Advances in Care of the Foot: 1800 to 1987

J. Leonard Goldner, MD

History

Current management of physiological and pathological conditions of the foot has evolved during the past 200 years, parallel with development of major advances in all other aspect of medicine and surgery. In the 19th century, emphasis was on anatomical and pathological dissection, and on the accumulation of data concerning clinical syndrome.

Roentgen's discovery in 1895 gave a reproducible method of obtaining data about fractures, inflammatory disease, and subtle differences in lesions that affect the osseous and cartilage structures of the foot. As systematic recognition of foot lesions became more obvious, emphasis was placed on classification of pathological lesions.

Embryonic Development of the Foot

An understanding of embryonic development of the foot requires a description of the embryonic anatomy compared to the foot structure in the newborn and subsequently, in the adult. These observations demonstrate rotational changes that influence the extensor or anterior surface of the foot that was initially lateral, and the flexor or plantar surface that was initially posterior. In the reconstruction of this progress by Böhm, the 18 mm embryo shows the talus and the calcaneus to be inclined medially, so that the foot appeared adducted. However, before the end of the embryonic period, lateral deviation of the foot had occurred. By 4 weeks (6 mm, stage 13), the vascular supply is visible, and by 7 weeks, practically all vessels of the adult limb are visible. By 5 weeks (8 mm, stage 15), nerves L2 to L5 and S1 to S3 form the lumbar and sacral plexus respectively. After an additional week, the tibial nerve reaches the plantar region of the foot, where it divides into medial and lateral plantar nerves. The adult pattern of dermatomes indicates that the lumbar nerves supply the adjacent territories along the pre-axial border of the limb bud, and the first and second sacral nerves supply the post-axial border. The vascular supply is visible by 4 weeks (6 mm, stage 13), and by 7 weeks, practically all vessels of the adult limb are visible.

Bardeen, in 1905, described the development of the human skeleton; in 1911, Ficke provided information about the anatomy of the foot. From these studies it was apparent that the foot anlage is oriented so that its future plantar surfaces initially face the umbilical cord and the head, and subsequently the plantar surfaces rotate to face rostrally and medially.

Straus, in 1927, described growth of the human foot and its evolutionary significance. These observations indicated that the foot and extremity developed from unsegmented body wall consisting of mesoderm covered by ectoderm. The nerves and blood vessels grow rapidly into the elongating limb buds. A continuous morphogenetic interdependency exists between the apical ectoderm and the mesoderm as the development of the limb structures occurs in the proximal distal sequence.

Milaire, in 1967, emphasized that the later growth and individualization of the digits result from active processes taking place in the distal tip of each blastema and from the involution occurring in the adjacent interdigital mass. He emphasized that the perichondrium, the muscles, and the tendons arise by centripetal migration from superficial mesenchyme while the skeletal blastema appear in the depth of the limb. This advanced information is based on the histochemical detection and localization of certain substances prior to morphologic differentiation.

Gardner and associates also contributed information about the embryonic development of the foot.\textsuperscript{1} This data was critical to relating the pathological and deformed foot to the five radiating mesodermal columns that are present in the developing embryo.

**Congenital Talipes Equinovarus (Clubfoot)**

Congenital deformity such as clubfoot, vertical talus, and hypoplastic lesions of the foot were initially managed by strong manual manipulation and constant external splinting. Occasionally, selective surgical procedures were performed; however, without general anesthesia or when anesthesia time was very limited, surgical efforts were incomplete and not curative.

The memoirs of Scarpa\textsuperscript{8} describe talonavicular deformity and other observations concerning clubfoot. Certain aspects of the pathological condition, accurately described in these observations, are now being made by many surgeons recognized not only by Scarpa but by other investigators at that time.

During the next 100 years, there were numerous articles and monographs related to description of the pathological lesions and the nonoperative and surgical treatment of clubfoot. In 1887, Bradford remarked at the first meeting of the American Orthopaedic Association that the clinical results did not match the enthusiasm of those performing the surgery, and that the claims were great but the correction was incomplete and recurrence was frequent.

**Gradual Alterations in Management of the Clubfoot**

Hoke, in 1911, described operative plans for correction of relaxed and untreated talipes equinovarus.\textsuperscript{9} He emphasized tarsal fusions and performed high tibial and fibular osteotomy to realign the medially deviated, internally rotated foot. Ober, in 1915, described an operation for the relief of congenital equinovarus deformity, with emphasis on operations on the medial and posterior structures.\textsuperscript{10} The results did not influence the pattern of management during the next several years. Kite, a student of Hoke's, noted complications and difficulties after surgical treatment. His effort was on frequent applications of plaster casts to avoid the fibrosis that resulted from surgical treatment, and yet to maintain the foot in a reasonable weight bearing position until improvement was obtained or until triple arthrodesis could be performed.\textsuperscript{11}

From early 1900 until 1950, most patients with a clubfoot deformity were managed by at least 1 or 2 years in plaster casts, 2 to 3 years in a children's hospital, and an unpredictable result by the time the patient was 12 years old. Persistent deformity was usually apparent, and resistant clubfoot was the rule rather than the exception.

In 1930, Kite described his nonoperative treatment of congenital clubfoot, his methods influenced most orthopedic surgeons and prevailed until 1950. Kite's contributions emphasized the importance of gradual elongation of skin and connective tissue. Positional and mild feet showed rapid improvement. However, moderate and severe feet were slow to improve, and radiographic studies demonstrated that spurious correction was occurring with the prolonged plaster treatment and frequent manipulations. At that time, however, this method of management was probably the best available, since surgical technique had not been well developed, small instruments were not available, and magnification was not considered as an essential part of the procedure.

**Other Methods of Treating the Clubfoot**

The Robert Jones strapping and the Denis-Browne splint were popularized in contrast to cast management.\textsuperscript{12} For many years, and even now, the comparison between cast treatment and external adjustable splints continues. This concept was important in providing an alternative method to demonstrate the amount of correction that was possible in feet with undefined severity.

Those surgeons who used the splints frequently resorted to forceful manipulation of the feet with or without anesthesia, and intra-articular damage did occur. The Denis-Browne splint, used in conjunction with a heelcord lengthening and not a posterior capsulotomy, resulted in maximum mobility of the sub-talar joint and minimal improvement at the ankle joint. However, the contracted medial ligament and tendons and the deformed tarsal bones persisted because of spurious correction in severe feet and improved position in feet with minimal deformity.

In 1920, Steindler described stripping of the os calcis.\textsuperscript{13} This procedure has been modified, but the concept persists in managing cavus and medial deviation of the calcaneus. In 1930, Brockman published a monograph on treatment of congenital clubfoot, but this was not sufficient to convince his British colleagues that this surgical treatment was
universally successful. In 1923, Dunn described a method of performing triple arthrodesis that provided a serviceable foot in the child with persistent equinovarus.

The combined observation of these many investigators demonstrated the value of open incision of contracted ligaments, the value of elongating contracted tendons, and the benefit of localized tarsal arthrodesis. However, since the entire problem was not approached systematically, the limited surgical procedures resulted in moderate improvement.

In 1950, a consensus as to operative or nonoperative treatment had not yet been reached. The methods of management of clubfeet varied in different parts of the world, and in different regions of the United States and Canada. Plaster casts were the mainstay of treatment and selective localized surgery was performed occasionally. External braces and splints were used to support the feet treated only by nonoperative methods but also by surgical procedures. Special shoes were the rule rather than the exception.

Goldner, in 1950, initiated a structured surgical approach to treatment of clubfoot in children under one year of age. This required use of the Beebe magnifying loupes, fine instruments, and an expert anesthesiologist to provide a reasonable chance of improving the anatomical alignment of the foot deformity by performing progressive procedures to correct all contractures and malalignment. This prospective study was actually initiated in 1955 and included a preoperative classification of severity of the clubfoot and defined the operative procedure such as: lengthening all contracted ligaments and tendons, decreasing the cavus, and realigning the calcaneocuboid area as a part of the total clubfoot operation. The hypothesis at this time was that the success of operative treatment depended on completeness of the surgical treatment. The more severe the initial deformity, the less successful the treatment was, unless all components of the deformity were corrected. The ankle joint should be the site of maximum mobility after treatment is concluded.

