plantar-flexed. The soft tissues under the head of the talus are subjected to excessive direct axial loading and shear stress. Firm or hard arch supports exaggerate these pressures. An aggressive stretching program for the Achilles tendon, performed with the subtalar joint inverted, may relieve the symptoms in this clinical situation. Failure to relieve this localized pain with prolonged attempts at conservative management is an indication for operative reconstruction of the foot (237).

An operation is rarely, if ever, indicated for flexible flatfoot. Nevertheless, an extensive list of surgical procedures to correct flatfoot has been proposed during the last century. The indications for these procedures, whether for correction of deformity, relief of symptoms, or prophylaxis, are difficult to ascertain from review of the articles. The procedures can be categorized as soft-tissue plications, tendon lengthenings and transfers, osseous excisions, osteotomies, arthrodesis of one or more joints, and interposition of bone or man-made materials into the sinus tarsi. Any procedure should be judged by its ability to achieve and maintain correction of even severe deformity while maintaining mobility of the subtalar joint, and by its ability to achieve and maintain relief of pain. There have been very few long-term outcome studies on any of these procedures. Nevertheless, those that have been reported have helped to narrow the surgical choices. Mosca (327) recently reviewed the literature and can be referenced for more detail on these procedures.

Procedures that rely entirely on soft-tissue plications and tendon transfers fail in the short term. Osseous excisions were abandoned years ago because of their obvious destructive nature. Arthrodesis of one or more of the joints in the subtalar complex has been abandoned because of the detrimental effect of eliminating the shock-absorbing function of that important joint complex. Subtalar and triple arthrodesis shift stress to the ankle and midtarsal joints leading to premature degenerative arthrosis at those sites (19–27).

The most popular procedures used during the last 60 to 70 years are the many modifications of Hoke's limited midtarsal arthrodesis (16–18, 307, 328–330). These procedures combine arthrodesis of one or more midtarsal joints with soft-tissue plication across the talonavicular joint. Favorable short-term results have been consistently reported, but unsatisfactory long-term results were reported in 49% to 70% of cases (16–18). The unsatisfactory feet in these series frequently showed degenerative changes at the talonavicular joints in addition to persistence or recurrence of pain and deformity. Furthermore, the originators of these procedures acknowledged that these procedures were not capable of correcting severe valgus deformities. They recommended triple arthrodesis for those feet. Though not known at the time of those recommendations, we now know the long-term results of triple arthrodesis to be the significant risk of developing degenerative arthritis and pain at adjacent joints (19–27). Therefore, present surgical recommendations focus on preservation of subtalar motion. Pseudoarthrodesis, or so-called arthroereisis, procedures were introduced between 1946 and 1977 as variations on a method to restrict excessive subtalar joint eversion by placing a bone block in the sinus tarsi (331–334). The bone grafts occasionally underwent resorption with recurrence of the deformity or remained and resulted in restriction of subtalar motion (essentially a pseudoarthrodesis) with its associated problems. Arthroereisis by means of synthetic implants was started in the late 1970s because of the reported problems and complications associated with the bony arthroereisis procedures. No less than 10 types of synthetic implants and methods for insertion have been reported, most with follow-up of <2 years (335–349). Reported problems and complications have led to an ongoing search for a better implant and a better method for implanting it. The variety and succession of past implant materials and designs have prevented a validation study from being performed to determine the overall effectiveness of the procedure or even to validate the concept of the procedure (346).

There is no clear consensus among proponents on the indications for arthroereisis. Nevertheless, many are performed, and the reported complication rate with the use of synthetic implants is 3.5% to 30%, with the most recent studies reporting rates of 3.5% to 11% (337–341, 343–349). The complications include those associated with inappropriate implantation (obviously not counted, but certainly a major issue, especially if one considers the often-reported indication of performing the operation in an asymptomatic physiologic FFF in a young child), surgeon error (malpositioning, overcorrection, undercorrection, extrusion of implant, wrong size of implant), biomaterials problems (breakage, degradation), and biologic problems (foreign body reaction, synovitis, infection, persistent and recurrent pain, implant-induced sinus tarsi impingement pain, intraosseous ganglion cyst within the talus, osteonecrosis of the talus, peroneal spasm, calcaneus fracture) (337–341, 343–349). Black et al. (337) and Verheyden et al. (338) both recommended abandonment of this procedure because of the high rate of negative outcomes.

The Maxwell Brancheau arthroereisis (MBA) implant, a large cylinder-shaped titanium screw (343, 344), and the Giannini Flatfoot Expanding Implant, a Teflon/stainless steel expansion drywall anchor design (339, 340), are perhaps the most commonly used implants at the present time, based on the number of articles in the literature. According to published descriptions, both are inserted into the sinus tarsi anterior to the posterior facet along the trajectory of the tarsal canal between the posterior and middle facets. The originators of these implants (339, 340, 343, 344), as well as other authors (341, 345–349) and even the product technique manuals, are evasive regarding the depth to which the implants enter the tarsal canal, though they certainly appear to enter it. Nevertheless, proponents consider them to be extra-articular, if inserted properly, because they do not technically touch articular cartilage, though they clearly encroach upon it. The arthroereisis implants have been shown to mechanically block eversion and also decrease total subtalar joint motion (342, 349), indicating that their effect is in fact intra-articular.

In published studies on subtalar and triple arthrodeses, stress transfer to adjacent joints with the development of degenerative arthrosis was not seen for at least 10 years, which is longer than the follow-up in any of the reports on arthroereisis. Additionally, these implants, not surprisingly, lead to resorption of the adjacent cortical surfaces of the talus and calcaneus (Fig. 29-85), the long-term effects of which are unknown.

Both the MBA and Giannini arthroereisis implants are now offered as bioabsorbable implants made of poly-L lactic acid (PLLA), but the original metal designs seem to be used most often, and the bioabsorbable implants have even shorter follow-up than the original designs. Saxena and Nguyen (348) found MRI evidence of residual bioabsorbable implant at >4 years after implantation. These authors stated that there were no cystic changes noted in the bones, but acknowledged that granuloma formation from PLLA can appear in a delayed fashion. Additionally, their MRI study of the subtalar joint in adults with these implants found that the tarsal canal is smaller in height and length than the implant sizes generally used. They felt that this was a particular problem for the metal implants and less so for the bioabsorbable ones, unless one considers that children and adolescents have an even smaller canal than the ones they studied. Finally, they questioned the benefit of the bioabsorbable implants since half of their patients required or were recommended to have explantation.

