathic Clubfeet

T. Hitachi

Treatment for idiopathic clubfeet should be discussed on the basis of the degree of severity, as the management varies with the severity. Until now, the severity of the clubfoot has been generally classified based on the results of management retrospectively without consideration of pathoanatomical changes in the deformed foot. I have classified the severity of the idiopathic clubfoot and have performed an effective initial conservative treatment for severe clubfeet.

In 1954, I had the occasion to examine several deformed clubfeet that had extremely severe contractures with neither active nor passive movement. As a result of these cases, I have subsequently documented the severity of all clubfeet (over the past 35 years) by the use of plaster models, x-rays, photographs (Figure 17.9), and rarely, videotapes. Since 1954, I have managed over 200 idiopathic clubfeet by a serial therapeutic program.

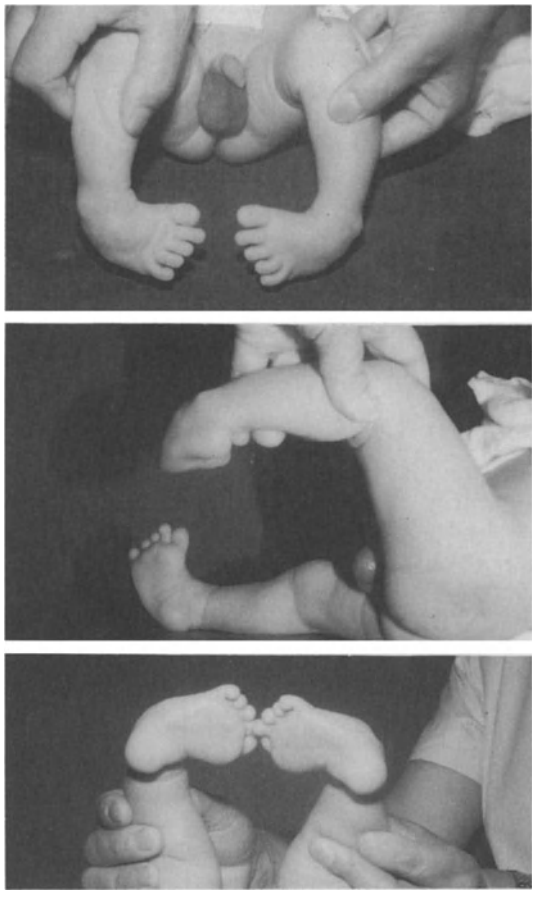
Between 1975 and 1977 I also examined the structural changes by dissection of more than 20 deformed feet of fetal or newborn babies, including seven severe clubfeet, in the anatomy department of Kyoto University. I observed the pathomechanics of the deformities as a result of my studies. These clinical and pathoanatomical investigations resulted in a practical classification based on severity, and a rational therapeutic procedure for severe clubfeet.

Practical Classification of CTEV Based on the Degree of Severity

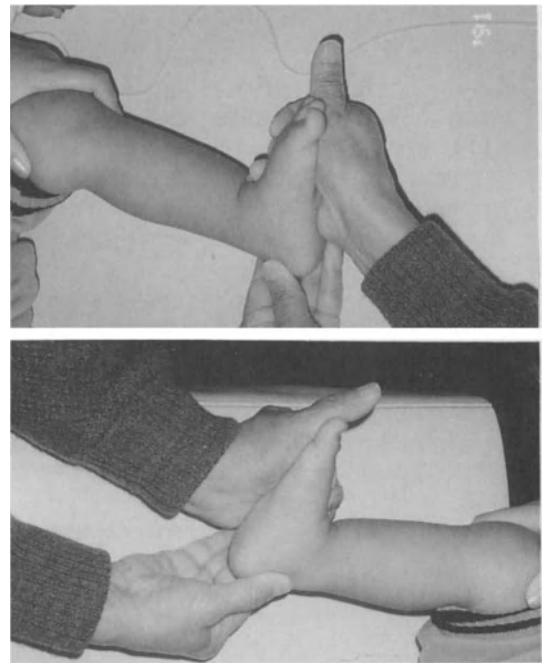
Idiopathic clubfoot can be divided into three groups: mild, moderate, and severe.

Mild clubfoot: The shape of the bony architecture and bony structural alignment are nearly the same as normal feet, allowing adequate active and passive movement. But there is mild resistance to eversion and abduction of this foot. As the bony structure is normal, several casts may be sufficient treatment.

Moderate clubfoot: Although it has an obviously deformed shape and somewhat stiff



A



B

FIGURE 17.9. A: Appearance of severe clubfeet. Severely deformed clubfeet are sometimes completely corrected by conservative treatment. Recently, equinus has been corrected by manipulation only. B: Same patient 8 months later. Equinus has been completely corrected by conservative treatment using manual stretching and casts.

contracture, this shape is different from the severe clubfoot. By serial manipulations and casts, all three elements of the deformity may be corrected gradually. The bony structure is in an exaggerated inverted position at the peritalar joints.

Severe clubfoot: This is a very deformed foot combined with medial ankle torsion. The shape of the foot is markedly supinated, showing an extreme varus and rotation of the hindfoot and adducted and supinated position of the forefoot.* In external shape, the varus and rotation of the hindfoot are equal to that of the supination and adduction of the forefoot. The entire foot is in the coronal plane and there is so much supination and adductus that the sole is vertical. The active and passive movement of the foot are almost entirely lost due to the extremely stiff contractures. The cases presented in this paper deal primarily with the *severe* group.

Outline of Serial Therapeutic Procedures

I have established a therapeutic approach for the severely deformed clubfoot. In part I, conservative correction is carried out mainly to correct hindfoot varus and rotation of the calcaneus and forefoot adduction and supination. In part II, a posterior release (modified Mori-

*The author used the terms *varus*, *adduction*, and *supination* to refer to deformities of the whole foot. The author's terminology has been changed to correspond to that in the rest of the monograph. The term *varus* applies only to the hindfoot (HFV), whereas *adduction* (FFA) and *supination* (FFS) refer only to the forefoot. Rotation of the calcaneus is around the vertical axis. See the Definition of Terms for further clarification.—ED.

ta's Kirschner wire leverage method) is used for the residual equinus element, which cannot be corrected conservatively.[7]

Treated Cases and Their Gross Evaluation

From 1951 to 1988, 268 CTEV feet (160 patients) were treated; 151 feet (101 patients) were severely deformed clubfeet. Almost all cases were referred from another orthopedic hospital. All feet were managed by me and none required a posterior medial release.

Fifty-two severely deformed clubfeet (38 patients) were treated from the onset. By 8 months successful results were achieved in all cases.