Dissection of Clubfeet in Stillborns

Bechtol, in 1950, discussed embryological studies of muscle abnormalities in a clubfoot, and Flinchum, in 1953, described the pathologic anatomy in talipes equinovarus. Muscle excursion was limited but muscle fibers appeared adequate in size and shape. Stewart, in 1951, discussed the anatomical physiological appearance of abnormal tendon insertions and encouraged more extensive surgical dissection of the tendon insertions in the surgical treatment. These observations suggested that there may be a difference between feet in Polynesian children and those in infants of Anglo-Saxon origin. This difference in family background has been documented by other investigators and is probably significant in classifying the severity of clubfeet.

Dissections of deformed clubfeet in stillborns added primary information about abnormal contour of the talus, malposition of the cuboid, the relationship of the talus to the ankle joint and the calcaneus, and data about abnormal tendon insertions. Also, the shortened ligaments, contracted skin, and other evidence of limb bud defects were documented, demonstrated the reasons for incomplete or spurious correction by closed methods of treatment, and emphasized the necessity of a direct surgical correction even though the final outcome might be non-anatomical. Settle, in 1963, presented observations on 16 dissected specimens. These specimens were not all idiopathic talipes equinovarus but did demonstrate that idiopathic clubfeet and those resulting from myelodysplasia or other causes do vary significantly. Irani and Sherman, in 1963, described the deformity of the talus and demonstrated again that the findings are consistent with a limb bud deficiency.

Clubfoot Surgery 1950 to 1960

Although plaster casts and Denis-Browne splints were the mainstay of treatment during this time, several investigators were accumulating information about surgical treatment. Bost and Schottstaedt, in 1960, described their method of plantar dissection that included extensive soft tissue elongation of the plantar structures of the foot. This part of the operative procedure, in conjunction with posterior ankle capsulotomy and heelcord lengthening, did shorten the duration of treatment and lessened the time that the child was maintained in the hospital. The cooperative effort of other surgeons resulted in a rapid accumulation of information relative to more aggressive surgery and, although recurrence and incomplete correction were relatively common, the evidence that appropriate surgical treatment was beneficial was accumulating. By 1960, the "handwriting was on the wall."
Clubfoot Surgery 1960 to 1970

Surgical investigators were accumulating patients and follow-ups that were significant. Until the child with a clubfoot reaches maturity, the initial end result of treatment is not known, and, until the patient reaches 40 years of age, the final result is not known. With or without surgical treatment, traumatic arthrosis may occur and result in pain either in the midtarsal or anterior tarsal joints, or in the subtalar and ankle joints. However, this is the trade-off for an early weight bearing foot without external support and without long periods of hospitalization. And even if reoperation is necessary prior to the age when growth ceases, the surgical treatment is justified.

From 1960 to 1970, the consensus was growing that a “true clubfoot” responded best to open surgical treatment with the surgeon using the benefits of atraumatic technique and magnification. If surgery was completed before one year, a tremendous amount of remodeling could occur. Even after 5 years, however, remodeling was possible and re-establishing congruity of articular surfaces was helpful in providing a weight bearing foot on which a conventional shoe could be worn. Adequate surgical correction eliminated external daytime bracing and required only night splints to assist in elongating collagen as a skeleton was growing.

In 1969, Goldner presented a 15 year experience which included classification based on severity and emphasis on a progressive four quadrant approach to the posterior, medial, plantar, and lateral aspects of the foot and ankle. Subtalar arthroscopy was minimal, the blood supplied to the talus was protected, and in moderate and severe feet, the entire deltoid ligament was lengthened and repaired so that the body of the talus could be aligned with the ankle joint, the talonavicular joint reduced, and the calcaneocuboid joint realigned. All medial and posterior tendons were lengthened and a plantar dissection was completed. The results were dependent on the classification. Mild feet resulted in excellent correction and severe feet frequently required a repeat procedure.

Clubfoot Surgery 1970 to 1980

In 1971, Turco presented a one stage posteromedial procedure with internal fixation. He emphasized extensive dissection of the subtalar joint, tenotomy of the posterior tibial tendon, lengthening of the heelcord, but not lengthening of the flexor hallucis longus or the flexor digitorum longus. At that time, he recommended cutting the talocalcaneal ligament and did not expose the lateral aspect of the foot. Classification based on severity was not presented.

During the next several years, the procedure was adopted by many surgeons and certain complications occurred. Overcorrection was common, recurrence was observed, and persistent in-toeing was frequently evident. The variations in results depended on differences in technique and the lack of any standard classification whereby one surgeon could compare results of the same kind of feet with those operated upon by another surgeon.

McCauley prepared a series of ongoing presentations from 1933 through 1972. He emphasized the wedge from the cuboid and progressive surgical treatment. Evans, in 1961 and in 1968, described arthrodesis of the calcaneocuboid joint for relapsed clubfoot in the older child. The patients in this series demonstrated the recurrence or resistance by the initial method of nonoperative or operative management and one way to manage the convex lateral border of the foot. This approach was helpful but occasionally over correction occurred. LeNoir emphasized the pathological aspects of the lateral border of the clubfoot and discussed the radiologic appearance of the foot and classification of the deformity. His material was gleaned from Steindler’s Clinic and demonstrated the problems related to management of clubfeet in the years from 1940 to 1950.

In 1973, Lichtblau reported on medial and lateral release operations for clubfoot. Thus, the emphasis at this time was on recognizing the site of the pathological lesion and attempting to correct the abnormality in the young child. In reviewing clubfoot clinics in Australia (Williams P, personal communication, 1966) and New Zealand, characteristics of the collagen, the severity of the deformity, and the results of limited surgery showed great variation. Necessity for preoperative classification was even more apparent as the end results in different surgeons’ series were difficult to analyze because preoperative characteristics of the foot were not clearly defined.

Simons reported on analytical radiography of clubfeet and re-emphasized the importance of preoperative assessment. He believed that intraoperative radiographs were essential but other inves-
tigators have not found this helpful. Dynamic radiographs from the lateral view, dorsiflexion and plantar flexion, anterior-posterior radiograph of the calcaneocuboid joint in abduction and adduction, and an anterior posterior stress view of the ankle joint are accepted by many investigators as essential to analysis of the foot prior to surgery and as part of the postoperative determination of correction. The benefit of radiographs in analyzing clubfeet almost 75 years after Roentgen’s discovery is now evident.

During this period, the discussion reigned as to the necessity of extensive or limited subtalar arthroplasty in the management of clubfoot. Bleck, in 1977, documented Goldner’s observations that limited or no posterior or middle facet arthroplasty was necessary in obtaining satisfactory position in correction of the clubfoot, but that complete lengthening of the superficial and deep fibers of the deltoid ligament was helpful and important in evertling, externally rotating, and dorsiflexing the talus and the ankle joint. By 1980, the consensus was that a true clubfoot is managed best by open surgical treatment following nontraumatic technique and using magnification and small instruments. Eight to 12 weeks in plaster, after which a low quarter canvas shoe is used to encourage ankle motion, has been successful in providing adequate correction, at least until adolescence.

**Clubfoot Treatment 1980 to 1990**

The argument continues as to where and how the foot surgery should be performed. McKay, in 1982, emphasized extensive subtalar release and rotation of the posterior calcaneus medially versus distal calcaneus laterally, which is actually in keeping with the concept of others who have recommended realignment of the talus with the fibula and tibia and external rotation and abduction of the distal calcaneus to the lateral aspect of the foot and correction of the deformed calcaneocuboid joint.

Malan has demonstrated a large number of patients with a severely displaced cuboid. This characteristic may be related to the endemic occurrence in that location as the subluxation or dislocation of the cuboid is more severe in his location of practice, South Africa. Hooker, in New Zealand, documents the concept of progressive correction, of limited subtalar arthroplasty, and of lengthening of the deltoid ligament. He, too, noted that there may be a difference in severity and characteristics of those treated in New Zealand as compared to those in other countries (Hooker C, personal communication, 1987).

Simons in 1985 presented 20 patients with extensive subtalar arthroplasty with a short follow up of approximately 2 years. He contended that his data agrees with that of McKay but also noted that after the dissection, he realigned the talus and the calcaneus in such a way that there was no overcorrection and no gaping. This author has examined some of these feet and the sinus tarsi is extremely deep. This is a preliminary study and the results will have to be analyzed in several years.