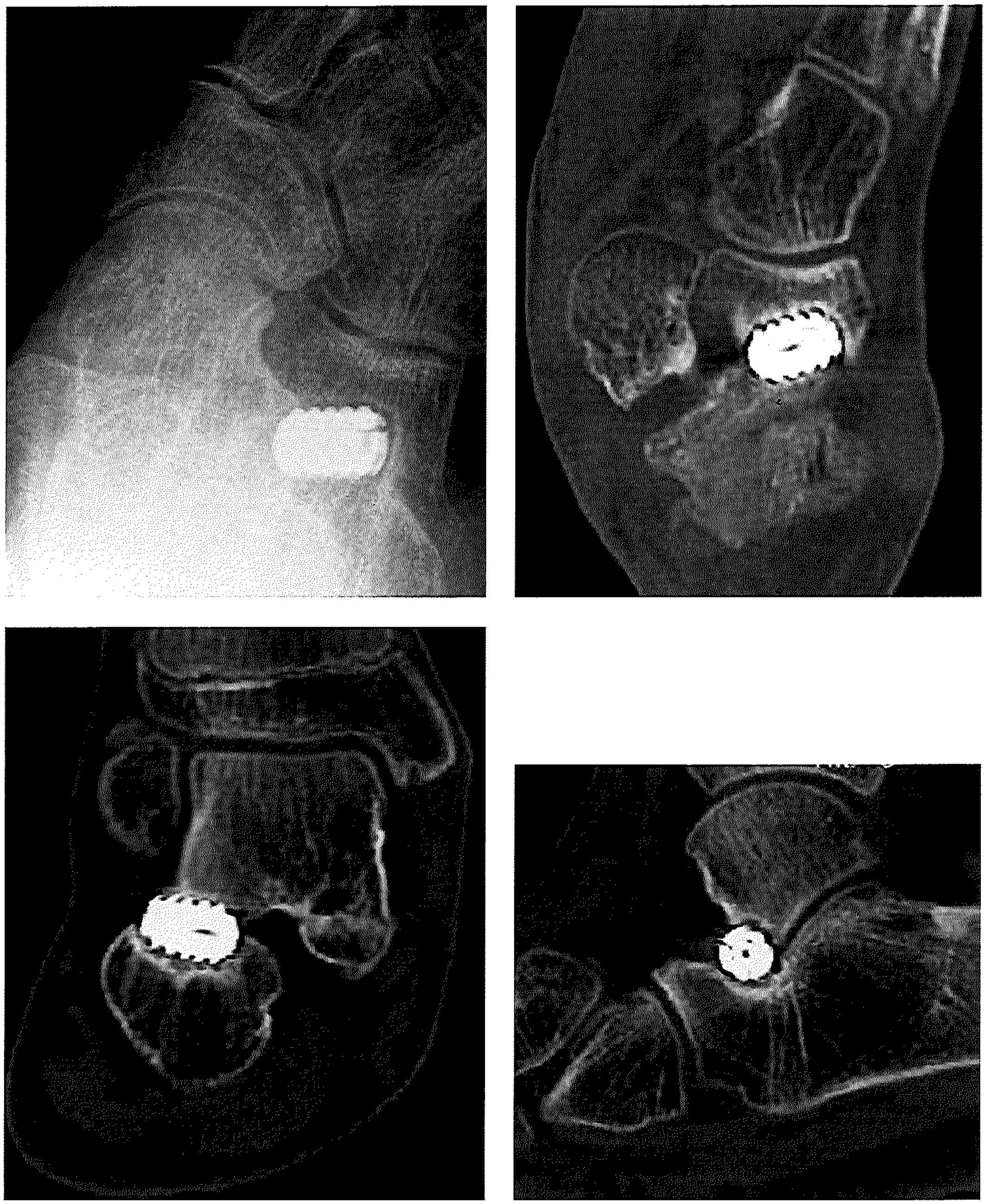

A B C D

FIGURE 29-85. X-ray and CT scan images showing bone resorption around an MBA implant. **A:** AP x-ray. **B:** Transverse plane CT scan image. **C:** Coronal plane CT scan image. **D:** Sagittal plane CT scan image. (From Mosca VS. Flexible flatfoot and skewfoot. In: McCarthy J and Drennan JC, eds. *The Child's Foot and Ankle.* 2nd ed. Lippincott Williams & Wilkins, 2009:147, with permission.)

The bottom line seems to be that more information and, in particular, long-term studies are needed before arthroereisis can be recommended for children with painful flatfeet. And even more important is the need for the proponents of arthroereisis to clarify surgical indications based on the best scientific evidence available.

Osteotomy is the last category of procedures that has been used to treat flatfeet. This is a biologic approach that does not depend on soft tissues, that are known to stretch out, and it avoids arthrodeses/arthroereisis and the known complications of those procedures.

Numerous osteotomies of the calcaneus to correct heel valgus have been described. The most popular original osteotomy was that described by Dwyer (80). However, wound problems resulting from the opening wedge and collapse of the graft have limited the use of this procedure. These potential problems are solved and the same goals are achieved by a medial displacement osteotomy of the posterior calcaneus (Figs. 29-86 to 29-90). The operation was first described by Koutsogiannis (235) but attributed to Pridie.

The posterior calcaneus displacement osteotomy does not actually correct the malalignment of the subtalar joint, but merely creates a compensating deformity to improve the valgus angulation of the heel. Recalling Scarpa's analogy to the hip (14), I believe the posterior calcaneal displacement osteotomy is the Chiari osteotomy of the AP. Koutsogiannis reported successful "correction" of valgus deformity in 30 of 34 feet, but arch restoration rarely occurred. Other authors confirmed these same results in FFF (350) as well as in paralytic flat feet (351). The posterior calcaneus osteotomy does not correct the multiple components of subtalar joint eversion, such as external rotation and dorsiflexion of the AP. Rathjen and Mubarak (352) reported good correction of flatfoot deformities by combining a modification of this osteotomy (medially based closing wedge with medial displacement) with a closing-wedge osteotomy of the medial cuneiform, an opening-wedge osteotomy of the cuboid, and medial reefing of the talonavicular joint.

The other osteotomy for correction of valgus deformity of the hindfoot is the calcaneal lengthening osteotomy, conceptualized by Evans (236) and elaborated by Mosca (237, 238) (Figs. 29-91 to 29-98). Evans believed that the lateral column of the flatfoot was shorter than the medial column, a situation exactly opposite to that found in a cavovarus foot. For painful flatfeet, he equalized the length of the columns by inserting a corticocancellous graft into an osteotomy of the anterior calcaneus that was made 1.5 cm proximal to, and parallel with, the calcaneocuboid joint. That was the entire extent of his description. By lengthening the calcaneus in this way, he showed that the heel valgus, talonavicular sag, and lateral subluxation of the navicular on the head of the talus could all be simultaneously corrected. Armstrong and Carruthers (353) recommended the technique and highlighted its advantages to be correction of hindfoot valgus without need for arthrodesis, preservation of some subtalar motion, versatility for pronated and abducted feet of different etiologies, and simplicity of execution. Phillips (354) reported a 7 to 20 year (average 13 years) follow-up of Evans' patients. Seventeen of the twenty-three feet had good to very good results when assessed by strict criteria. Anderson and Fowler (355) also reported very good results with this procedure in 9 feet followed for an average of 6½ years. They reaffirmed the correction of all components of the hindfoot deformity by this simple technique and advised performing the procedure between ages 6 and 10 years in appropriate individuals to allow remodeling of the tarsal joints, a consideration not mentioned by Evans.

In 1995, Mosca (237) reported the short-term results of calcaneal lengthening for valgus deformity of the hindfoot from various underlying etiologies in 31 feet in 20 children. He reported correction, at the site of deformity, of all components of even severe eversion of the subtalar joint complex, including dorsiflexion, pronation, and external rotation of the AP around the talar head. Function of the subtalar joint was restored, symptoms were relieved, and, at least theoretically, the ankle and midtarsal joints were protected from early degenerative arthrosis by avoiding arthrodesis. He stressed the need for strict indications for surgery, specifically a flexible or rigid flatfoot with Achilles or gastrocnemius contracture and intractable pain in the medial midfoot and/or sinus tarsi despite prolonged attempts at conservative management.

As noted above, Evans provided very little information on the technique, which made interpretation difficult and surgical success inconsistent by those who read his article. Mosca thoughtfully considered Evans' concept and applied an understanding of foot biomechanics and the principles of foot deformity-correction surgery to develop a reliable method for achieving consistently good surgical outcomes. His published contributions (15, 237, 238, 356) include the location of the skin incision (modified Ollier), the specific location and direction of the osteotomy (exiting medially between the anterior and middle facets), the shape of the bone graft (trapezoidal), management of the soft-tissue constraints along the plantar-lateral border of the foot (lengthened) and the soft-tissue redundancy along the plantar-medial border (plicated), stabilization of the calcaneocuboid joint to prevent subluxation (using a Steinmann pin), the need to recognize and concurrently manage rigid forefoot supination deformity if present (plantar-based closing-wedge osteotomy of the medial cuneiform), and the importance of lengthening the Achilles or gastrocnemius tendon if contracted (which is usually the case in the symptomatic FFF).

It must be stressed that the calcaneal lengthening osteotomy does not correct flatfoot deformity. It corrects valgus/eversion deformity of the hindfoot. In all flatfeet, the forefoot is supinated. In young children and adolescents, the forefoot supination deformity will often spontaneously pronate to neutral after the hindfoot deformity is corrected with the calcaneal lengthening osteotomy. In most older adolescents, the forefoot supination deformity does not correct and must be identified and operatively corrected under the same anesthetic. A plantar-based closing-wedge osteotomy of the medial cuneiform, that is internally fixed with a wire staple, is an effective procedure to correct this deformity. And

Text continued on page 1479

Posterior Osteotomy of Calcaneus for Valgus (Figs. 29-86 to 29-90)

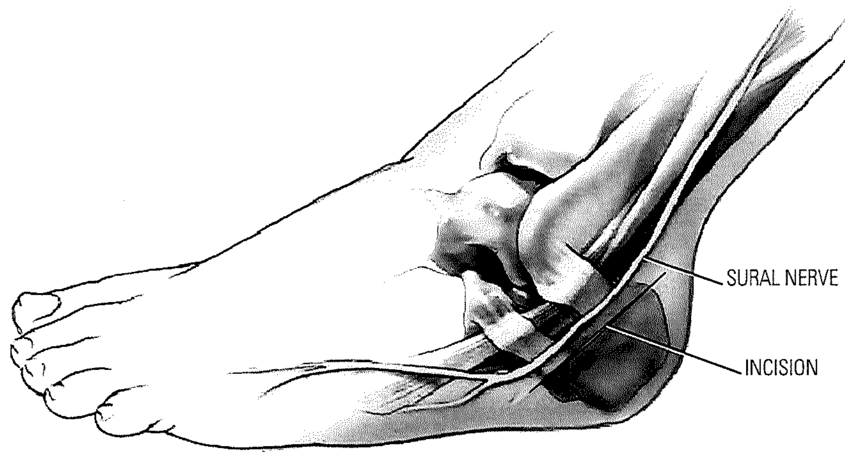


FIGURE 29-86. Posterior Osteotomy of Calcaneus for Valgus. An oblique incision is made over the lateral side of the calcaneus for a posterior calcaneus medial displacement osteotomy. The incision is posteroinferior to the peroneal tendons. It should be long enough to allow exposure of the inferior and dorsal surfaces of the tuber of the calcaneus, which actually means that it does not have to be very long. It is important to avoid damage to the sural nerve, which runs slightly inferior to the peroneal tendons.