Seventy-two severe clubfeet (52 patients) were treated by various forms of treatment at another hospital. Some were resistant clubfeet (Figure 17.10), whereas others were spuriously corrected feet. (The most striking finding on radiographs was the fact that the toes were abducted laterally at the MP joints.) Although some feet needed reintervention due to recurrence, they were successfully treated by serial combined procedures. Moreover, even a 6-year-old boy with a severely deformed foot was cured completely by this technique.

This method is useful in a small child, but it is most valuable for the severe clubfoot that cannot be cured completely before the child is old enough to stand. Except for my procedure, traditional conservative corrective procedures for severe clubfeet cannot achieve correction and aggressive surgical procedures are usually performed.

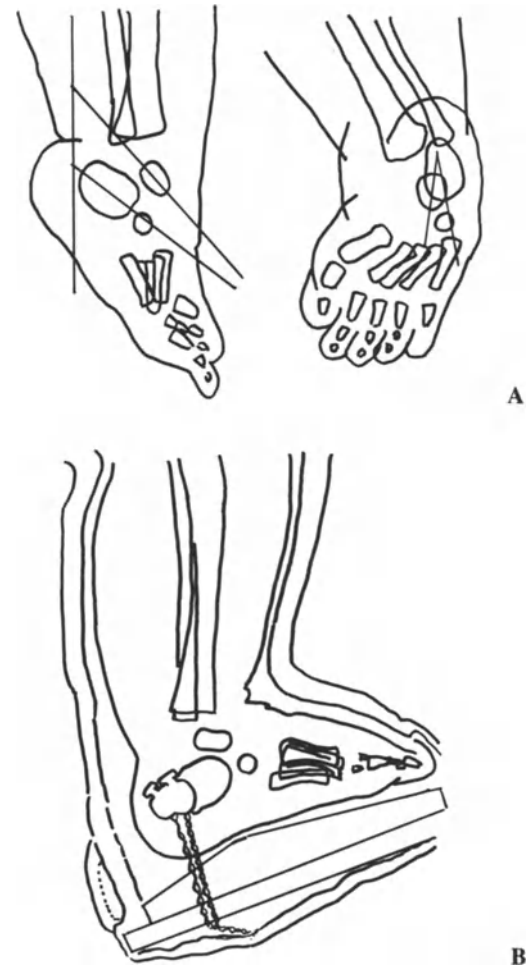


FIGURE 17.10. A: Tracings of radiograph of a resistant clubfoot after 8 months of treatment elsewhere. B: Tracing of radiograph taken through plaster demonstrates leverage traction cast system that was applied for correction of equinus deformity. Note that the equinus is completely corrected.

Treatment Procedure for the Severely Deformed Clubfoot

1. Hindfoot varus and rotation and forefoot adduction and supination should first be corrected conservatively, including medial torsion of the ankle. Correction of these deformities is performed by repeated manipulation and cast applications aimed at maintaining the corrected position. These techniques are described later. The key point is to bring the navicular in front of the talar head within the joint capsule and simultaneously to replace the calcaneocuboid joint upward and laterally to the normal position. On the first day the correction is so small that it is not apparent but, in 3 to 4 weeks, the HFV (and rotation) and FFA and FFS of the foot may be completely corrected, and normal bone alignment is achieved.

   The completion of correction must be ascertained clinically by alignment of the outer margin of the abducted forefoot to the hindfoot and radiographically by an anterior-posterior view. *The direction of the longitudinal axis of the talar ossification*

center in relation to the metatarsi is the most reliable criterion for evaluating complete correction when the ossification centers of the navicular and cuboid have not yet appeared. The APTC angle as well as TC index are less valuable. The medial ankle torsion also should be corrected simultaneously.

2. The corrected position of the HFV, calcaneal rotation, FFA, FFS, and medial ankle torsion is maintained by immobilization in casts for 4 months or more to prevent recurrence. During this period, manual correction for the equinus component is carried out at each cast change. However, the conservative correction for equinus is not easy, because of the difficulty in maintaining the heel in its corrected position in the cast.

   The growth of the foot may contribute to the prevention of recurrent HFV and FFA due to remodeling of the bone and soft tissues and return of muscle strength. Recurrence may be caused by incomplete correction of HFV and FFA or an insufficient period of immobilization.
3. When equinus persists, the least invasive posterior release operation (i.e., leveraged Kirschner wire traction cast) should be applied at 6 months after the onset of treatment.

After this procedure a Denis Browne splint or corrective shoes are unnecessary because of the low frequency of recurrence. When there is concern that HFV and FFA may recur, a plaster cast or night splints are applied, but these cases are rare if correction is complete and the period of immobilization is sufficient.

Generally, it takes 8 months on the average to complete the treatment. After that, other surgical intervention such as posteromedial release,[8] posterolateral release,[6] Evans' procedure,[3] Dwyer's operation,[1,2] and Matsuno's talar neck osteotomy[5] have proved to be unnecessary. Results are excellent without residual pathoanatomical changes of bones and joints. The feet have a normal external appearance, improved bony alignment radiographically, and adequate activities of daily living.

Recording the Foot Deformities

To record the foot deformities, plaster models and photographs taken from several directions are useful. Recording on videotape demonstrates the deformed shape of the foot and results of the therapeutic procedure in three steps are evaluated in our museum.

The degree of contracture is shown in a picture taken while the foot is drawn by a spring scale weight of 1 kg, although this has been done only once, as it goes against the corrective principle.

These methods of recording to classify the severity of clubfeet are not commonly used. Moreover, presenting one frontal picture is customary, but it is not useful in the assessment of the degree of severity. When we see a photograph of an adducted normal foot, this foot seems to be a mild clubfoot.

Pathoanatomical Studies of the Severely Deformed Clubfoot

It is most important to clarify the characteristic pathoanatomical structure of severely deformed clubfeet in order to assess the degree of severity and establish corrective principles.

The bony structural changes of severe clubfoot of a fetus with other congenital abnormalities, e.g., intestinal occlusion and an imperforate anus, were the same as idiopathic severe clubfoot. The clinical findings of severe clubfeet of a mother and daughter and of identical twin siblings were the same as those of idiopathic severe clubfoot. It is impressive that the severe idiopathic clubfeet show the same structural changes in spite of any teratologic or hereditary condition.

Characteristic Shape of Severe Clubfeet

The severe clubfoot shows HFV, calcaneal rotation, and FFA with the following findings:

1. The whole foot is located in the coronal plane.
2. As the foot inverts, the sole assumes a vertical position and it has a slight cavus component.
3. The medial surface of the forefoot turns upward.
4. The hindfoot is also in varus and the medial plane of the hindfoot is at a right angle to the leg.