**Observations in 1987**

Classification of clubfoot preoperatively should be performed to grade the degree of severity. Progressive surgical procedures will then be selected and the surgeon will concentrate on obtaining correction as the operation progresses. The biomechanics of the foot indicate that maximum motion at the ankle joint is desirable, that a limited degree of subtalar movement is in keeping with satisfactory foot function, and that extensive subtalar arthroplasty is not essential to obtain a satisfactory talocalcaneal relationship postoperatively.

The problems of overcorrection, recurrence, and alignment between the talus and the calcaneus, in the midtarsal region, or upward displacement of the navicular after extensive dissection should all be avoided.

The best method of learning about clubfeet is in the operating room. The goal should be: 1) preoperative classification, 2) intraoperative description and documentation of the pathological lesion, 3) postoperative management to encourage collagen stretch during growth and development, 4) preoperative distinction between a positional clubfoot and a limbud deficiency, 5) discussion of familial and genetic components of clubfeet, and 6) relative early surgical treatment using the benefits of magnification, nontraumatic technique, and small instruments to obtain correction without articular cartilage damage. Further growth of the cuboid may require a removal of the central wedge. Every deformity observed should be corrected.

Observing the course of this condition during the past 200 years and observing the changes in methods of management during the past 37 years provides a model for the development and understanding of
prospective studies related to idiopathic congenital talipes equinovarus.

Ideally, a controlled group of patients' clubfeet of similar severity could be classified and operated upon at about the same age, so that those of the same severity will be compared with each other and that end results would be graded according to the severity of the foot. Thus, mild feet would be compared with mild feet and severe feet with severe feet, but the entire group would not be used as a mix to determine a specific percentage of end results.

Supplementary procedures such as wedge resection from the neck of the talus for the deformed talus, external supramalleolar tibial osteotomy alone for correction of in-toeing and deformed talus, and osteotomies of the calcaneus to correct persistent inversion all require prospective studies and careful observation and long follow up.

Benefits of Early Clubfoot Surgery in 1987

Early surgical treatment, 3 months to 12 months, allows maximum correction, maximum remodeling, and weight bearing with the feet in physiologic position when the infant begins to stand and walk. Hospital stay has been diminished from several months or even years to a few days. Length of time that casts are used depends on the age of patient at the time of operation. If the child is operated upon at 3 months then the preoperative cast time is relative short and the postoperative cast period is about two months. Conventional shoes are satisfactory.

Although recurrence and resistance are not eliminated completely, the incidence of second and third operations has been diminished significantly. Initial deformities are recognized and improved at the time of the initial surgical procedure. A future for the infant born with clubfeet is much better in 1987 than it was in 1947.

Congenital Talipes Equinovalgus Rigid (Vertical Talus)

Treatment of vertical talus is parallel with the methods of management of idiopathic congenital clubfoot. Application of these concepts to the vertical talus was a natural extension of information from one area of pathology to another. The similarities and differences of the deformities became apparent as the investigation proceeded; and the importance of maintaining maximum motion at the ankle joint, stabilizing and realigning the subtalar joint, balancing muscle forces, and elongating contractures were all essential parts of the treatment.

The characteristics of the foot deformities suggest that a limbud deficiency occurred and that non-operative treatment for 3 months had failed in the effort to establish anatomical realignment.

Henken described the condition in 1914.37 Lamy and Weissman presented the first manuscript in English in 1939.38 There has been general disagreement about the terminology, but from an anatomical standpoint, congenital talipes equinoconvex valgus-rigid talus describes the various characteristics.

Hark, in 1950, described "rocker foot" and emphasized the displacement of the navicular dorsally and laterally on the head of the talus and lateral position of the calcaneus.39 Osmond-Clark, in 1953, used the term "congenital vertical talus," and as treatment, transferred the anterior tibial tendon to the neck of the talus in mild feet.40 This procedure however, is not successful unless the posterior capsule and the heelcord are lengthened, and the anterior tendons are lengthened to allow relocation of the forefoot.

The spectrum of deformity from mild to severe and management by one stage operative procedure for correction was presented by Goldner in 1964.41,42 The author noted the similarities between congenital pes valgus and congenital clubfoot and reemphasized the importance of performing a one stage operative procedure to correct moderate and severe feet. The mild feet are also managed in the same way, but the positional feet with minimal deformity, referred to as the oblique talus, is usually managed by external casts.

Grice attempted reduction in 1959 by tightening of the capsule and rerouting of the anterior tibial tendon under the neck of the talus.43 The subtalar arthrodesis was also performed. Goldner managed the patients under 2 years of age by a single stage medial, lateral, and posterior reconstruction. The anterior tibial tendon, the extensor digitorum communis and the peroneal tendons were all lengthened. The calcaneus was realigned under the talus and, if necessary, a subtalar arthrodesis was performed. This latter procedure was added to the single stage operation if the deformity was severe, if the sustentaculum tali was deficient, and if the deformity could not be maintained by soft tissue plication and fixation. The mild and moderate feet usually responded well to the soft tissue procedure only, whereas the
severe feet required soft tissue realignment and subtalar arthrodesis.\textsuperscript{41}

Coleman and Martin described a two stage procedure with reduction of the talonavicular, calcaneocuboid and calcaneus during the first stage, and posterior capsular release, heelcord lengthening and subtalar arthrodesis during the second stage.\textsuperscript{44} Coleman and Stelling depended on this procedure for their patients with this deformity reported in 1970.\textsuperscript{45} In 1976, Robbins described naviculectomy for this condition. The feet were severe and the navicular was difficult to realign with the head of the talus.\textsuperscript{46} Herndon and Heyman attempted open reduction and pin fixation across the talonavicular joint in 1959 and 1963,\textsuperscript{47} and Wainwright described his ideas about the recognition and treatment by open operation in 1966.\textsuperscript{40}

Currently, the most important aspects of managing the congenital rigid talipes convex equinovalgus are: 1) the early use of dynamic radiographs to determine the true position of the talus and to determine the movement of the forefoot during up and down motion; 2) early four quadrant approach to realign the talonavicular, calcaneocuboid, and talocalcaneal joints; 3) the anterior tibial, extensor digitorum communis, and peroneus longus and brevis tendons require lengthening; pin fixation will be necessary across the talocalcaneal and talonavicular joints in the severe feet. In feet with mild deformity, absorbable suture will maintain the correction once it has been obtained. Subtalar arthrodesis is considered at the primary operation, even in the infant. This procedure will not affect bone growth significantly.

The decision to perform a subtalar arthrodesis depends on the surgeon's ability to realign the joints at the time of the first operation. If the child is 3 months old, soft tissue incisions and realignment may be sufficient. Once the child is walking, approximately 18 months old, if the calcaneus does not remain in the corrected position, then a subtalar arthrodesis is performed at the second stage.

**Hallux Valgus**

Hallux valgus is arbitrarily divided into adolescent and adult deformities associated with metatarsus primus adductus. The adults also demonstrate stretching of the supporting connective tissues and degenerative arthritis.

The initial management of the deformity is described by the eponyms used in the early publications. The Silver procedure referred to tenotomy of the adductor tendon of the great toe, resection of the medial prominence of the first metatarsal head, and a medial capsulorrhaphy of the metatarsophalangeal joint. More recently, the capsulorrhaphy has been performed by maintaining the capsule intact proximally, incising the flaps over the phalanx after which the plication occurs distally.