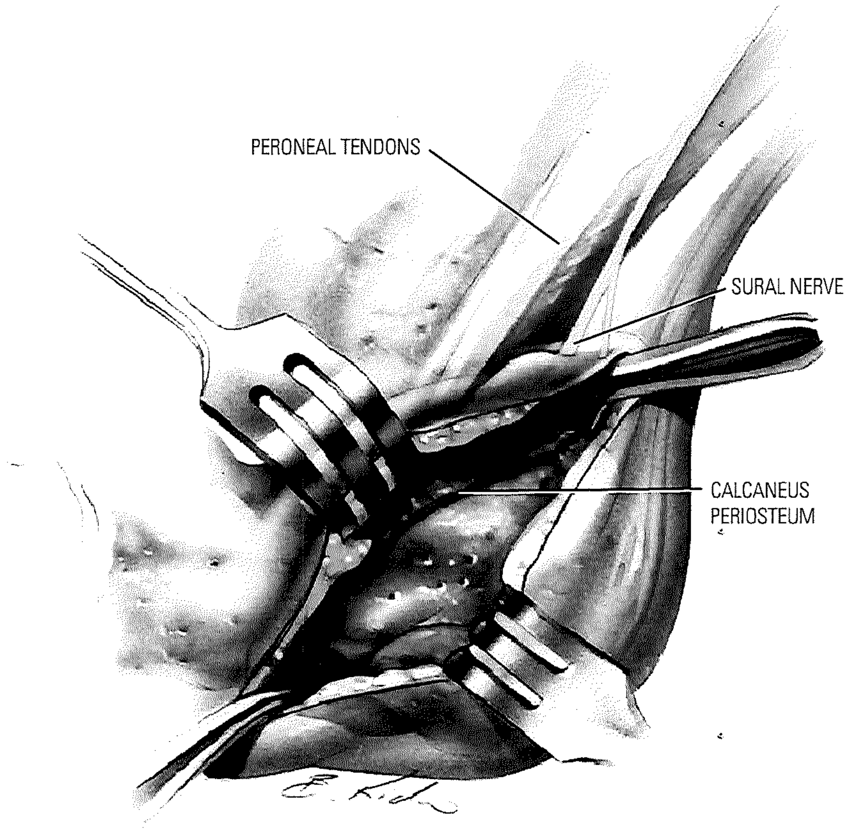


FIGURE 29-87. The incision should reach the periosteum of the calcaneus with a minimum of undermining. A narrow curved retractor (e.g., a Joker or a Crego) is slid extraperiosteally over the dorsal surface of the calcaneus, anterior to the Achilles tendon and adjacent to the capsule of the posterior facet of the subtalar joint. It continues extraperiosteally on the medial side of the calcaneus deep to the posterior tibial neurovascular bundle. A similar retractor is slid extraperiosteally under the calcaneus at a position slightly more anterior than the dorsally placed retractor. It, likewise, remains deep to the neurovascular bundle. Curved Crego elevators are useful here for the purposes of dissection, retraction, and soft-tissue protection. A straight incision is made in the periosteum dorsally, laterally, and plantarward. It is elevated for about 5 mm on each side of the incision. The capsule of the posterior facet of the subtalar joint should be seen but not disturbed. This ensures that the osteotomy is anterior enough to prevent the creation of too small a posterior calcaneal fragment.

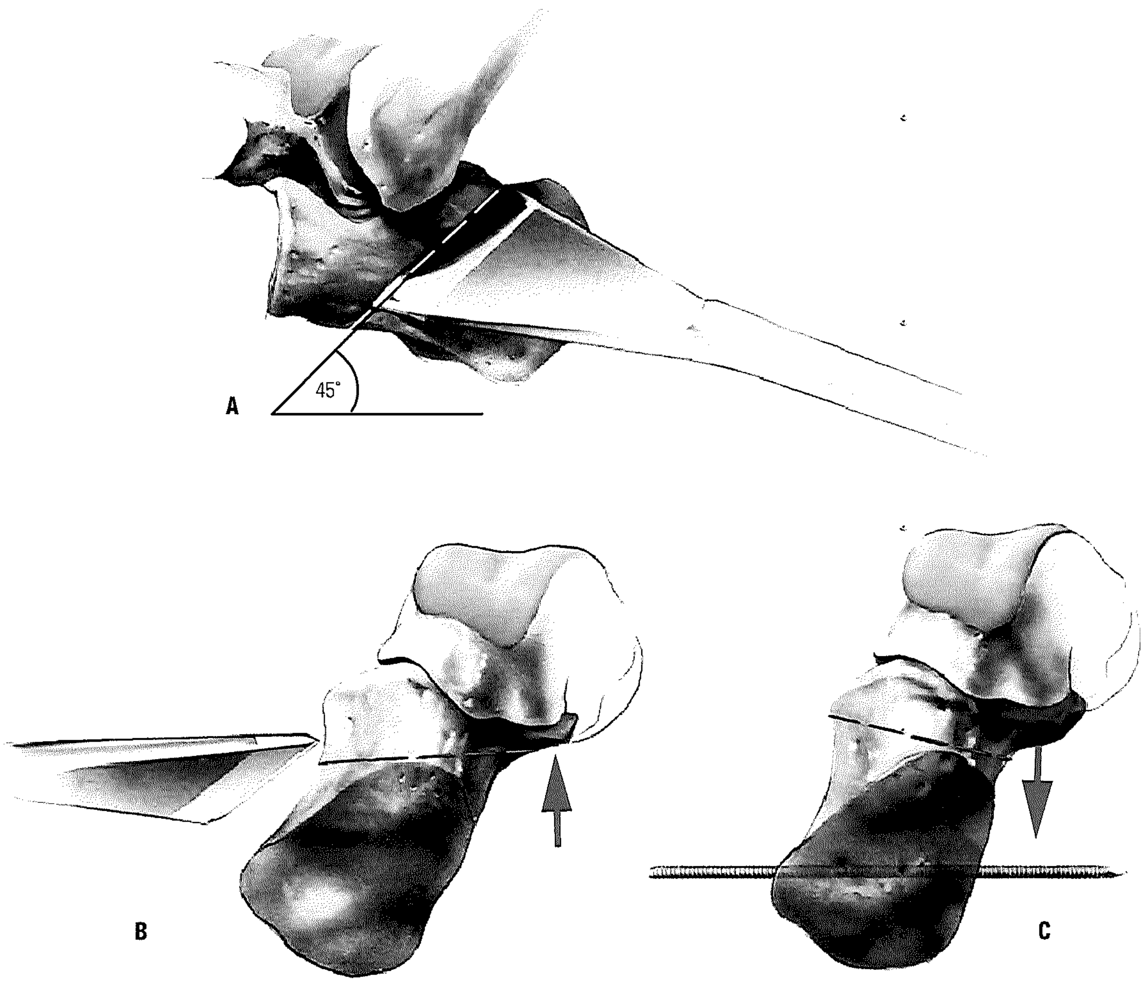


FIGURE 29-88. The osteotomy can be made with a power saw or with a broad osteotome. The placement and direction of the osteotomy is important. The osteotomy should start about 1 cm posterior to the capsule of the posterior facet of the subtalar joint. The saw blade or osteotome should be positioned obliquely in relation to the plantar aspect of the foot **(A)**. As the cut is made across the calcaneus, it should remain in the transverse plane. If it is angled slightly toward the subtalar joint **(B)**, the vertical height of the calcaneus will be decreased after the fragment is displaced. If it angles away from the subtalar joint **(C)**, the vertical height of the calcaneus will be increased and the fragment will tend to bind as it is displaced, making displacement much more difficult. A 2 mm threaded Steinmann pin should be inserted in the postero-plantar corner of the calcaneus in the transverse plane of the MT heads as a reference guide for the osteotomy and as a joy stick to displace the posterior fragment. Caution must be used in completing the osteotomy through the medial cortex because of the proximity of the posterior tibial vessels and nerve. Crego retractors help ensure protection of those structures, though they do not guarantee it.