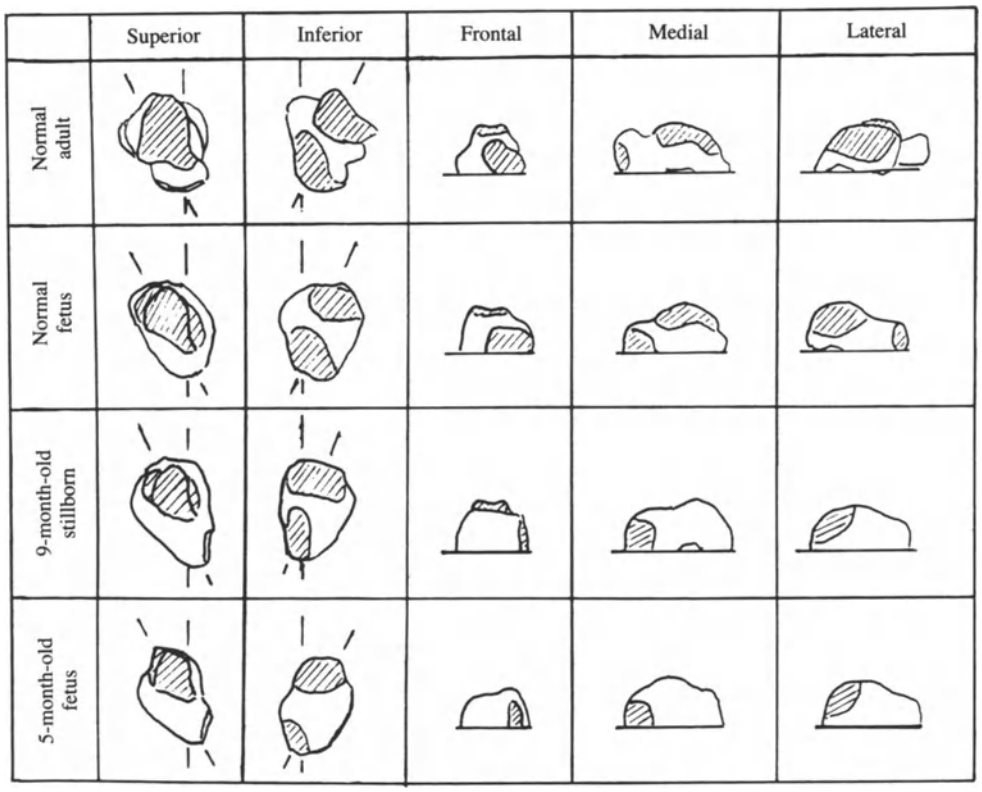


FIGURE 17.11. Drawings of the tali of a normal adult, a normal fetus, a 9-month-old stillborn infant with clubfoot, and a 5-month-old fetus with a clubfoot. Drawings of superior, inferior, frontal, medial, and lateral views of the clubfoot tali. This demonstrates that the normal fetal talus differs from that of the adult talus in that there is no constriction of the neck in the former. The anterior articular surface lies horizontally and extends medially to the neck. Both long axes of the talus run obliquely through the talus from posterolateral to anteromedial. In a severe fetal clubfoot, the shape of the talus does not differ markedly from that of the normal fetus, except for the sharp form of the head, which results from the navicular subluxation overlying this area with secondary adaptive changes occurring because of the navicular position. There is no medial deviation of the neck; the axis of the neck is parallel with the long axis of the talus, just as it is in the normal talus.

5. There is a concave deformity of the medial edge of the foot.
6. There is a convex lateral edge of the foot.
7. The heel is filled with fatty tissue.

Bony Structural Change

The findings in all of the specimens were fundamentally the same.

Talus

The shape of the normal fetal talus differs from that of the adult. The former has no constriction of the neck, i.e., it does not have a narrow neck, and its anterior articular surface lies horizontally and extends medially to the neck. Both long axes of the talus run obliquely from posterior lateral to anterior medial (Figure 17.11).

In the severe fetal clubfoot, the shape of the talus does not differ markedly from that of the normal fetus, except for the sharp form of the head that results from the medial surface of the anterior joint having been in contact with the navicular in the sagittal plane (this runs parallel with the axis of the trochlea). There is no medial deviation of the neck. The axis

of the neck is parallel with the long axis of the talus, i.e., just as in the normal talus (Figure 17.11).

Histologically, the articular cartilage covers not only the medial aspect of the talar head but also the lateral aspect as seen in normal feet. In the lateral area, the luster is lost, which is to be expected because of the lack of mobility of the navicular during the long fetal life, but this facet is within the joint capsule. The medial joint capsule is folded and lies between the navicular and the medial malleolus. In cadaver experiments, I was able to push the navicular distally and laterally in front of the talar head within the joint capsule. These findings give the talus an appearance of medial deviation of the neck (as is widely believed) because previous investigators have considered only the area that has luster as the whole anterior joint surface (Figure 17.12).

In my anatomical examinations I extirpated the talus of an infant with a severe clubfoot. It showed that the external shape was almost the same as the normal and the ossification center occupied the neck and a small part of the body. *Deviation of the neck did not exist.* This center grows and forms a normal talus.

To prove that the deviation of the neck did not exist, I measured the angle between the long axis of the trochlea and the axis of the neck. The result was almost 24°, the same as a normal talus. This confirmed the absence of deviation of the neck.

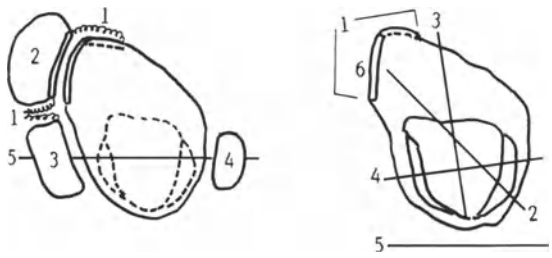


FIGURE 17.12. A: The navicular is fully subluxated medially. This demonstrates the layers of the talonavicular joint capsule: 1, joint capsule; 2, navicular; 3, medial malleolus; 4, fibula; and 5, intermalleolar line. B: This drawing demonstrates that the navicular has been manually reduced on the distal end of the talus. The navicular was pushed onto the distal end of the talus while remaining within the capsule: 1, talonavicular joint; 2, long axis; 3, trochlear axis; 4, intermalleolar line; 5, coronal plane; and 6, surface area, which retains contact with the navicular.

Calcaneus

The most obvious change was a tilting of the anterior articular surface approximately 45° medially. The rotation and varus of the calcaneus under the talus are secondary to the deformity of the talus.

Other Bones

The forefoot of the severely deformed clubfoot is almost the same as a normal foot. When the skeleton is discussed, the forefoot is dealt with as one bone.