The Heuter resection of the first metatarsal head was described in 1871. This procedure was modified by Mayo in 1908 and now is used primarily for rheumatoid arthritis rather than hallux valgus.\textsuperscript{48} The McBride operation, described in 1935 was similar to the Silver operation, but added a resection of the laterally displaced sesamoid and reattached the adductor hallucis tendon to the neck of the first metatarsal.\textsuperscript{49,50} Unless this tendon is actually passed through a drill hole in the bone, it will not perform its expected action in the new position. The Lapidus procedure, published in 1934, included the Silver operation, a first cuneiform metatarsal joint arthrodesis, and also the second metatarsal.\textsuperscript{51} The concept of proximal fusion or osteotomy has withstood the test of time. The modified McBride procedure described by Mann changed the unreliable McBride procedure to a more predictable operation by adding an osteotomy at the base of the first metatarsal.\textsuperscript{52}

The Keller procedure, described by Reidel in 1886 and Davies-Colley in 1887, was initially published by Keller in 1904.\textsuperscript{53} This became the most widely used operative procedure for hallux valgus with incongruity or arthritis, even though the original description made no attempt to reattach the short intrinsic muscles, all of which should insert on the proximal phalanx or to form collagen or bone after the resection of the proximal end of the proximal phalanx. Thus, the sesamoids migrated proximally and the remaining digit frequently became fixed in dorsiflexion.

Kelikian modified the Keller operation by suturing the adductor hallucis tendon distally to the remaining phalanx and suturing half of the tendon to the adductor and the short flexor of the great toe. The phalangeal attachment of the capsule and the sesamoids were sutured to the periosteal flaps of the phalanx to prevent proximal recession.\textsuperscript{54} Furthermore, if metatarsus primus adductus is severe, an osteotomy should be performed at the base of the metatarsal, a total joint replacement should be used rather than the Keller procedure, and osteotomy of the metatarsal performed.
The Lelièver modification of the Keller operation includes resection of the exostosis of the first metatarsal, resection of the proximal end of the proximal phalanx, relocation of the sesamoid pad medially, and resection of an elliptical segment of the medial capsule and the bursa, and closure of the capsular gap corrects the hallux valgus. This procedure may or may not require an osteotomy at the base of the metatarsal.\textsuperscript{55}

The Akin procedure included removal of the exostosis of the first metatarsal and a closed wedge osteotomy of the proximal phalanx, and removal of osteophytes from the proximal segment of the phalanx. This osteotomy will not compensate for metatarsus primus varus, but will diminish the hallux valgus. This procedure is a valuable adjunct to osteotomy at the base of the first metatarsal in severe metatarsus primus adductus-hallux valgus.\textsuperscript{56}

Goldner and Gaines described double osteotomy (the Akin procedure plus proximal metatarsal) of the first ray, soft tissue realignment, and resection of the exostosis of the head of the first metatarsal for both adult hallux valgus and adolescent deformities.\textsuperscript{57} This procedure: 1) insures congruity between the proximal phalanx and the first metatarsal, 2) avoids unnecessary or excessive displacement of the phalanx after the exostosis has been removed and 3) corrects the metatarsus adductus by osteotomy at the base of the metatarsal.\textsuperscript{58} Medial displacement of the shaft avoids the dangers of Mitchell osteotomy through the neck of the metatarsal, the Chevron osteotomy through the neck of the metatarsal, and the Reverdin osteotomy through the subchondral bone of the metatarsal head. The latter three osteotomies are currently used widely for mild deformities. Although the procedures are considered to be successful, many complications from each of these have been observed. An advance in foot surgery would be made if osteotomy at the base of the metatarsal was used more frequently and if neck osteotomy was used less frequently.

Arthrodesis of the first metatarsophalangeal joint, performed by Batchelor, was included in his management of severe hallux valgus and demonstrated several patients with painless functional feet without recurrence (personal communication, 1955). McKeever described the procedure. It is a useful, valuable operation that has not been used frequently enough for failed hallux valgus procedures associated with mini-incisions and torque drills.\textsuperscript{59} Also, joints that have had infection or extensive resection of the proximal phalanx or of the metatarsal head and shaft may be retrieved by the addition of iliac bone and smooth pin fixation. The sesamoids may require realignment or the insertion of fat between the rough sesamoid and the bone graft.

Hemi and Total Joint Arthroplasty with Prosthetic Replacements

The silicone hemioprosthesis as a substitute for the Keller procedure or for the treatment of hallux rigidus has been reasonably successful.\textsuperscript{60} However, the cartilage of the metatarsal head will eventually wear. The patient must be advised that total joint replacement may be necessary in the future; or an arthrodesis or removal of the hemiartroplasty if it fragments or becomes painful. A total joint replacement with heavy duty silicone or with silicon dacron is a useful procedure in managing patients who have total joint involvement and who are not candidates for an arthrodesis.\textsuperscript{61} The prosthesis has proven to be successful for several years and although the range of motion is limited, the length of the toe is maintained, the alignment is satisfactory, and the soft tissue procedures that are done in conjunction with the total joint insertion follow the same concepts as those for managing hallux valgus. Osteotomy at the base of the metatarsal is necessary if metatarsus primus varus is severe. Although the complications of breakage, fragmentation, and soft tissue reaction do occur occasionally, the risk benefit ratio is low.

The major advance in hallux valgus surgery is the emphasis on those concepts that attempt to retain as much of the metatarsophalangeal joint complex as possible, such as: avoid resecting the proximal end of the proximal phalanx, maintain a congruous metatarsal head, do not excise the sesamoids if they can be managed in any other way, and do not allow the sesamoids to recede proximally. Multiple osteotomies, soft tissue release, and modified arthroplasties in older patients, or prosthetic replacements, are reasonable options for the adult with severe hallux valgus.\textsuperscript{56} For the adolescent and the younger adult, multiple osteotomies and soft tissue balancing procedures are physiological.

Advances in Foot Management

Examination Methods

The terminology used to describe both normal and
abnormal positions and appearance of the foot have evolved from the current use of terms in standard textbooks and handbooks. Such books designate the position and motion of the foot and divides the foot into hindfoot, midfoot, and forefoot. Foot and motions are differentiated into those that occur at the ankle, subtalar, midtarsal, and tarsometatarsal joints. Coordination of these joints producing a summation of motion is implied.

Biomechanics of Gait

Elftman, who initiated gait studies in 1934, discusses the cinematic study of the distribution of pressure in the human foot. Inman developed a gait laboratory, and with his colleagues, was pioneered in defining and recording many aspects of human gait, foot, motion, and the action of muscles during walking and running.

Schwartz also provided fundamental information concerning quantitative analysis of recorded variables in walking patterns of normal adults. The information from these laboratories and these observations have been applied to shoe design, shoe insert instruction, and the planning of certain operative procedures.

Tarsal Coalition

Before 1900, there were descriptive terms concerning tarsal coalition. Badgley, in 1927, described a calcaneonavicular coalition. Subsequently, sporadic papers provided information about coalition and their anatomical descriptions. Harris and Beath, as a result of their examination of Canadian recruits from 1941 to 1943, reported results concerning the flatfoot with a contracted heelcord. In their descriptions were included the talocalcaneal medial coalition and emphasized the lack of mobility of the subtalar joint when a coalition existed. The Harris radiograph projections were popularized by their studies. Tomography of the foot provided more detailed information about partial or complete coalitions and their imaging technique has been complemented by the use of CT scan.

Several different coalitions of the foot have been described, some of which are symptomatic and others are asymptomatic. Cowell popularized excision of the calcaneonavicular bar and used a muscle flap to discourage reformation of the bony bridge. An alternative to muscle is gluteal or abdominal fat. Preoperative CT scanning will aid in the decision either to resect a talocalcaneal medial bar or to perform an arthrodesis of the tarsal bones. If 60% of the articular surface of the talocalcaneal joint of the middle facet is uninvolved, then resection followed by bone wax and muscle or fat interposition may be successful.

Paralytic Foot

Management of the paralytic foot varies according to etiology of the condition. Prior to the use of the Salk vaccine in 1956 and the Sabin oral vaccine a few years later, poliomyelitis was the major cause of foot deformity due to anterior horn cell damage. The usual pattern of management was the application of a brace until the child was 12 years old. After that, surgical treatment was used to eliminate the brace or realign the foot so that bracing was more satisfactory. The extent and kind of surgery used depended on the severity of the deformity, the contour of the foot, and the tightness of the original connective tissue prior to onset of the paralytic condition.

Tendon Transfers

Tendon transfers without joint arthrodesis in the child younger than 8 years of age have proven to be helpful in lessening severe calcaneus deformity and in improving the balance of a varus or valgus or equinus foot. Supplementary bracing was frequently necessary. The importance of Blixt's curve, as it relates to the tension of the transfer, has given improved results. Also, preoperative accuracy of muscle testing has been reemphasized so that muscles of good and normal strength were transferred rather than fair or poor muscles. Multiple transfers to perform a specific action, accurate placement of the transferred tendon, and placement of tendon into bone resulted in the most satisfactory function.