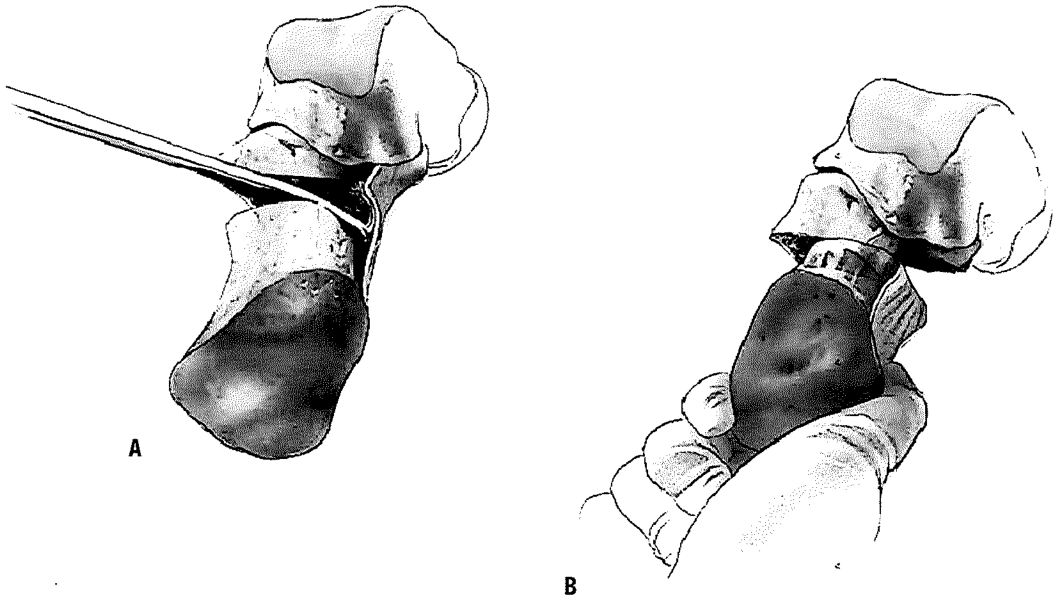


FIGURE 29-89. The large weight-bearing portion of the calcaneus can be displaced. It is usually necessary to displace it at least half of the width of the calcaneus. At first this will not seem possible, but with a little perseverance it can be done. A broad stout osteotome or periosteal elevator can be inserted to pry the two fragments apart **(A)**. Strong repeated manipulation of the fragment tends to elevate the periosteum on the medial side by stripping it from the bone **(B)**. Because the Achilles tendon and the plantar fascia hold the fragments together when taut, the foot should be held in plantar flexion for all of the manipulations. If a very large amount of displacement is needed, it may be necessary to remove a medially-based wedge of bone from the posterior fragment. A small lamina retractor can be used to separate the fragments and provide better access while stretching the taut medial periosteum. Finally, the long plantar ligament (not the plantar fascia) can be divided if needed.

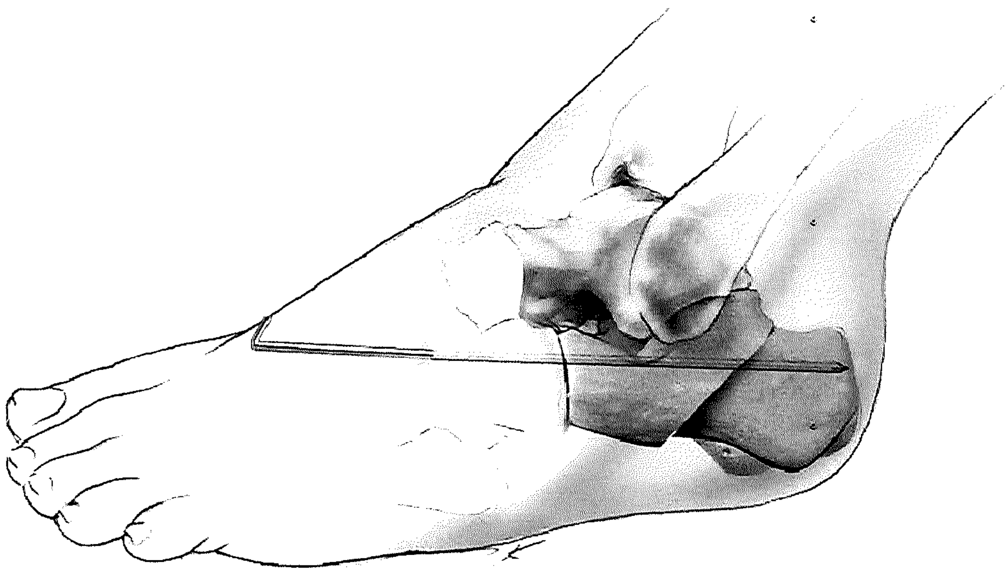


FIGURE 29-90. The foot is plantar-flexed, and the loose posterior fragment of calcaneus is pushed medially. It must be ascertained that it does not displace dorsally. The foot is dorsiflexed to compress the osteotomy surfaces and stabilize the displacement. To ensure that the displacement is maintained, a large screw or smooth Steinmann pin can be used. A cannulated screw, inserted antegrade in the calcaneus from posterior to anterior, is desirable in adolescents and need not be removed. In skeletally immature patients, a 2- to 3-mm smooth Steinmann pin can be inserted antegrade or retrograde across the osteotomy. It will not affect apophyseal growth. I prefer one inserted retrograde from the region of the beak of the calcaneus that ends in the apophysis. It can be bent at the insertion site and easily retrieved in clinic at 6 weeks. It will not be possible to close the periosteum. The deep fascia and the skin are closed with interrupted sutures, taking care not to damage the sural nerve, and a short-leg cast is applied. The patient is non–weight bearing on the operated foot for 6 weeks. The cast is changed in the office, and the Steinmann pin, if used, is removed from the bone. A short-leg walking cast is applied for 2 additional weeks while the patient gradually resumes full weight bearing.

Calcaneal Lengthening Osteotomy for the Treatment of Hindfoot Valgus Deformity (Figs. 29-91 to 29-98)

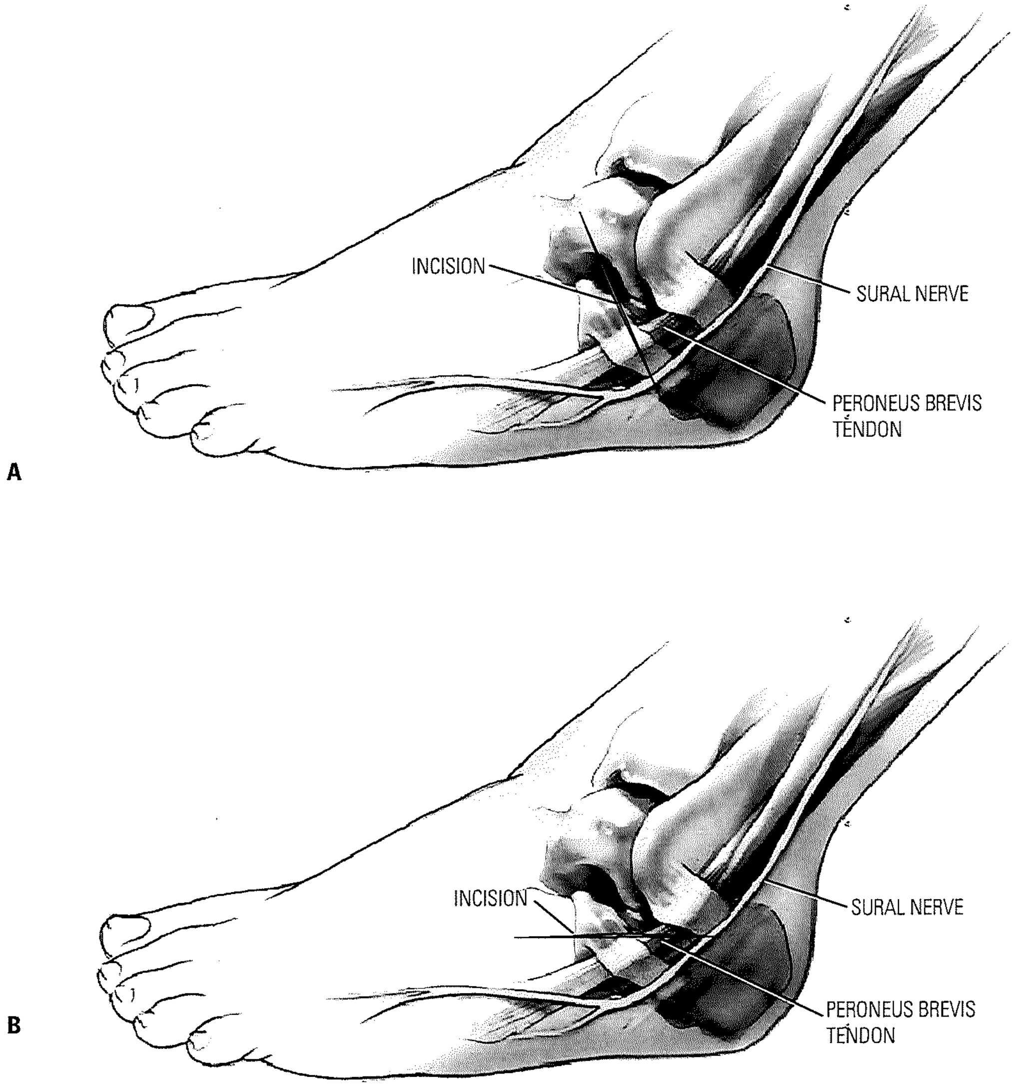


FIGURE 29-91. Calcaneal Lengthening Osteotomy for the Treatment of Hindfoot Valgus Deformity. The incision for the calcaneal lengthening osteotomy can be either an oblique Ollier type of incision that crosses the sinus tarsi **(A)**, as suggested by Mosca (237,238), or a transverse incision directly above the peroneal tendons, as originally described by Evans (236) **(B)**.