Soft Tissues

The contractures of soft tissues are considered as secondary.

Abnormal Bone Alignment of Severe Clubfoot

The forefoot can be considered as one bone unit as it has little soft tissue. The bony structure is understood by knowing how this supinated and adducted forefoot connects with the hindfoot, i.e., investigation of the connecting relationship among the forefoot, talus, and calcaneus.

From this anatomical investigation, I have presumed that the origin of the severely deformed skeleton may be the forceful adduction of the forefoot, which is caused by the motion of the leg and foot in the very early stages of pregnancy. The changes in the talus and calcaneus occur because the foot had no mobility throughout the long prenatal period. The fact that the same structure was found in the severe clubfoot of a 5-month-old fetus suggests that those changes occurred much earlier, due to the lack of mobility of the foot for a long time, i.e., until the 5th month of pregnancy.

The forefoot must be in a supinated position to allow the greatest adduction, like a hinged door. This causes the following changes in the hindfoot: the calcaneocuboid joint moves directly beneath the talonavicular joint and the calcaneus rotates medially until it is parallel to the talus. As this is a secondary change, this rotation of the calcaneus disappears when the

calcaneocuboid joint is corrected to its normal position. To obtain this normal position of the calcaneocuboid joint, it is necessary for the navicular to move in front of the talar head simultaneously.

For both joint surfaces to face medially, the above-described changes of the talar head and neck and anterior joint of the calcaneus occurred, causing slight adduction of the talus at the ankle joint. The calcaneus rotates medially until it becomes parallel to the talus, and it takes a slight varus position in the subtalar joint. But these changes in position are not sufficient to make the surfaces of both joints face medially, so the medial ankle torsion occurs for this purpose.

Observation of specimen: If we look at a foot amputated at the ankle joint, we see the dorsal plane of the hindfoot, which is in a plantar flexed position, but in the forefoot we see only its medial surface, as it is in a supinated position.

The navicular is in contact with the medially extended facet of the talar head, and the forefoot is adducted to about a 130° angle to the hindfoot.

The calcaneus is parallel to, and beneath, the talus. When we extirpate the talus and the navicular, we see that the anterior joint surface of the calcaneus, which tilts medially about 45°, contacts the cuboid bone, which makes an angle of about 130° between the forefoot and the hindfoot.

As the navicular is on the medial side of the talus, the more plantar flexed the talus, the more the tip of the navicular tuberosity turns upward and pushes the medial malleolus and makes a dent. So the plantar flexion of the talus in the ankle joint may be the cause of the adducted position of the forefoot.

These findings teach us that in severe clubfeet the supination and adduction of the forefoot and varus of the hindfoot should be corrected before the equinus.

Observation of the severely deformed skeleton: (a) From in front, we see the back of the adducted forefoot in a supinated position. The tip of the navicular tuberosity pushes against the medial malleolus. (b) From the medial side, we see the tips of the forefoot in a supinated position. (c) From the back, we see the sole of the forefoot in adduction and supination and the hindfoot in slight varus. In this slightly varus position the sustentaculum tali pushes on the malleolus and the subtalar joint is not seen. (d) From the lateral side, the hind part and lateral side of the calcaneus is seen.

From my experiment with fetal specimens I learned the principles of correction. During my dissections of fetal clubfeet, I cut off all the tendon attachments. In the mild CTEV, the deformity could be easily corrected, but in a severe clubfeet of a 5-month-old fetus, the deformity was so stiff that it could not be corrected because of severe joint contractures (producing bony deformities), which resulted in malalignment of the tarsal bones. Enucleation of the calcaneus to remove this contracture allowed easy correction of the forefoot to its normal position by bringing the navicular in front of the talar head within the joint capsule (Figure 17.13). This experiment taught me that the severely deformed clubfoot has severe ligamentous contractures in addition to the tendon contractures. To correct HFV and FFA conservatively, a serial therapeutic procedure is necessary.

Focus of Conservative Treatment

Understanding of the nonsurgical correction of CTEV is so important that the orthopedist should grapple with it very seriously. Jinnaka[4] stated: "Even if one adopts surgical procedures in orthopedics, one should keep an orthodox mind and be well versed in nonsurgical treatment. Surgical management can only be performed by someone who has mastered nonsurgical treatment."

Correction and fixation should be dealt with separately. Correction means that one corrects the deformities of clubfoot to bring about a normal form or an overcorrected form. Fixation means maintenance of correction to prevent recurrence. When the correction is insufficient, however, shoes and casts should not be used as corrective devices, as they are maintenance devices and are only effective once correction has been achieved.

This is the principle of conservative correction of the HFV and FFA. However, it is also necessary to know the corrective principle the author has described for the conservative correction of equinus in severe clubfoot, which is somewhat different, as fixation in the cast is difficult. When the equinus remains or dorsi-

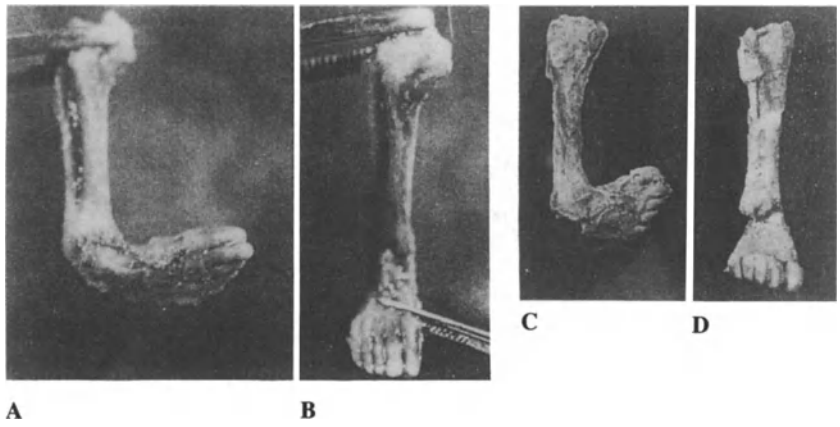


FIGURE 17.13. A: Moderate clubfoot deformity. B: After removal of the tendon insertions, the foot can be easily abducted into a normal alignment. C: The severe clubfoot of a 5-month-old fetus. The foot is very stiff. D: The forefoot could be turned outward and the navicular moved in front of the talar head only after the calcaneus was removed.

flexion is impossible, a minimal posterior release is carried out.

As to when the treatment of severe clubfeet should be started, my results have shown that, when treatment starts at $2\frac{1}{2}$ months of age, the results are equal to those started immediately after birth.