Triple Arthrodesis

The concept of triple arthrodesis described by Dunn in Britain and Hoke in the United States provided a method of performing joint arthrodesis that improved foot stability. Other surgeons such as Gallie described tendon transfers; Goldthwaite described ankle arthrodesis as a way of managing equinus deformity. Steindler, in 1923, recommended panastragaloid arthrodesis for the flail foot-ankle. Whitman, in 1901, used astragaloplasty for treatment of the severe paralytic calcaneus foot. Techniques for performing triple arthrodesis vary.
Ryerson concentrated on geometric cuts and segmental resections while Hoke removed the head of the talus and the adjacent joints and then replaced the head between the talus and the navicular. Goldner developed a technique for triple arthrodesis that saved bone and adjusted the calcaneus, the cuboid, and the navicular to establish a longitudinal arch, realign the foot with the ankle; he also replaced the head of the talus and bone chips in the sinus tarsi to hasten union. This procedure was modified by Goldner with homologous or autogenous bone added to the sinus tarsi to assure rapid union and stability without the necessity of using staples, pins, or internal fixation.

Extra-articular Subtalar Arthrodesis

This procedure was described by Grice and provided a bridge between the 4-year-old and the 10-year-old with paralytic foot deformity. The extra-articular fusion immobilized the subtalar joint, diminished progressive deformity, and made a brace easier to apply (or it was eliminated). This concept of subtalar arthrodesis has been used to treat other conditions in the small child with foot deformity such as cerebral palsy, myelodysplasia, congenital talus, even congenital vertical talus, and even congenital clubfoot.

Tendon Transfers for Paralytic Foot Deformities

The concept of tendon transfers was firmly established by the success of transferring plantar flexors as dorsiflexors and the use of the muscle evertors as either plantar flexors, invertors, or dorsiflexors. It was observed that phased tendon transfers functioned best, but phase conversion did occur. For example, a posterior tibial tendon transferred to the dorsum of the foot functioned voluntarily and did allow the patient to dorsiflex the foot. An electromyogram indicated that the phase was neutral or not strongly converted. From a practical standpoint, the transfer diminished equinus, was strong and active for a few hours a day, but fatigued toward the end of the day.

The peroneus longus was transferred successfully to the dorsum of the foot or to the calcaneus to reinforce plantar flexion. However, if the peroneus longus is used as a dorsiflexor, the calf muscles should be normal, or if the peroneus longus is eliminated as a evertor plantar flexor, the push off may be weakened. When the anterior tibial tendon is transferred from the first metatarsal to the third metatarsal, there is little or no loss of strength. The concept that a tendon muscle unit always loses one grade of strength after transfer has not been documented if phased muscles are transferred to perform the same phase activity.

Also, the flexor hallucis longus will function as an evertor muscle of the foot and reinforce a weak peroneus brevis, reinforce a weak anterior tibial muscle, or add strength to a weak calf muscle. Use of this muscle for tendon transfer is now done more frequently than previously.

A combination of established concepts concerning early tendon transfers of strong muscle-tendon units, the use of extra-articular combined intra-articular arthrodesis at the age of 3 or 4, segmental osteotomies of the cuboid bone or of the calcaneus, and localized osteotomies of the first metatarsal or arthrodesis of the first cuneiform metatarsal have added additional methods of management and greater flexibility to the surgical treatment of a child’s foot deformity than existed previously. The child’s foot can be balanced and stabilized early, and the adult foot can usually be made brace free and strength and stability distributed in a helpful way.

The use of triple arthrodesis, pantalar arthrodesis, and the benefits of low tibial fibular or high tibial fibular osteotomy provide methods of realigning the foot with the ankle and the knee joint. These methods maintain appropriate weight bearing forces after a paralytic condition has resulted in weakness of this extremity or after trauma has resulted in traumatic arthrosis or malalignment.

Other Paralytic Conditions Improved by Surgical Treatment

Foot deformities in myelodysplasia will be diminished if the same concepts and techniques used in poliomyelitis are applied to the foot affected by myelodysplasia. However, the limited or diminished sensibility of the affected foot may influence the end result in an adverse way. Bone healing requires a longer period of immobilization and diminished skin sensation may result in pressure or trophic ulceration.

Other paralytic conditions with sensory deficiency are Hansen’s disease and Charcot-Marie-Tooth. Brand has developed a program of management of the insensitive foot for patients with leprosy (personal communication, 1978). The program has included medications, neurolysis, and custom made
shoes with special inserts for shifting and protecting weight bearing points.81

The sensory alteration in Charcot-Marie-Tooth is not extensive. These feet are stabilized by either osteotomies and tendon transfers or by triple arthrodesis. These stabilizing procedures will diminish progressive cavus and varus formations. Surgical treatment may be initiated in the young child by a tendon transfer and osteotomy or even by extra- and intra-articular subtalar arthrodesis. There is no reason to delay treatment until the child reaches adolescence or adulthood.

Management of the Insensitive Foot

Special foot clinics for patients with diabetes, peripheral vascular disease, renal disease, and neurotrophic lesions resulting from peripheral nerve trauma or myelodysplasia have been beneficial in diminishing the frequency and severity of large unhealed trophic ulcers and eventual amputation.82

Jacobs, Brand, and Wagner have been leaders in establishing clinics in their communities and throughout the country to apply the concepts of elevation, meticulous wound excision, revascularization if possible, antibiotics, total contact casts, and protective shoes that unload abnormal pressure points for the patients who either have, or might develop, trophic lesions.83 Furthermore, progress has been made in performing elective surgery even in the presence of open lesions to eliminate rigid pressure points, to realign severe claw toes, and to elevate or eliminate prominent metatarsal heads. By these techniques, long periods of chronic ulceration have been shortened, and digits and feet have been saved from amputation.

Conversely, accurate advice has been given to patients who will benefit best by amputation. Not only the patient, but also the health care personnel are saved hundreds of hours of treatment that, in spite of this, ultimately result in failure to save the foot. Carefully prepared advice of an expert in the field who has had wide experience in management of trophic lesions is beneficial to the patient so that expense, time, and emotional stress are conserved.

Flexible Flat Feet

In 1952, Crego and Ford described 53 children with flat feet that had been treated surgically.84 The cases were divided into two groups: flat feet due to tarsal coalition (17) and relaxed pronated feet (83). This information clearly differentiated the rigid and the flexible flat foot and emphasized the importance of preoperative classification of the pathological lesion. They concluded that triple arthrodesis was the best form of management for the tarsal coalition. Subsequently, however, Cowell popularized resection of the calcaneonaviccular coalition.70

Crego and Ford also concluded that subtalar arthrodesis and talonavicular fusion was the most satisfactory procedure for relaxed pronated feet. However, other investigators have been successful in correcting flat feet by tarsal arthrodesis or osteotomy and advancement of medial ligaments and the posterior tibial tendon and heel cord lengthening.85 Giannestras used a combination of the most desirable features of several operations.86 His operation combined certain aspects of procedures described by Lowman,87 Hoke,75 Miller,88 and Caldwell89 who reported on the Durham procedure.

The critical steps of any procedure to correct severe flexible flat feet and avoid subtalar or triple arthrodesis is to lengthen the heel cord and to plicate medial soft tissues including the deltoid ligament, plantar calcaneonaviccular ligament, and to diminish the plantar concavity of the navicular cuneiform joint. A strong short windlass is formed on the medial plantar surface of the foot. The action of the posterior tibial tendon must be maximal across the talonavicular and mid tarsal joints.

During the past 20 years, the author has used the concept of dorsal opening wedge osteotomy of the first cuneiform, and a lateral opening wedge—the cuboid. Autologous or homologous bone is used to maintain the new contour of the foot. These osteotomies will assist in forming an elevated longitudinal arch, and improve the weight bearing force on all of the metatarsals. Occasionally, a lateral opening wedge osteotomy of the calcaneus will diminish eversion of the hindfoot. More recently, medial displacement osteotomy of the calcaneus and the Achilles tendon has been proposed as primary treatment of the relaxed flat foot.