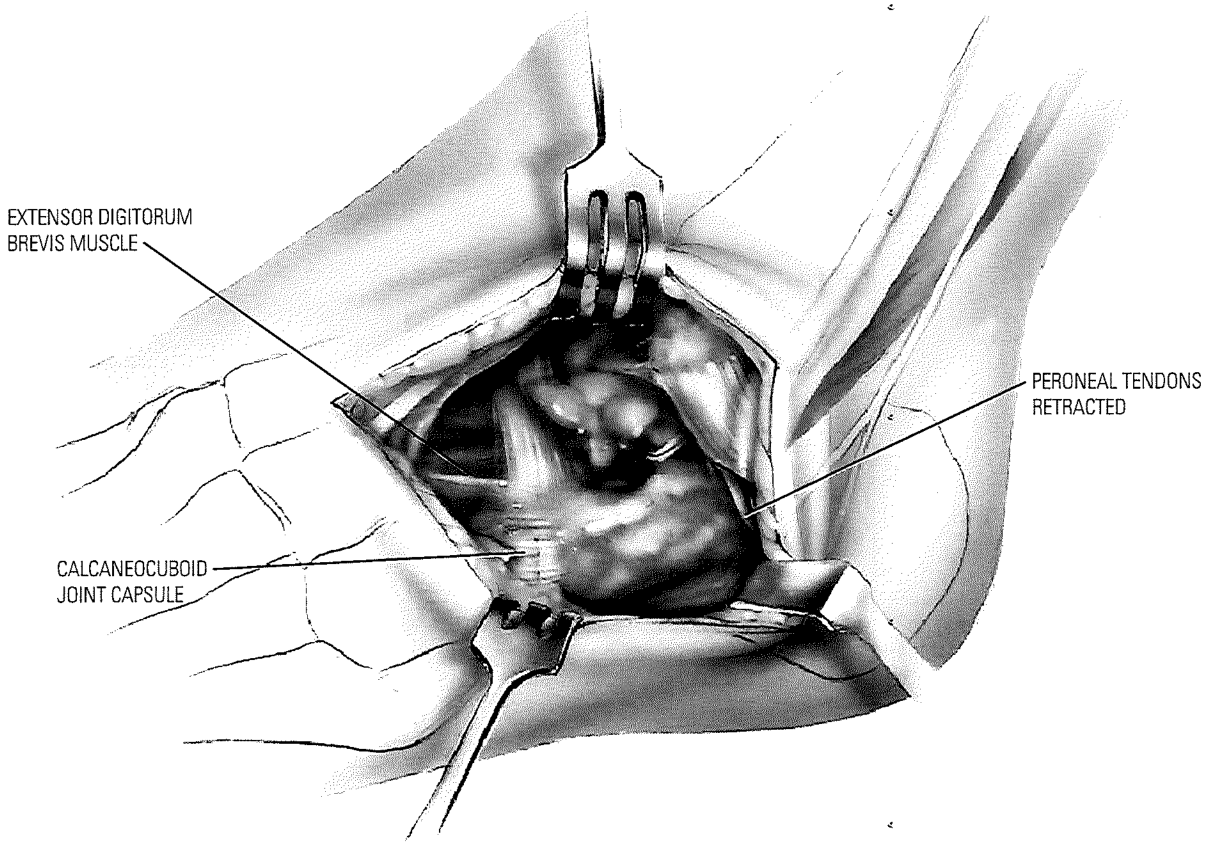


FIGURE 29-92. After the incision is deepened through the skin, the superficial peroneal and sural nerves are identified, retracted, and protected. The peroneal tendons are released from their sheaths and the septum between them is resected. The peroneus brevis is Z-lengthened and the peroneus longus is retracted.

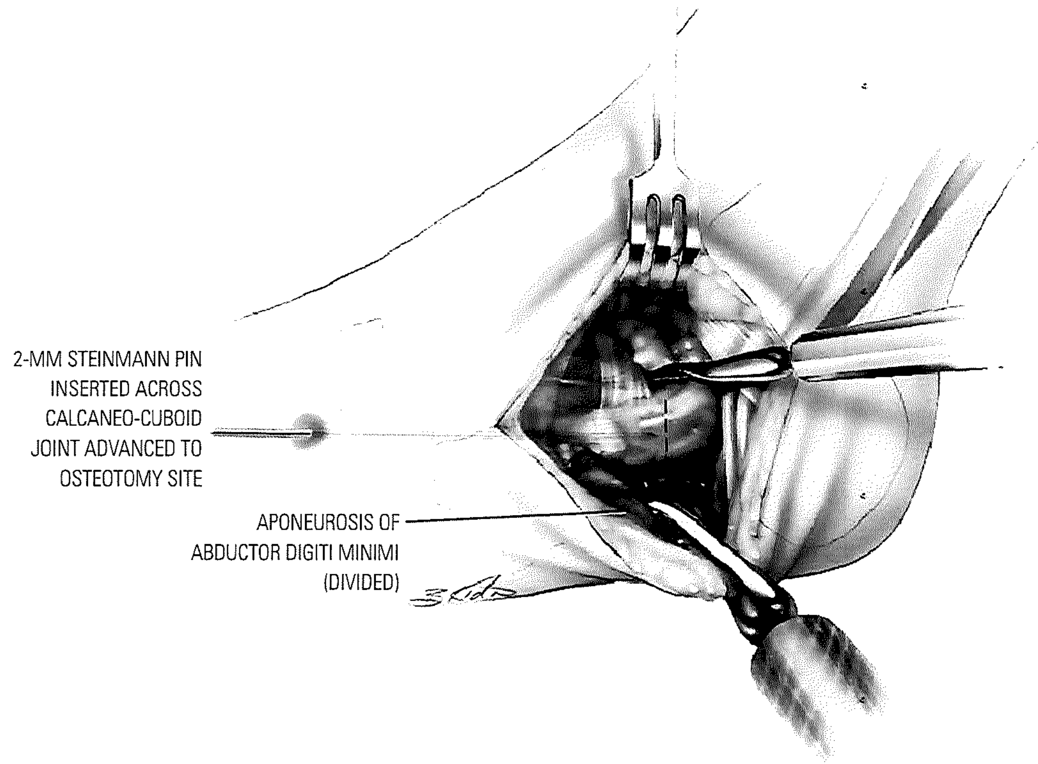


FIGURE 29-93. The soft-tissue contacts of the sinus tarsi are elevated from the isthmus of the calcaneus, which is the lowest point of the sinus tarsi and that part of the calcaneus that is proximal to the beak. The calcaneocuboid joint should be identified by its landmarks but not opened; its capsule is important in providing stability to the anterior calcaneal fragment. The aponeurosis of the abductor digiti minimi is divided transversely 2 cm proximal to the calcaneocuboid joint. The soft tissues are elevated from the undersurface of the isthmus of the calcaneus using a Joker elevator or Crego retractor. After the osteotomy is performed and while holding the foot in the fully everted (flatfoot) position, a 2-mm smooth Steinmann pin is inserted retrograde from the dorsolateral aspect of the forefoot across the calcaneocuboid joint stopping at the osteotomy. Use minifluoroscopy to ensure perfect placement of this pin across the anatomic center of the calcaneocuboid joint and to make sure the joint is not pre-subluxated. This pin is extremely important as it prevents subluxation of the calcaneocuboid joint that might otherwise prevent full deformity correction.