In the corrective cast methods widely performed in Japan, most surgeons attempt to correct all elements of the CTEV deformity, including equinus, at the same time. They correct the deformed foot by externally molding the cast while the cast is soft, thus hurting the infant and causing the infant to cry. As a result, the conservative correction of a severe CTEV becomes impossible as a spuriously corrected foot or an iatrogenic, resistant clubfoot is produced. The front part of the foot faces forward, but the varus and rotation of the hindfoot remain. The most striking finding on radiographs was the fact that the toes had abducted laterally at the MP joints, so surgeons believe that they must perform posterior medial release operations, etc.

After 3 months of conservative treatment, they perform posteromedial releases on the deformed feet. In this operation they have trouble with skin closure because the foot has a severely deformed shape.

As they correct all components surgically at the same time, the complete correction is difficult. Furthermore, they use Denis Browne bars, corrective shoes, and foot plates for a very long time to maintain the corrected position.

Treatment of Hindfoot Varus, Forefoot Adduction, and Medial Ankle Torsion

Conservative Correction of Varus and Adduction

In the severe clubfoot I always first correct the HFV and FFA elements conservatively. Unlike the moderate clubfoot, the severe clubfoot cannot be corrected conservatively when all three components are manipulated at the same time.

The principle of this conservative treatment is to stretch the ligaments, tendons, and muscles gradually, and to correct the deformed bony structures. The soft tissue is lengthened by serial manipulations and plaster casts. The deformed bone alignment is corrected by serial techniques based on pathoanatomical and pathomechanical study as described later.

The bone alignment is hidden from the exterior, but the structure must be understood and each bone must be palpated.

In severe clubfeet, the HFV and FFA (rotation) are corrected by gentle serial manipula-

tions and a holding cast that maintains the slightly corrected position thus obtained. This is done every other day during the first phase or until the middle of the second phase, and thereafter once a week. But infants who come a long distance are treated once a week from the beginning. As the correction obtained in 1 hour is almost equal to that obtained in 20 minutes, 20 minutes of manipulation at a time seems adequate. Although the contracture is very rigid on the first day, the correction progresses satisfactorily step by step. In 3 to 4 weeks complete correction of HFV and FFA will be obtained.

The criteria to evaluate the completeness of correction of HFV and FFA are the shape of the foot and the AP radiographs. On clinical examination, the talus plantar flexes at the ankle joint; when the HFV and FFA have been completely corrected, the corrected foot might be plantar flexed. The forefoot appears abducted, i.e., the lateral edge of the foot is concave, the medial edge is convex. The heel takes a slight valgus position, which is inspected only in the dorsiflexed position. The AP radiograph shows normal findings as described later.

The tarsal bone alignment has become normal, i.e., the navicular has moved forward onto the anterior tip of the talus, the calcaneocuboid joint has reduced to a normal lateral position, and rotation and FFA of the calcaneus have disappeared. The ligaments, muscles, and tendons have been extirpated, but joint incongruity may remain.

In the second phase, to avoid recurrence of HFV and FFA, cast immobilization is used with the foot in the corrected position for 4 months. These tissues remodel with growth and the strength of involved muscles is restored. In this phase, manual correction of equinus is performed when the casts are changed.

Practical Manipulative Techniques to Correct HFV and FFA

In the severe clubfoot, the talus plantar flexes strongly and adducts slightly; the calcaneus rotates and takes a slightly varus position in the subtalar joint. The forefoot adducts to the hindfoot about 130° and it takes the greatest supinated position. The plantar flexion of the calcaneus is not so important because it is a secondary product of movement of the calcaneocuboid joint.

To correct HFV and FFA of the whole foot, the extremely supinated and adducted forefoot must be corrected by this maneuver so that the navicular is brought in front of the talar head from its medial facet. This facilitates the mobilization of the calcaneocuboid joint to the normal position.

The practical manipulative technique to accomplish correction is as follows: pathomechanically, one should consider that there are two lever systems in which the lateral wall of the talar head and neck represent a fulcrum; the head of the talus may be easily palpated as a small prominence on the dorsolateral aspect of the foot. It may be preferable for two levers to be applied simultaneously in different directions. In the forefoot, the navicular, cuneiforms, and metatarsals are placed in straight alignment. These form the arm of the first lever needed for the correction of adduction. The first lever will permit abduction of the forefoot, while forefoot traction is applied to the medial osseous column of the forefoot, which is everted to the normal position. To abduct the forefoot, I push the medial edge of the forefoot laterally, pulling this column distally to move the navicular anteriorly in front of the talar head.

The second leverage system allows one to push up on the sole of the calcaneocuboid joint toward a normal lateral position to correct the varus (and rotation) of the calcaneus and the supination and adduction of the forefoot.

Without the mobilization and distraction of the navicular, the mobilization of the calcaneocuboid joint cannot be achieved. Consequently, these two levers have to be applied at the same time, being controlled by external forces provided by the fingers as follows: For the right clubfoot, the surgeon uses the tip of his left thumb as a fulcrum for leverage on the lateral plane of the talar head or neck. His right index finger is placed on the medial edge of the forefoot, and the thumb and middle finger grasp the medial osseous column. The ring finger of either hand is placed on the plantar surface under the calcaneocuboid joint to push it dorsally and laterally, trying to recover realignment of the calcaneocuboid, the talonavicular, and the subtalar joints (Figure 17.14). The aim of this manipulation is to correct the

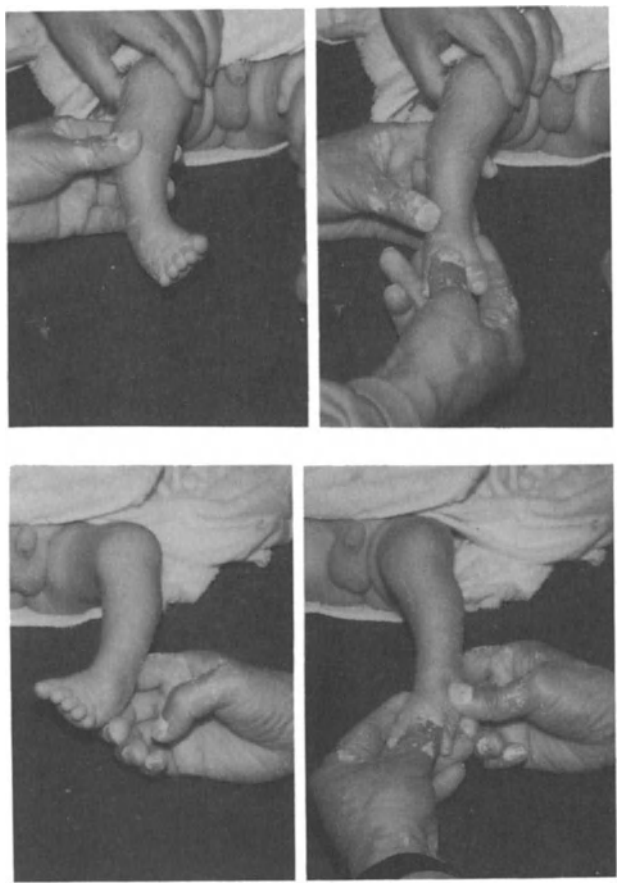


FIGURE 17.14. The manipulative technique for the correction of HFV, FFA, and FFS.

tarsal bone alignment by the rhythmical application of a weak force.