Goldner and associates reviewed 60 patients with relaxed flat feet and contracted heel cords treated surgically during a 30-year period. The results were satisfactory, with definite improvement in each instance. Of all the flat feet seen during that same period however, only 1% to 2% were actually considered to require surgical correction.85 Caution must be taken in treating flat feet by
surgical methods. The differential diagnosis between a tarsal coalition and a relaxed flat foot may be difficult in an adolescent. Also, the accessory navicular may be managed by the Kidner procedure, but that advancement of the posterior tibial tendon alone will not correct a severe flexible flat foot.90

Prostheses have been inserted to correct or improve flexible flat feet. The results are not predictable. Silicone will wear and the Sta-peg, made of metal and high density polyethylene, is not biological and is still experimental. Preoperative dynamic radiographs, a clinical foot mobility test, and a determination of collagen elasticity and determination of heel cord contracture are the essential items in the analysis of a flat foot. Certain individuals with relaxed flat feet will complain bitterly whereas others may be completely painless. Treatment should be planned to relieve pain and not to arbitrarily construct an elevated longitudinal arch.

Other Procedures for Treatment of Flat Foot

Other variations of surgical treatment that have been popular during the past 50 years are the Chambers procedure, which is based on the concept of adding bone graft to the sinus tarsi and building a bone block which prevented the calcaneus from everting and externally rotating.91 A bone graft prevented the navicular from displacing laterally and held the talus in a more neutral position. Traumatic arthrosis developed and success of the procedure was not generally predictable.

The Kidner procedure is useful in managing the accessory scaphoid usually without a contracted heelcord and usually without a severe flatfoot. The concept is to remove the accessory bone, which is usually irritated by the edge of the shoe or by one foot hitting against the other, and reattach the posterior tibial tendon to the medial and undersurface of the navicular. This procedure has occasionally been used to manage severe relaxed flat feet, however, it will not be successful because only the posterior tibial tendon is involved, and not the capsule nor realignment of the foot as used with osteotomies or localized arthrodesis.92

The Sta-peg has been described as a subtalar insert that is placed in the space between the posterior and the middle facet of the calcaneus. This is anterior to the posterior articular surface of the talus and diminishes the forward sliding affect of the talus and diminishes eversion of the calcaneus. However, the metallic component, methacrylate, and high density polyethylene used to treat growing children and young adults is open to question when soft tissue procedures and bone grafts will provide a more biological solution to the problem.

Consensus Concerning the Surgical Treatment of Flat Feet

Radiographs are important in assessing the deformity and in planning the treatment. The lateral weight bearing talocalcaneal angle is a guideline but must be interpreted in conjunction with the standing anterior posterior talonavicular metatarsal-angle. Also, the standing anterior posterior projection of the ankle joint is necessary to determine relationship of the talus in the ankle mortise.

In children, dynamic lateral x-rays are important to determine the position of the talus and whether or not it is mobile. The term "oblique talus" has been introduced to imply a partially mobile talus that is not a true congenital rigid vertical talus. Triple arthrodesis or subtalar arthrodesis should be avoided in the management of severe relaxed flat feet. There is evidence that the combination of procedures including heel cord lengthening, medial tendon and ligament plication, and appropriate tarsal osteotomies will provide a serviceable painless foot without subtalar arthrodesis or triple arthrodesis. However, posterior tibial tendon shortening alone or even capsular plication and navicular cuneiform arthrodesis are not sufficient to manage the severe flat foot.

Flat Foot Treatment in Poliomyelitis

In 1952, Grice described an extra-articular arthrodesis of the subtalar joint for the correction of paralytic flat foot in children. This procedure has stood the test of time and will be successful if the proper indications are used and the exact technique is followed. Grice used autogenous tibial bone. Current studies have shown that midshaft fibular bone is also successful and avoids the occasional complication of tibial epiphyseal deformity or deformity of the tibial tubercle.43 Homologous bone, although radiographically amalgamating in about 50% of the patients, has resulted in stable feet and is clinically successful in poliomyelitis.

The Grice procedure has also been used in managing the foot in myelodysplasia. It is less successful in this condition and does require a longer period of immobilization and more bone must be added to the
subtalar joint. If the subtalar joint is packed with bone chips in addition to the vertical graft and if the articular surfaces of the talus and calcaneus are removed by sharp dissection, a successful fusion is more likely in conditions other than and including poliomyelitis than if the extra-articular bone graft alone is used.

During the past 35 years, the author has been involved in a prospective study related to analyzing children with various degrees of flat feet. The experience has revealed that arch supports, special shoes, exercises, and external supports will not tighten loose collagen and will not change relaxed flat feet to feet with a supportive longitudinal arch.92

Physiologic Variations

Although many prominent surgeons have been adamant in their recommendations that childhood sleeping patterns should be changed in order to control femoral, tibial, and foot rotational positions, the current evidence presented by Stahleit and Goldner, and previously by Sherman and others documents that there is spontaneous improvement in these characteristics. Correction to an average position may not occur in each person but function is satisfactory.

If asymmetrical positions exist initially, surgical correction may be necessary to provide symmetrical feet or extremities. These physiologic variations usually do not require surgical treatment. Furthermore, they do not respond to shoe corrections or external supports. The ultimate benefit of interosseous external support has not proven to be successful in altering physiological variations.92

Metatarsus Adductus

Positional metatarsus adductus is very common. Cowell and his associates, (personal communication, 1985) Goldner et al.,93 and Bleck94 have recognized minimal, mild, moderate, and severe degrees. The great toe and the adducted phalanges may be the major deformity in certain feet, others have deviated metatarsals that correct passively. Cast treatment may result in spurious correction at the talonavicular or calcaneocuboid joints. Casts, however, will not alter the abducted great toe.

The patient with mild metatarsus adductus does not require treatment. The moderate feet that are not passively correctable may improve with cast treatment but spurious correction may result. The severe deformities will require surgical treatment such as lateral wedge removed from the cuboid, and "open" first cuneiform wedge with bone graft and possibly metatarsal osteotomies. In the moderate and severe feet, early plaster correction is attempted, but if not successful within 3 or 4 months, surgical treatment may be indicated.

The suggested management for metatarsus adductus is: 1) observation of mild and moderate feet; 2) plaster cast to stretch the skin and ligaments of moderate and severe feet, and 3) surgical correction of severe feet. Examination of adult feet indicates that metatarsus primus adductus is a common finding, and most adults with hallux valgus demonstrate metatarsus primus adductus that would not have responded to plaster treatment initiated even in infancy.

Curly Toes

Price and Morley reviewed material on flexed toes in infants and children (personal communication, 1970). They managed flexion deformities of the digits that were symptomatic by performing tenotomies of the flexor tendons though a medial midlateral digit incision. Continued movement of the digits is possible with the intrinsic muscles and the remaining flexor and extensor tendons.

At the present time, the curling digits are corrected by lengthening of the flexor digitorum longus at the level of the medial malleolus. Tenotomies of individual digits are performed in the older patient if the flexible toe deformity persists.

Serpentine Feet

This rare form of triple deformity shows the calcaneus to be everted, the talonavicular joint is opened medially, the cuboid is displaced proximally, and the metatarsals are adducted medially.95 Special shoes and wedges will not correct this deformity. Surgical correction is desirable to realign the calcaneus, and to reposition the talonavicular and calcaneocuboid joints, and to align the metatarsals with the remainder of the foot. A subtalar arthrodesis is usually necessary in the child as the deficient sustentaculum tali will not provide adequate support even with soft tissue shortening and heel cord lengthening. A combined flat foot procedure, a subtalar arthrodesis, will realign the hindfoot and the midfoot, and metatarsal osteotomies will improve the forefoot. The Heyman-Herndon tarsometatarsal arthroplasty operation is helpful in infants up to one year of age.
but after that age, the changes in the joints may result in traumatic arthrosis as the child becomes older.96

**Idiopathic Pes Cavus**

Severe cavus without muscle imbalance has been managed by triple arthrodesis and plantar soft tissue incisions. Steinbicker’s os calcis stripping served as a prototype for releasing the plantar fascia and the short flexors. This has been modified to avoid incision on the medial aspect of the heel and thereby to avoid damage to the medial plantar branch of the posterior tibial nerve which supplies the calcaneus. A plantar incision in the non-weight-bearing area is convenient and physiologic for removal of plantar fascia, release of the short flexors, and if necessary, tarsometatarsal arthroteny.