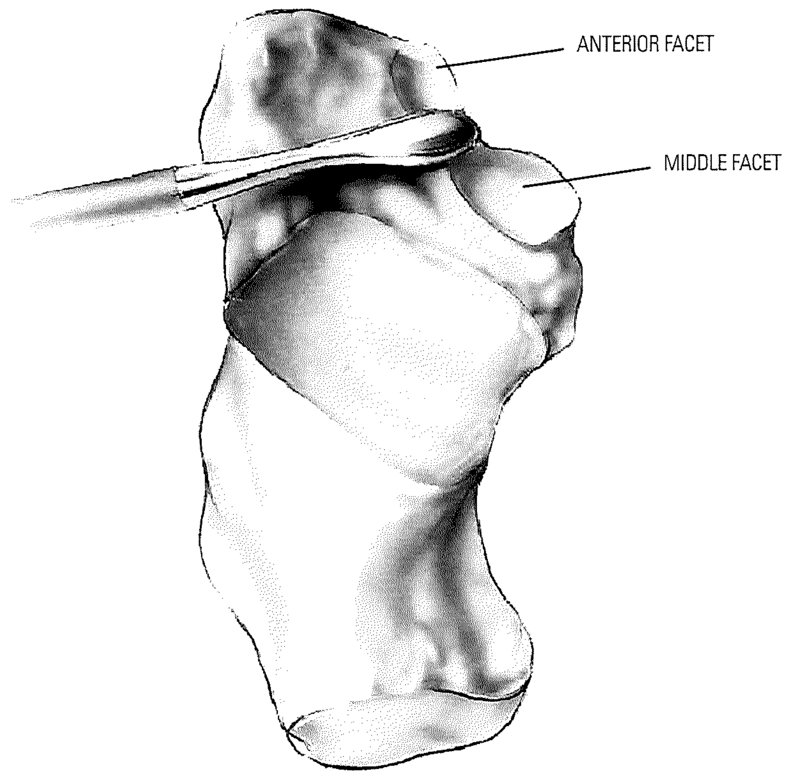


FIGURE 29-94. The starting point for the osteotomy is approximately 1.5 to 2 cm proximal to the calcaneocuboid joint at the lowest elevation point of the isthmus of the calcaneus. Mosca (237,238) believes that the exit point should be between the anterior and middle facets of the subtalar joint. To identify this, a Freer elevator is slid across the isthmus of the calcaneus to the medial side where the middle facet is encountered. Slowly probing anteriorly, the surgeon will find the interval between the anterior and middle facets. This position can be confirmed by minifluoroscopy. It is to be noted that the plane of this osteotomy is neither perpendicular to the lateral border of the foot nor parallel with the calcaneocuboid joint. Passing over the dorsum of the calcaneal isthmus, a Joker elevator is placed in the interval between the anterior and middle facets. It is met in that interval by a narrow curved Crego retractor that is passed plantar to the isthmus. These instruments are used to identify the path of the osteotomy and to protect the soft tissues from the sagittal saw or osteotome.

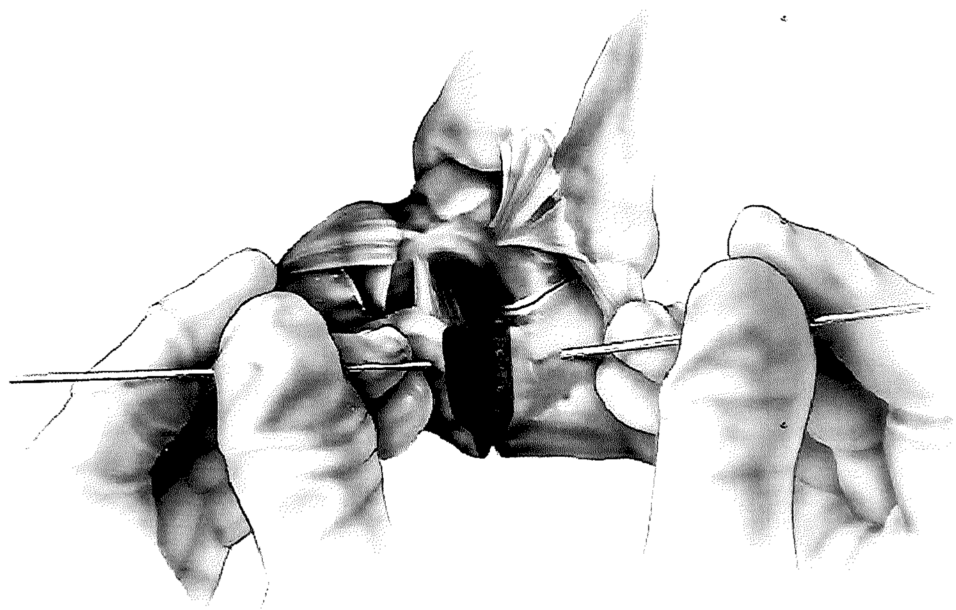


FIGURE 29-95. Perform the osteotomy. A 0.062-inch smooth Steinmann pin is inserted from lateral to medial in both calcaneal fragments. These will be used as joy sticks to distract the osteotomy when the graft is inserted.

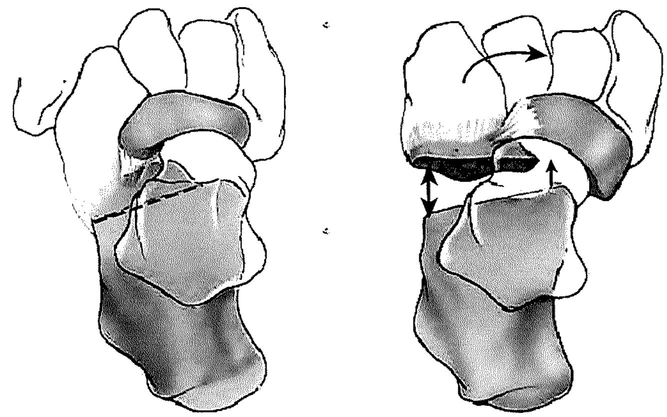


FIGURE 29-96. To assess the size of the graft to be inserted, a lamina spreader is used. With it in place, the foot is inspected to make certain that the desired amount of correction is achieved. This should be confirmed by minifluoroscopy. Release of the dorsal talonavicular joint capsule may be necessary. It is important to realize that the graft should be trapezoidal and that the center of rotation is not the medial cortex of the calcaneus but rather a point closer to the center of the talar head. The navicular and anterior calcaneal fragment move as a unit plantar-medially around the talar head as the osteotomy is opened.

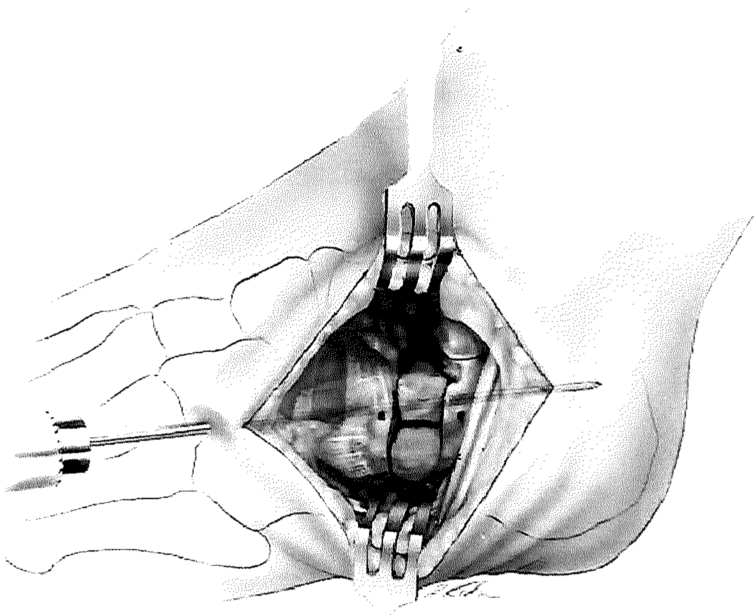


FIGURE 29-97. The osteotomy is held open by the two Steinmann pins while a trapezoidal tricortical iliac crest graft is inserted. This should be placed so that at least one cortex of the graft is in contact with the cortices of the calcaneal fragments to give structural stability to the construct. Generally, one graft is sufficient unless the graft is thin. Two can be used in that situation. The first is placed more plantarward and the second dorsally. The previously inserted 2-mm smooth Steinmann pin is advanced retrograde through the graft and into the posterior calcaneal fragment. It is bent at the skin insertion site and cut long for easy retrieval in clinic.