Correction of Medial Torsion of the Ankle

In the severe clubfoot, the medial malleolus cannot be palpated before the start of treatment. However, with the advancement of the correction of HFV and FFA, the medial malleolus becomes palpable as a little protuberance. The medial tibial torsion may be easily found on examining the direction of the transmalleolar line when the knee joint is extended and the kneecap directed forward. This test can be used in youngsters as well as in the aged without radiographs.

As this deformity is considered to be due to the rotation of the tibia, it can be corrected by repeated casting, which provides a torsion force directly to the tibia. A callus-like shadow may be found on a roentgenogram after complete correction of the internal tibial torsion.

The internal tibial torsion should be cured early in infancy as it is one of the causes of an internal rotation gait. It is important not to overlook those cases that have not achieved normal lateral rotation of the lower leg in infancy.

This treatment is effective even in walking children, as the child can still walk with a cast with the knee bent to a right angle.

Plaster Casts for HFV and FFA

The purpose of this holding plaster cast is to maintain correction obtained by manipulation. This cast is a retentive, not a corrective, apparatus. This cast is an above-knee cast that is always applied from the groin to the toes with the knee flexed at a right angle to maintain the

corrected foot, to prevent the cast from slipping, and to avoid damaging the peroneal nerve.

Plaster Casts for Internal Tibial Torsion

Correcting internal tibial torsion is done when the correction of HFV and FFA has progressed moderately. While an assistant holds the hardened cast that extends from the groin to the distal one-fourth or one-fifth of the leg, another assistant extends the cast down to both malleoli and the operator holds the foot in a corrected position. The cast is then molded to the correct position of varus and adduction.

Evaluation of Correction of the HFV and FFA

The complete correction of HFV and FFA can be evaluated both radiographically and clinically; however, the radiographic views provide more important criteria than the external shape.

After the HFV and FFA of a severe clubfoot are corrected, the bone alignment becomes normal in 3 to 4 weeks. Then AP radiographs are taken, one in the natural position and the other in a maximally corrected position. The views in the maximally corrected position are more important.

As the ossification centers of the navicular, cuneiforms, and frequently the cuboid are not present at birth, the skeletal construction of the foot must be judged by the talus, calcaneus, and 1st metatarsal. Improvement and the completion of correction have been assessed using the long axis of the talus and the 1st and 5th metatarsal axes as shown in the following description.

During early treatment, the AP radiographs in the natural and maximally corrected positions show that the axis of the talus points to the area close to the base of the 5th metatarsal (Figure 17.15A). When correction has progressed slightly and the foot becomes straight, the AP radiographs taken with the foot in both the natural position and the maximally corrected position show that the axis of the talus does not yet point to the base of the 1st metatarsal. The axis of the 1st metatarsal passes medial to the talar head (Figure 17.15B).

When the correction has progressed moderately, the radiographs taken in the natural and maximally corrected positions show improvement. The long axis of the talus points medial to the base of the 1st metatarsal as in the normal foot, although views in the natural position show less improvement of both axes (Figure 17.15C).

At the end of treatment, the radiographs show no difference between the natural position and the maximally corrected position. When the correction of HFV and FFA is complete, the external shape of the forefoot is widely overabducted in relationship to the hindfoot, i.e., the medial edge of the forefoot is convex and the lateral edge concave. The heel is in valgus position when the foot is dorsiflexed, the abduction of the foot is conspicuous as there is external tibial torsion, and the skin of the foot below the lateral malleolus is wrinkled. But the completion of correction should be decided by radiographs.

The radiographs with the foot both in the natural position (Figure 17.15D, left) as well as in the maximally corrected position (Figure 17.15D, right) show that the talar axis passes medially to the base of the 1st metatarsal while the 1st metatarsal axis passes through the talar head. The orientation of the axis of the talus is normal, much more medial than the base of the 1st metatarsal, and penetrates the medial edge of the foot. The longitudinal axis of the 1st metatarsal passes through the talar head, as it should when fully corrected (Figure 17.15D). 17.15D).

When the adduction of the metatarsals is the only element of deformity, it must be treated by the same method (Figure 17.15E, left). The radiographs of the metatarsal adduction show that the axis of the talus passes far medial to the base of the 1st metatarsal and the axis of the 1st metatarsal is directed far lateral to the talar head. When corrected, the talar axis passes through the medial side of the foot while the 1st metatarsal axis passes through the talar head, as it should (Figure 17.15E, right).

Although the TC angle and TC index have been considered important criteria in the past, based on my experience of over 200 cases these measurements are of little value in assessing the increase of correction of HFV and FFA. Moreover, the TC angle does not show a fixed value, varying from day to day or even during the same day. Therefore, I use the talar neck