Other aspects of the cavus foot are managed either by osteotomy at the base of the metatarsals for moderate deformity or dorsal wedge resection of the cuneiform bones.97 A lateral wedge from the cuboid may be helpful if the forefoot is adducted and if supination is present.

Lateral calcaneal osteotomy, described by Dwyer will evert the heel and realign the hindfoot. Cavus will improve only if the foot is flexible. If the forefoot and midfoot deformities are rigid, additional surgical treatment is necessary to correct malposition of the forefoot.98

Fowler described an opening wedge of the first cuneiform supplemented by a plantar bone graft and soft tissue elongation. This operation has merit in certain feet but will not improve the calcaneus. The open wedge may cause excessive cartilage compression of the adjacent joints.99

Stryker believes that the posterior tibial tendon is the major cause of cavus foot. If attachments and the shortening of the posterior tibial tendon are released and if the tendon is elongated then correction can be obtained. This is not universally accepted even by those who attempt to correct that aspect of the deformity caused by the posterior tibial tendon (Stryker W, personal communication, 1985).

At the present time, a logical method of managing idiopathic cavus feet is a combination of procedures that include an osteotomy of the calcaneus, plantar elongation of soft tissues including the posterior tibial attachment, lengthening of the posterior tibial and the toe flexors if necessary. An osteotomy at the base of the metatarsals and/or through the cuneiform bones will diminish the cavus. Triple arthrodesis is not indicated unless severe traumatic arthrosis exists or unless muscle imbalance is progressive. The latter does occur in patients with Charcot-Marie-Tooth.

**Arthroplasty of the Foot**

Excisional arthroplasty of different segments of the foot has been performed for many years. In the patient with rheumatoid arthritis, the metatarsal heads are excised and the bony prominences of the metatarsal shafts are trimmed so that the patient bears weight on the forefoot and the remaining metatarsal and tarsal bones. Hoffman described the plantar incision which continues to be popular.100 Other investigators have noted that two vertical incisions will allow removal of the metatarsal heads and the metatarsal shafts, elongation of extensor tendons and realignment of the toes without encountering the plantar digital nerves and without the risk of delayed healing of the plantar incision.101

Arthroplasty of the great toe, resection of the metatarsal head and insertion of capsular flap; or by removal of the proximal end of the proximal phalanx are helpful if the soft tissues are realigned. These procedures are effective in rheumatoid disease.

Resection of the distal end of the proximal phalanx of the digits may result in deviation of the distal segment of the toe or in a painful pseudoarthrosis. Although the procedure is helpful at times, it is not consistently reliable. Removal of small exostosis however will decrease recurrence of cavus formation. If the joint can be saved and the cartilage damaged, then removal of exostosis and syndactylyism may eliminate the cavus. Those joints that are irreparable can be managed by the silicone prosthesis introduced by Swanson or the silicone-dacron prosthesis designed by Neibauer.

Total joint replacement of the great toe may be helpful in certain patients who require a substitute for the entire joint. An alternate of hemi-resection or arthrodesis may not be acceptable.

Complications do occur with silicone and silicone-dacron prostheses. The patient may be limited, or breakage of the prosthesis may occur and fragmentation may result in a local tissue reaction. The treatment for the failed prosthesis is either replacement by another prosthesis, realignment of the digit by osteotomy at the base if the stress points are excessive, inlay bone graft for arthrodesis of the metatarsophalangeal joint, or resection arthroplasty.
without replacement. Silicone prosthesis for the metatarsophalangeal joints of the second through fifth digits has been recommended but a consensus has not been reached about the value of silicone as compared to metatarsal head resection in the patient with rheumatoid disease. The attempts to use silicone joints in the lesser toes has usually resulted in failure.

Thin sheets of silicone may be used to buffer the worn sesamoids or to protect peripheral nerves that have been deeply embedded in fibrous tissue. Silicone has proven to be a valuable adjunct in managing certain pathological conditions.

**Static Encephalopathy**

Foot deformities occur frequently in the child with cerebral palsy. Bracing, stretching, active exercise and other forms of nonoperative treatment are successful only in mild positional deformities. A contracture of the Achilles tendon or an imbalanced foot because of overpull of the anterior and posterior tibial spastic muscles usually require tendon elongation and/ or transfer with or without joint stabilization or osteotomy in order to place the foot in a weight bearing position. Detailed analysis of muscle strength, assessment of the degree of spasticity, and gait analysis with or without electromyography will provide sufficient data for planned treatment is predictable and successful.

Heelcord lengthening, lengthening of the posterior tibial tendon, transfer of the anterior tibial tendon to the second or third metatarsal, and reinforcement of weak peroneus brevis and longus with the flexor hallucis longus will maintain foot balance and avoid triple arthrodesis for many years. **102**

Osteotomy of the calcaneus with autogenous or homologous bone graft or subtalar arthrodesis with bone graft will provide increased stability and realign axial loading in order to diminish external bracing and prevent progressive soft tissue stretching as the child grows. Stöffel, in 1913, emphasized nerve crush and neurectomy. Vulpian described musculotendinous junction lengthening of the gastrocnemius soleus, and Strayer reported on recession of the gastrocnemius to relieve spastic contracture. Siverskiold, in 1924, emphasized the two joint muscles of the leg and an operation to change the position of the foot by considering the effect of the knee joint on the gastrocnemius soleus.

Baker and his associates, in 1952, were successful in eliminating bracing early and in diminishing equinus and valgus by aggressive use of calcaneal osteotomy and tendon lengthening and rerouting. **103**

Modifications of the action of the posterior tibial were described by Green and Griffin, **104** and the phase activity and accuracy of muscle action during gait were re- emphasized by Perry. **105**

Bleck gathered all of this information in his monograph on surgical procedures for cerebral palsy and the recent edition has emphasized the use of many of these procedures in the patient with static encephalopathy. **106**

**The Adult With Static Encephalopathy**

If the child has not had surgical treatment to diminish the foot deformity, the same concepts still apply in adulthood. The decision to select tendon lengthenings, tendon transfers, or combinations of lengthenings and transfers and joint arthrodesis depends on the inherent nature of the foot and the existing deformity. Determination of muscle strength, assessment of gait patterns, and decisions to perform specific operative procedures are better known and understood by larger numbers of orthopedists than was the case 25 years ago. The careful analysis and the decision making is the major part of the current advance in management of spastic feet. The technical details and the methods of management are somewhat improved because of safe tourniquets, appropriate instruments, and careful handling of the soft tissues and avoidance of damage to cutaneous and deep nerves and vessels. **107**

**Spasticity and Weakness**

**Associated With Cerebral Vascular Injuries**

Abnormal gait of the patient who has had a stroke is not always due to foot problems alone. However, a contracture of the calf muscle, overactivity of the anterior tibial, or posterior tibial muscle and weakness of the peroneals will cause an equinovarus foot. After a reasonable period of recovery time, the condition becomes static so long as the major disease component is under control. External bracing, external exercise programs, electrical stimulation all have a place in managing the unbalanced foot. However, heelcord lengthening, transfer of the anterior tibial tendon and lengthening of the posterior tibial tendon are justifiable operative procedures to diminish the external bracing entirely or to lessen the size and weight of the brace. By one or two years after the initial incident, the degree of recovery is usually
evident. Specific surgical procedures can then be planned and their success is predictable if the condition is not progressive.

The Surgical Rehabilitation Service at Downey, California has been involved in using internal and external nerve stimulators for several years. In certain individuals the electrical stimulator will activate the peroneal muscles by stimulating the peroneal nerve which has an intact reflex through the spinal cord and a spastic component because of the cortical injury. The driving affect of the stimulator substitutes for weak impulses. A dampening effect of the overactive muscles has not yet been developed but presumably excessive nerve stimuli through the spastic muscles might someday be controlled by appropriate neutralizing current medications or local injections.