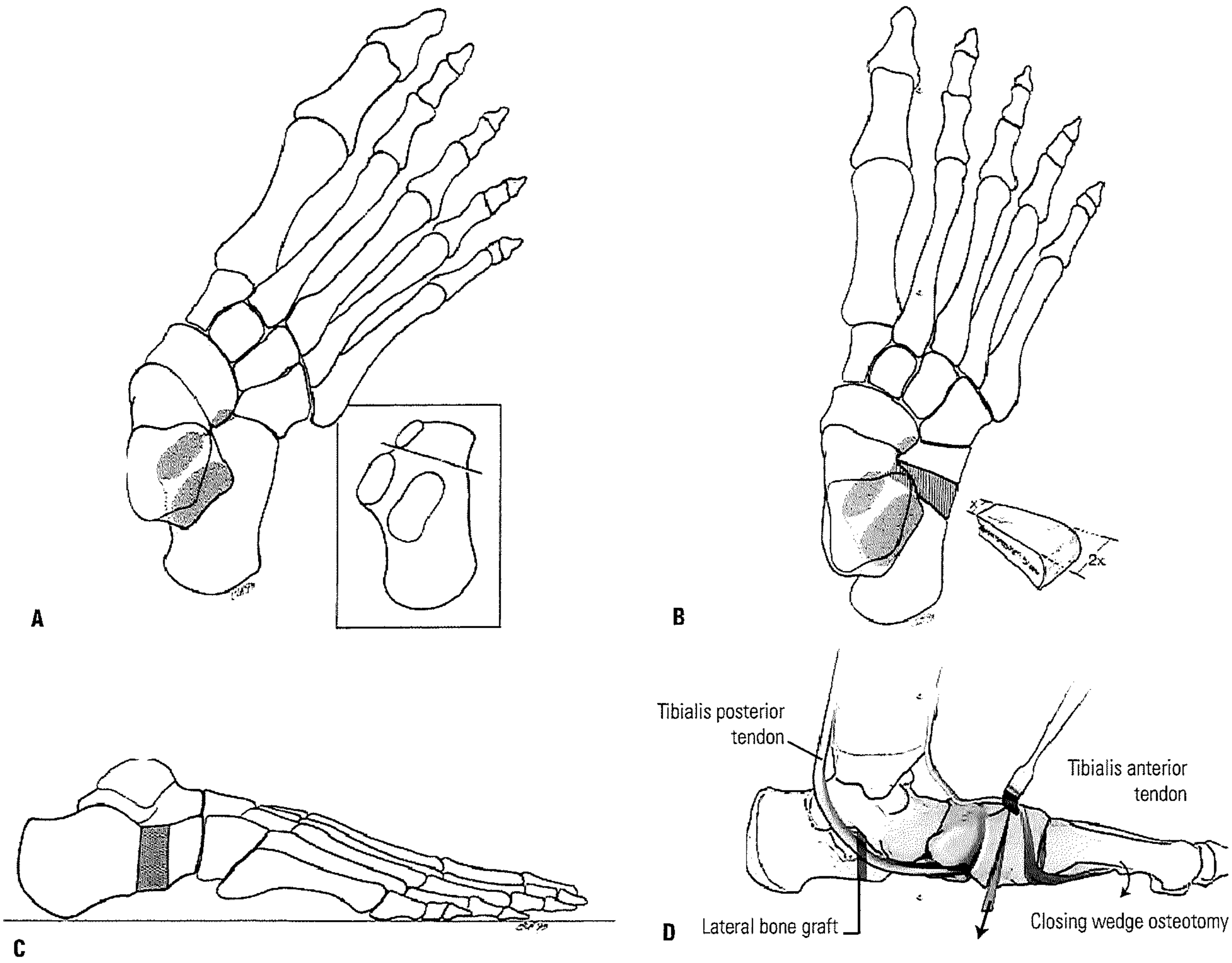


FIGURE 29-98. **A:** Calcaneal lengthening osteotomy. Dashed line indicates the position of the oblique osteotomy between the anterior and middle facets of the calcaneus. **B, C:** Insertion of the trapezoid-shaped tricortical iliac crest bone graft corrects all components of the valgus deformity of the hindfoot. **D:** A plantar-based closing-wedge osteotomy of the medial cuneiform corrects the supination deformity of the forefoot. Lengthening of the gastrocnemius or the Achilles tendon is almost always necessary. (**A–C**: Mosca VS. Calcaneal lengthening for valgus deformity of the hindfoot. Results in children who had severe, symptomatic flatfoot and skewfoot. *J Bone Joint Surg Am* 1995;77:500–512, with permission; D: Anderson AF, Fowler SB. Anterior calcaneal osteotomy for symptomatic juvenile pes planus. *Foot Ankle* 1984;4:274–283, with permission.)

finally, the deformity that created the pain in the flatfoot, the contracted heel cord, must be surgically treated by either a gastrocnemius recession or an Achilles tendon lengthening, based on the intraoperative Silfverskiold test (Fig. 29-98).

The graft takes about 8 weeks to heal. If desired, the pin can be removed in the office after 6 weeks and the cast changed. Weight bearing is not permitted during the time it takes for the graft to incorporate, that is, the full 8 weeks.

Ragab et al. (357) performed a descriptive anatomic study of cadaver bones and found that 33% of whites and 60% of blacks (46% of the total) had conjoined anterior and middle calcaneal facets. Although this was merely a description of the anatomic shapes of the bones, they used their findings to condemn the calcaneal lengthening osteotomy. Despite presenting no clinical data, they argued that the osteotomy is intra-articular and would likely cause degenerative changes in the subtalar joint. This result has not been born out by any published data.

Evans (236) may, in fact, have created a true intra-articular osteotomy in most cases. He wrote that the osteotomy should be performed 1.5 cm proximal to, and parallel with, the calcaneocuboid joint. In most adolescent feet, that location is within the middle facet. Nevertheless, in the average 13 year follow-up study of Evans' patients, Phillips (354) reported some cases with degenerative changes in the calcaneocuboid joint, but not the subtalar joint. And a possible explanation for the calcaneocuboid joint arthritis is that Evans did not protect that joint from subluxating with a longitudinal wire, as is recommended by Mosca (237, 238).

Mosca (237) reasoned that it would be best to perform the osteotomy between the anterior and middle facets of the calcaneus to preserve the facets and to maintain the structural stability of the AP. The very fact that there are so many anatomic variations in the size, shape, and even existence of the anterior facet speaks to the possible insignificance of that structure (358). Furthermore, the anterior facet does not support the head of the talus, even in the neutrally aligned subtalar joint. It is plantar-lateral and seems to act merely as an attachment point for the spring ligament (358).

Additionally, the major displacement of the calcaneal fragments occurs laterally, away from the facets. The only potential problem in separating the conjoined or separate facets would be vertical translation of the calcaneal fragments (358), which, I believe, can be avoided by attention to the details of the procedure as they have been described in the literature (237, 238).

Other authors have subsequently confirmed the efficacy of the calcaneal lengthening osteotomy for relieving pain and correcting deformity in painful flatfeet (359–367).

In summary, if the requisite indication for the calcaneal lengthening osteotomy is intractable pain in a flatfoot with a short Achilles tendon, the relative risk of a theoretically intra-articular osteotomy compared with the reported excellent clinical results of the procedure is obviated.

Freiberg Infraction

Definition. In 1914, Freiberg (368) described a painful condition of the second metatarsal head that was characterized by flattening of the articular surface of bone with areas of both lucency and sclerosis. Postulating a traumatic origin, he labeled it an "infraction" rather than an "infarction," which would imply an ischemic origin.

Epidemiology. The incidence of this condition is unknown, but it occurs most commonly in adolescent girls and is, surprisingly, the only "osteochondrosis" with a predilection for the female sex. The second metatarsal is most commonly affected, followed by the third, while the first, fourth, and fifth are rarely involved. Less than 10% of individuals have bilateral involvement.

Etiology. The etiology is unknown. Like Kohler disease, Freiberg infraction is considered to be an osteochondrosis, an idiopathic condition characterized by disorderliness of endochondral ossification. However, unlike Kohler disease, it has been classified by Siffert (369) as a primary articular osteochondrosis that may or may not progress to disruption of the subjacent bony epiphysis. These histologic changes occur in constitutionally and biologically susceptible metatarsal heads for unknown reasons. Proposed theories include trauma, repetitive stress, vascular anomalies, and high-heel shoe wear (370, 371).

Clinical Features. Typically, a mid- to late-adolescent female presents with forefoot pain that is exacerbated by weight-bearing activities and relieved by rest. There is soft-tissue swelling, tenderness, and restriction of motion of the involved metatarsophalangeal joint. When the pain, swelling, and tenderness are located more proximally on the metatarsal shaft and there is full motion of the metatarsophalangeal joint, the diagnosis is more likely to be a metatarsal stress fracture.

Radiologic Features. Radiographic findings are evident on AP and oblique radiographs of the forefoot within several weeks of the onset of symptoms. There is increased subchondral sclerosis, lucency, and apparent flattening of the articular surface (Fig. 29-99) with an appearance somewhat reminiscent of Legg-Calve-Perthes disease of the hip. The radiographic findings of Freiberg infraction, like the physical findings, are varied and tend to correlate with the pathologic stage of the disease, but not necessarily with the physical complaints. The prognosis cannot be determined by the extent of involvement seen radiographically. Classification systems for this disease based on radiographic appearance exist (371–373) but have not been particularly useful in clinical management.

A B

FIGURE 29-99. **A:** Freiberg infraction of the second metatarsal head. Early stage with crescent sign. **B:** Later stage with collapse of the metatarsal head. The patient, a young woman, was asymptomatic. (From the private collection of Vincent S. Mosca, MD.)

Pathoanatomy. There are three stages of pathologic changes (374). The intra-articular and periarticular soft tissues are thickened and edematous during the first stage. In the second stage, the cells of the epiphysis that receive nutrition by diffusion from the joint fluid are deprived as a result of the edematous pressure from chronic synovitis. Blood vessels within the epiphysis are incompetent secondary to thrombosis or microfractures of the trabeculae. The epiphyseal contour becomes deformed because of this disordered osteogenesis and chondrogenesis. Repair takes place during the third stage with gradual replacement of the necrotic bone. Alternatively, the necrotic bone segment(s) may separate as an intra-articular loose body leaving a defect in the articular surface.

Natural History. The disease generally progresses through the three stages described in the preceding text, with reconstitution of a satisfactory articular surface and relief of pain. The long-term results depend on the severity of the damage to the articular surface and whether loose bodies result.

Treatment. Nonoperative treatment is indicated to relieve symptoms and to allow healing, as will occur in many cases. Modalities include restriction of activities, avoidance of weight bearing, cast immobilization, metatarsal bars and other shoe inserts to relieve pressure under the metatarsal head, and modification of shoe wear. Avoiding high-heeled shoes that place more pressure on the metatarsal heads is advised.