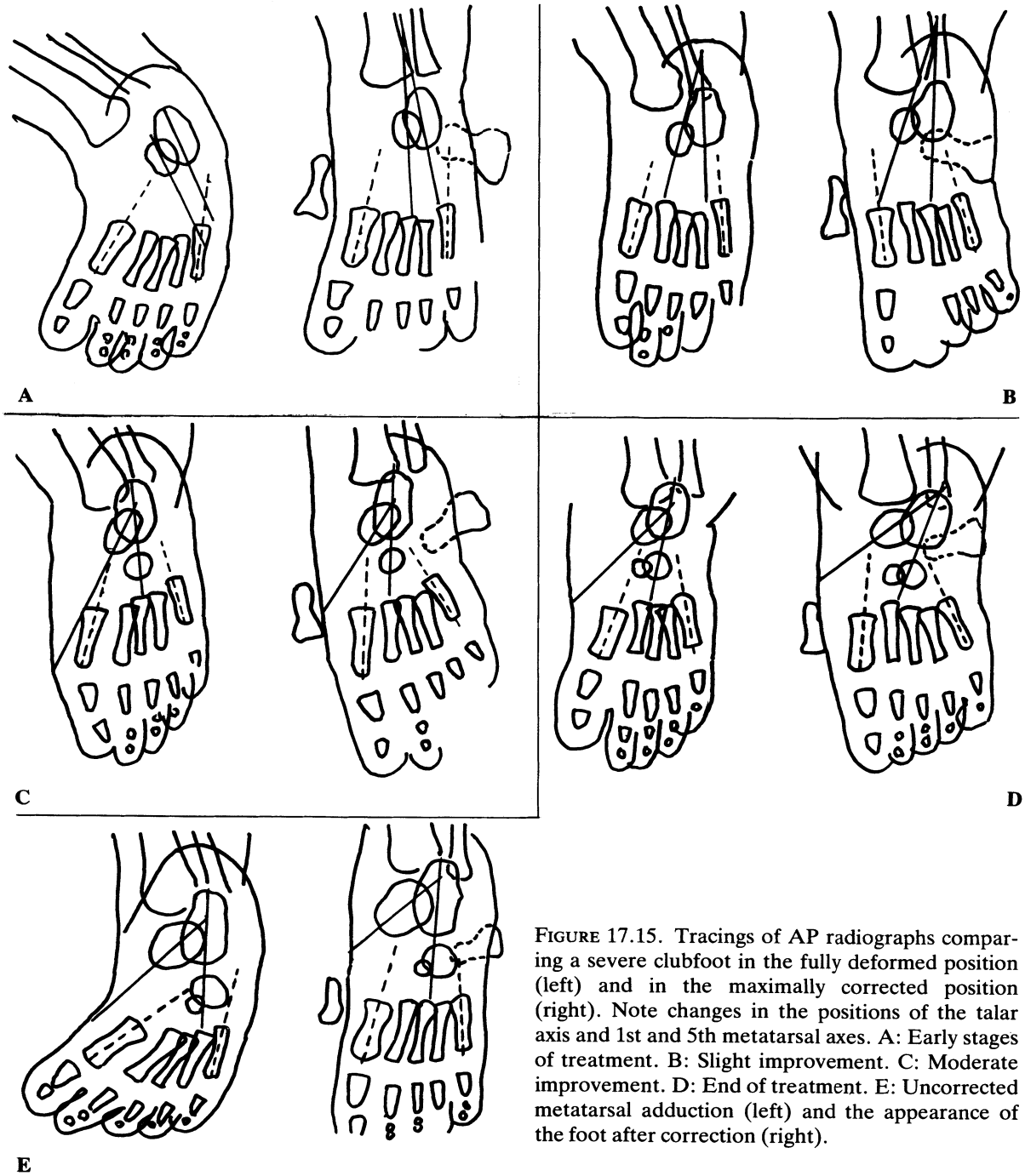


FIGURE 17.15. Tracings of AP radiographs comparing a severe clubfoot in the fully deformed position (left) and in the maximally corrected position (right). Note changes in the positions of the talar axis and 1st and 5th metatarsal axes. A: Early stages of treatment. B: Slight improvement. C: Moderate improvement. D: End of treatment. E: Uncorrected metatarsal adduction (left) and the appearance of the foot after correction (right).

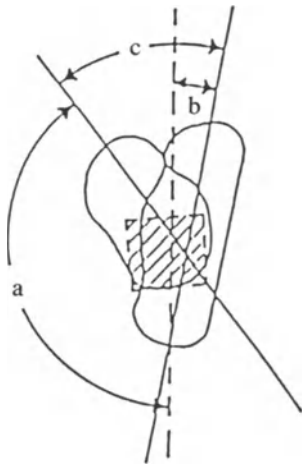


FIGURE 17.16. Line drawing of an AP projection of the talus and calcaneus: a, the angle between the calcaneal axis and the talar neck axis, the "talar neck angle"; b, the true talocalcaneal angle formed by the calcaneal axis and the true talar neck axis; c, the false talocalcaneal angle formed by the calcaneal axis and the false talar neck axis. Matsuno et al.[5] believe that the talar neck deviates medially and, consequently, that the talocalcaneal angle in severe clubfeet is erroneous. However, I believe that the neck of the talus is not deviated medially and that the talocalcaneal angle is a valid measurement, but it is not useful in assessing correction of hindfoot varus or forefoot adduction.



FIGURE 17.17. The technique for manipulation of equinus is performed with the knee flexed and then continued with the knee extended.

axis and the axis of the 1st metatarsal rather than the talocalcaneal angle to evaluate the correction of HFV and FFA.

Matsuno et al.[5] at Hokkaido University stressed that the talar neck deviates medially; consequently, they insisted that the use of the TC angle in severe clubfeet was erroneous. However, as I explained earlier, the neck of the talus does not bend medially, so I believe that the talar neck is a valid landmark (Figure 17.16).

Correction of Equinus

Manual Correction

To correct equinus conservatively, it is necessary to stretch the triceps surae muscle and maintain the elongated position with one's fingers. The problem is that one cannot push the calcaneal tuberosity downward in a holding cast. Manipulations of equinus are performed when the cast is changed in the second phase. To stretch the triceps surae, the index finger presses deeply above the upper end of the calcaneal tuberosity while the thumb and middle finger firmly grasp the calcaneal tuberosity from both sides and pull it downward.

Instead of using a holding cast, the corrected position obtained by manipulation is repeatedly held manually for as long as possible, even if it is only for a minute or two.

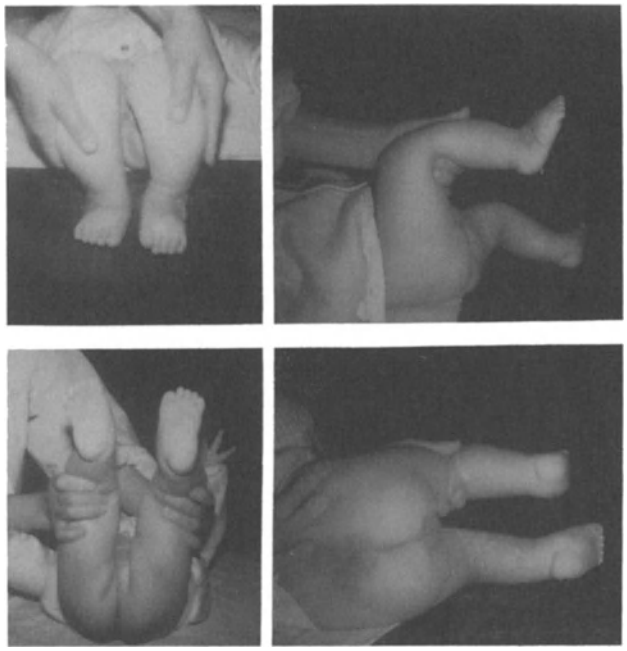


FIGURE 17.18. The appearance of corrected feet. The hindfoot varus, forefoot adduction, and forefoot supination are all completely corrected.