At the present time, the comparative value of surgical lengthening of muscle or phenol nerve injection are open to debate. The present evidence suggests that the surgical treatment is probably safer and more reliable when mixed nerves are involved although phenol may be beneficial when applied only to a motor nerve. The problem that arises in deciding to use phenol injection is which nerves, how many nerves, and how reliable is the procedure?

**Perineural Fibrosis of the Plantar Digital Nerves**

This condition was recorded in England in 1845 by Durlacher who described it as an abnormality of the plantar nerves. In 1876, T.G. Morton suggested that digital nerve irritation occurred from compression by abnormal movement of the metatarsal joint. He advised excision of the joint together with the surrounding soft parts. In 1893, T.S.K. Morton also advised resection of the metatarsal joint, and Jones, in 1929, reported relief of pain by excision of the metatarsal head or the joint. Other ways of improving the problem were amputation of the toe, insertion of a heated needle into the nerve, injection of carbolic acid, and excision of the digital plantar nerve. The continued use of the term Morton's neuroma is not accurate and the anatomic description of perineural fibrosis of the plantar digital nerve is suggested.

In 1940, Betts described a dorsal surgical approach for removing the lesion. Operative treatment has been the popular method of management for about 35 years. However, several clinicians have noted that nonoperative management by unloading the fore part of the foot with appropriate foot pads and metatarsal bars, and by injection of corticosteroid directly into the nerve may defer or eliminate the necessity of surgical treatment for many years or even permanently. However, surgical treatment is occasionally necessary and revives the question of location of the incision. The dorsal incision requires cutting of the transverse metatarsal ligament and spreading of the metatarsals during the procedure. The plantar incision makes an unnecessary incision on the weight bearing surface and requires longer protection for healing. An incision in the web allows the digital nerve and artery to be separated and with loupé magnification, the involved nerve is observed back to the junction of the plantar nerves, proximal to the lesion. Bipolar cauterization of the proximal nerve and removal of the lesion is relatively non-traumatic, avoids cutting the transverse metatarsal ligament, and avoids a plantar incision.

Occasionally, after the primary operation, the proximal nerve becomes adherent to the metatarsal head, to the flexor tendons, or to the transverse metatarsal ligament. Recurrent lesions should be operated on through a plantar incision.

**Neurologic Syndromes Affecting the Foot**

Perineurofibrosis of the plantar digital nerves between the third and fourth digits is the most common nerve involvement of the foot. The recognition of this condition and the management has already been mentioned.

Posterior tibial nerve compression secondary to fractures of the calcaneus was documented in 1953. Keck, in 1962, reconfirmed the observation of posterior tibial nerve compression in army recruits with tarsal tunnel syndrome.

The anterior tarsal syndrome relates to compression of the superficial peroneal nerve on the dorsum of the foot and this cutaneous neuralgia either postoperatively or after unrecognized repetitive trauma is better known now than it has been previously.

Iatrogenic cutaneous nerve injuries are relatively common associated with surgical treatment of hallux valgus, triple arthrodesis, ankle fractures, and other operative procedures about the foot. Information about the cutaneous anatomy has been made available to those doing foot surgery and with emphasis on the anatomic location of the cutaneous nerves and avoidance of stretch and contusion and laceration.
the development of postoperative pain syndromes should lessen.

Burning feet are the complaint and the exact diagnosis of cause of the paresthesias is better determined now by sensory, nerve conduction studies, motor nerve conduction readings, and better recognition of peripheral neuropathy associated with systemic disease such as diabetes, pernicious anemia, renal disease, and alcoholic neuropathy. Nutritional neuropathies, dietary sensitivities, and Hansen's disease are other causes for foot pain and burning.

Causalgia continues to involve the foot after trauma to the sciatic nerve, to the SI-S2 nerve roots, or to deep peroneal nerve or other cutaneous nerves of the foot. The syndrome is usually associated with overactivity of the autonomic nervous system and may involve either the sympathetic or the parasympathetic fibers. Excessive action of norepinephrine, serotonin, free oxygen radicals, or other humoral substances acting on nerve receptors results in severe burning, excessive sweating or excessive dryness, vasospasm, hyperpathia, edema, and subsequent fibrosis.

The various conditions that are referred to as reflex sympathetic dystrophy may be separated by controlled cold studies, thermography as an indicator of vasodilatation or vasoconstriction, and post-thermography cold stress tests.

Technetium 99 bone scan will show diffuse uptake around the ankle joint, foot joints, and throughout the entire foot in the three phase test. This suggests the presence of vascular shunts, vasoconstriction or vasodilatation of small vessels, interference with oxygenation, run off of CO2 and waste products.

Once the diagnosis is suspected and documented by cold studies and diagnostic nerve blocks, then autonomic nerve blocks are performed, and beta-adrenergic receptor-blocking agents such as Inderal (Propranolol Hydrochloride) are used. Other pharmacologic agents such as Guanethidine, alpha adrenergic receptor-blocking agents such as Dibenzylane, and calcium channel blockers such as Nifedipine (Procardia) are helpful, as are parasympathetic blocking agents such as Pro-Banthine. Corticosteroids are used to affect the cell membrane and a transcutaneous stimulator is used to decrease sensory input and to increase blood flow. Peripheral nerve blocks are beneficial in decreasing the intensity of pain and in reversing the pain pattern. Other physical therapy activities such as assistive exercise, walking casts, and protective shoes with rocker bottoms are valuable in decreasing the pain and improving motion.

**Nerve Trauma**

If a particular nerve has been lacerated, entrapped, compressed, or traumatized, surgical management, neurolysis, and fat grafts—or restoration of blood flow by vein grafts—may decrease the abnormal sensory input, diminish the vasospasm, and improve function of the foot. Terminology should be as exact as possible. Causalgia refers primarily to a specific nerve injury with or without accompanying vascular injury. The term reflex sympathetic dystrophy includes all of the syndromes that might occur from trauma or other systemic conditions with direct or indirect damage to the autonomic nervous system.

**Skin and Nail Pathology**

Dermatologists have added diagnostic techniques and definitions of syndromes which are applicable to patients with foot problems. Therapeutic agents for herpes simplex, for viral lesions, and management of these lesions depends on pharmacologic agents, immunologic concepts, and similar information that is now being directed toward treatment of viral lesions to prevent not only autogenous inoculation but was also spread to other individuals.

**New Imaging: Diagnosis and Treatment of Foot Pathology**

The xeroradiogram is helpful in detecting foreign bodies, alterations of the subdermal tissue, and lesions that develop in the fat compartments of the heel. Nonopaque foreign bodies may be detected with the the xeroradiogram but not seen on the routine radiographs.

Tomography continues to be useful in diagnosing occult fractures about the foot or in reconstructing information about osteochondral injuries. Destuctive lesions of a single bone or joint lesion may be detected by tomography but not seen on routine x-rays.

Computerized tomography is beneficial in detecting tarsal coalition, in providing two dimensional information about fractures of the calcaneus and the tarsal bones, and in defining soft tissue lesions such as a hemangioma or lymphangioma.

Magnetic resonance imaging may assist in detecting avascular necrosis of the talus, irregularities of
the cartilaginous surfaces of the tarsal bones, or soft tissue masses in the muscles of the deep layers of the foot.

Venography and arteriography are helpful in determining quality and quantity of arterial flow to a particular digit or to the foot; the procedure is essential prior to transferring a toe digit to the hand, and the procedure is helpful for preoperative assessment of progressive vascular lesions that require excision.

Three phase Technetium-99 scanning provides information about blood flow, about soft tissue uptake of the Technetium, and about bone uptake. This is valuable in analyzing lesions that require excision such as neoplasms.

Arthroscopy

Arthroscopy of the ankle joint has been helpful in detecting cartilage lesions, loose bodies, and in recognizing osteochondral fractures. Synovial biopsy, hemorrhagic lesions, and combined synovial and cartilaginous pathology may be recognized with the arthroscope. Arthroscopic surgery may not only provide adequate material for biopsy, but may also eliminate the lesion thereby avoiding open surgical treatment.

Force Plate Gait Studies

Force plate readings will provide information about pressure points of the forefoot and will localize unusual pressure areas that cause the patient to unload the painful foot by inversion or eversion. Gait studies provide information about the distribution of forces after foot trauma, after elective operative procedures when pain persists, and prior to final planning for reconstructive foot procedures.

References

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