To lengthen the gastrocnemius muscle, the knee is repeatedly extended while the foot correction is maintained manually. This manual correction of the equinus is performed with the knee in an extended position (Figure 17.17).

When the degree of equinus is not so severe, the leverage Kirschner wire traction cast can be applied without surgery. In the third step, occasionally vigorous stretching exercises performed several times a day may be successful.

Leverage K-Wire Traction Cast

Excellent results can be obtained with this method even with severe equinus (Figure 17.18). It is the least invasive posterior release procedure because it involves only lengthening the Achilles tendon and making transverse incisions in the capsules of the ankle and subtalar joints. No other tendons or ligaments are lengthened or incised and insignificant bleeding eliminates the need for a tourniquet.

To determine the length of elongation of the Achilles tendon, a diagram of the dorsiflexion view is made from lateral dorsiflexion radiographic views. The predicted length of elongation is determined by comparison with present views (Figure 17.19). It is not necessary to lengthen the Achilles tendon excessively as it puts strong tension on the calcaneus. One need not be concerned if the tendon at the time of operation seems not to have been lengthened enough; strong traction can be used.

In the late results, although the muscle belly of the calf is somewhat thin based on inherent abnormality within the muscles, the muscle force is so strong that many boys with CTEV win races with their friends.

After transecting the Achilles tendon by z-lengthening, the foot is easily dorsiflexed by merely pulling with a pointed hook on the lower end of the calcaneal tuberosity.

It is most important that the Kirschner wire pass through the ossification center of the calcaneus so that it does not pull through the cartilage. I pass a 2-mm Kirschner wire through a hole of a trocar needle, which is inserted by hand. The wooden foot plate and the leverage plate are fixed to the Kirschner wire by clasps and twisted wires (Figure 17.20).

I have had a case of a small plantar ulcer that produced hard scar tissue and required a skin graft. Therefore, I now insert a sponge plate between the wooden foot plate and the sole (Figure 17.20).

The severed ends of the Achilles tendon are sutured with the foot in plantar flexion and the wound is closed. The patient is moved to a

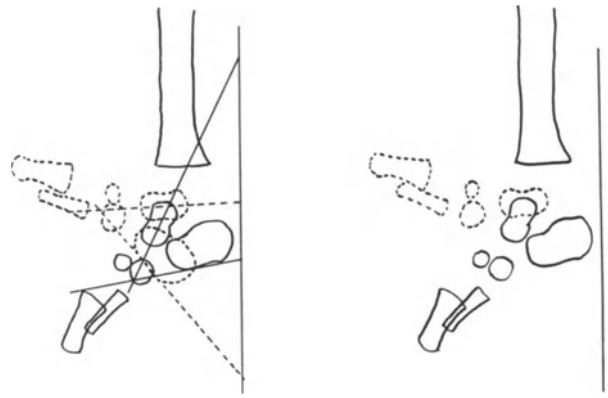


FIGURE 17.19. Two tracings of radiographs each with two superimposed lateral views of the foot showing changes in position of the hindfoot bones as correction of equinus occurs. These can help to determine the amount of Achilles tendon lengthening needed.



FIGURE 17.20. Wooden foot plate.

supine position and an above-knee cast is applied in dorsiflexion, incorporating the leverage Kirschner wire traction system. When this cast is changed for suture removal in 2 weeks, lateral roentgenograms should be taken to check the correction in the dorsal and plantarflexed positions of the foot. The cast is applied with the leverage plate at approximately 60° in relation to the leg. The second cast is removed at 1 month following surgery.

The leverage Kirschner wire traction cast method has even given successful results in a junior high school boy and an adult who walked without putting their heels down. In such cases, we use 3-mm Kirschner wires.

My method utilizes a modified Morita's leverage Kirschner wire traction cast. It differs from Morita's original method[7] in the following ways:

1. I use this method to correct equinus only, after the HFV and FFA have been corrected and there is no fear of its recurrence at 5 to 6 months. The original method was used to correct the HFV and FFA together.
2. Unlike the original method, the modified method corrects the equinus by setting the lever plate so that its posterior part is long, thus pulling the foot toward the plantar side. Now the anterior part of the lever is held in such a way that the trochlea of the talus does not get compressed. I have not had any cases of flattop talus in my late results.
3. To avoid ulceration due to excessive plantar pressure, which has been a problem with the leverage Kirschner wire traction cast, a sponge plate is inserted between the sole and the wooden foot plate and the foot plate fixed so that the pressure is not excessive.
4. The wooden foot plate, which is molded to the corrected HFV and FFA position, is raised to the level of Chopart's joint.

Summary

There is general agreement that operative methods should be performed when conserva-

tive correction fails. Conservative treatment is felt to produce injury to bone or cartilage tissue when it is continued for a long time. Therefore, operative procedures for severe clubfeet are frequently adopted when conservative treatment is insufficient.

However, in the first step of the corrective program I have presented, the HFV and FFA are completely corrected in a period of 3 to 4 weeks. In the second step, recurrence is prevented and manual correction of equinus is attempted. In the third step, a posterior surgical release and a modified Morita's leverage Kirschner wire traction cast is used if correction of equinus was not achieved with step two. This is the least invasive technique available.

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Editor's Comments

Hitachi's approach to the treatment of clubfeet resembles that of Ponseti[4] and Kite.[2] He uses conventional cast and manipulation techniques, followed by a minimal posterior release, if necessary, to correct equinus deformity. The technique of posterior capsulotomy at the ankle and subtalar joints is performed along with insertion of a Kirschner wire through the calcaneus to produce leveraged traction as previously described by Morita.[3] Hitachi describes several modifications to this technique. He claims that he is able to achieve correction of older, as well as severe, cases in addition to the typical cases of clubfeet in almost every instance. Therefore, he finds no place for procedures such as the posteromedial release, the posterior lateral release, Evans' procedure, Dwyer's procedure, or talar neck osteotomy.

Hitachi bases his technique of conservative treatment on anatomical dissections that he performed in Kyoto a number of years ago. At that time, he made the observation that the talar neck was not abnormally angulated, but rather has a normal talar neck angle and the navicular is markedly displaced on it. He also observed that the talar head could be moved within the capsule, and that the capsule, therefore, was not adherent to the head. In addition, he observed that tibial torsion is a constant deformity of the clubfoot, whereas, in recent years, it has been fairly well documented that tibial torsion is not a significant deformity in the clubfoot, as was believed in the past.[1,5,6]

Finally, **Hitachi** states that when treatment starts at 2 or $2\frac{1}{2}$ months of age, he can achieve results equal to those started immediately after birth. I think the majority of surgeons today do not achieve results as good at 2 months of age as one can achieve at birth.

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