Surgery is indicated when prolonged attempts at nonoperative management have failed to alleviate the symptoms; however, there is no consensus on the best technique. Surgical options include joint debridement and removal of loose bodies (368, 372, 375), elevation of a collapsed articular surface with bone grafting (373), excision of a metatarsal head and shortening of a metatarsal (376), and metatarsal dorsiflexion osteotomy (371, 372, 375). Debridement of periarticular osteophytes or prominent bone impinging on metatarsal–phalangeal joint motion is a procedure that usually gives satisfactory symptomatic relief (368, 372, 377) if required. In more advanced stages of the disease, joint debridement alone might not be sufficient. The addition of a distal metatarsal dorsiflexion osteotomy has been reported to relieve symptoms and to restore joint motion (371, 372, 377). Attention to the details of the procedure is important in order to avoid iatrogenic disruption of the vascularity of the metatarsal head and to avoid the creation of transfer lesions to adjacent metatarsal heads (371).

Juvenile Hallux Valgus

Definition. Juvenile hallux valgus is defined as >14 degrees of lateral deviation of the hallux on the first metatarsal that has its onset in preteenage or teenage years when the growth plates of the first metatarsal and proximal phalanx are still open. This term applies regardless of the age at the time of treatment. Other features include minimal bursal thickening over a relatively small medial eminence, and a good range of motion and a lack of degenerative changes in the first metatarsophalangeal joint.

Epidemiology. The incidence is unknown. It is much more common in girls than boys, with girls accounting for over 80% of operative cases (378).

Etiology. The etiology is also unknown. There is a maternal inheritance in over 70% of cases (379, 380). Studies and case reports indicate that juvenile hallux valgus may be associated with either an X-linked dominant, autosomal dominant with very variable penetrance, or polygenic transmission (378, 381).

Clinical Features. Most adolescents with hallux valgus are asymptomatic and have learned to choose their shoe wear so as to avoid pressure and pain on the medial aspect of the first metatarsal head. Some are merely dissatisfied with the appearance of the foot. Others report pain only when wearing certain style shoes that fit poorly and are biomechanically inferior. Still others are symptomatic despite attempts to modify shoe wear. The pain is located in the superficial medial soft tissues due to pressure from the shoe on the bony prominence of the first metatarsal head. The shoes are inspected for the fit and the pattern of wear.

Intra-articular pain is rare in juvenile hallux valgus. Likewise, it is rare to find restriction of motion of the metatarsophalangeal joint. Look for other causes of pain surrounding the metatarsal–phalangeal joint such as arthritis, infection, or lesions of the local soft tissues or bone. There may also be pain associated with the overlapping of the second toe on the distal end of the hallux.

The foot should be assessed in weight bearing to determine the alignment of the midfoot and hindfoot, looking in particular for associated flatfoot deformity. Gait is observed with a focus on the position of the forefoot during push-off. A thorough motor and sensory examination is performed. The tightness of the Achilles tendon must be ascertained. Although difficult to quantify, mobility of the metatarsocuneiform (MTC) joint should be evaluated.

Most importantly, the child's major concerns, symptoms, expectations, and goals must be elicited.

Radiographic Features. Standing anteroposterior and lateral radiographs of the foot are necessary to evaluate juvenile hallux valgus. Assessment of overall foot alignment, including the midfoot and hindfoot, is important. This should include measurement of the CP and the talus–first metatarsal angle on the lateral radiograph (Fig. 29-83). Forefoot assessment includes measurement of the hallux valgus angle (Fig. 29-100), the 1 to 2 intermetatarsal angle (Fig. 29-100), distal metatarsal articular angle (DMAA) (Fig. 29-101), MTP joint congruity (Fig. 29-102), relative lengths of the metatarsals, MTC orientation, proximal phalanx articular angle, and lesser metatarsal orientation (378). The importance of determining the DMAA has been stressed in the literature. Unfortunately, identification of the location of the articular cartilage on the metatarsal head is difficult on radiographs of the feet of children and many adolescents. A radiographic study on cadavers by Vittetoe

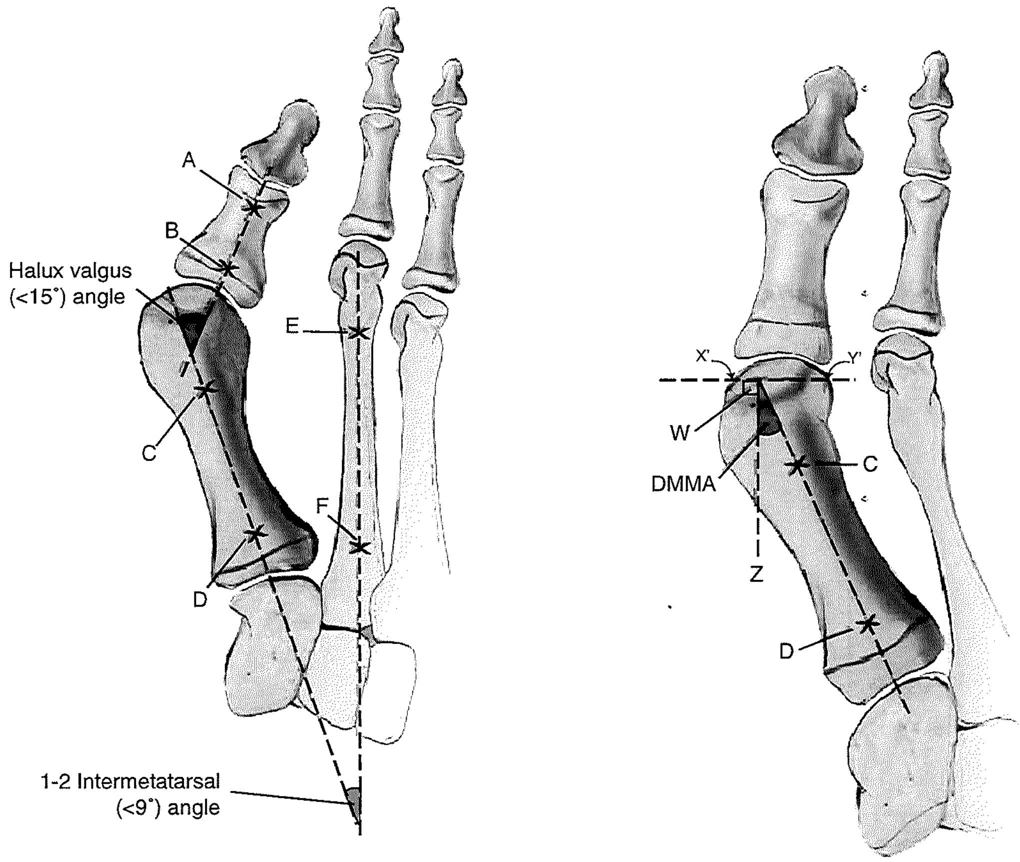


FIGURE 29-100. Hallux valgus and first–second intermetatarsal angle: **(A, B)** axis of proximal phalanx; **(C, D)** axis of first metatarsal; **(E, F)** axis of second metatarsal. (From Coughlin M. Juvenile hallux valgus. In: Coughlin M, Mann R, eds. *Surgery of the foot and ankle*, 7th ed. St. Louis, MO: Mosby, 1999:270, with permission.)

et al. (382) showed that although intraobserver reliability for DMAA measurement was high, interobserver reliability for the measurement technique was poor.

Pathoanatomy. The causes of hallux valgus deformity are both extrinsic and intrinsic. Studies in developing countries have shown an increased risk of hallux valgus in children who wear shoes compared with those who do not (191, 383). However, the majority of evidence supports the conclusion that juvenile hallux valgus is caused by structural abnormalities of the bones and joints (379, 380, 384), but is negatively influenced by constricting footwear.

Flatfoot deformity and ligamentous laxity have been reported to be risk factors for the development of hallux valgus, as well as its recurrence following surgical correction, by a number of authors (385–387). However, others feel that flatfoot deformity does not predispose to the occurrence of juvenile hallux valgus deformity (379). Coughlin (379), Kilmartin and Wallace (388) and Canale et al. (389) found no correlation between pes planus and the rate of success with surgical correction. These data should not, however, be used to completely discount the effect of severe valgus deformity of the hindfoot and significant ligamentous laxity on the development and progression of the juvenile hallux valgus deformity.

The association of juvenile hallux valgus with the length of the first metatarsal is also controversial. An excessively long (379, 385, 390), as well as an excessively short (391), first metatarsal has been implicated in the incidence, severity, and recurrence of juvenile hallux valgus deformity. Coughlin (379) has recently provided data showing that the relative lengths of the first and second metatarsals in children with juvenile hallux valgus are statistically similar to the normal population.

There is an association between metatarsus primus varus, which is defined as an intermetatarsal angle between the first and second rays of >8 degrees (Fig. 29-100), and juvenile hallux valgus. The cause of the varus deformity of the first metatarsal is related to the orientation and flexibility of the first MTC joint (378, 380, 390, 392, 393). Medial deviation of the MTC joint creates metatarsus primus varus. The distal articular surface of the first cuneiform is normally transverse; however, an oblique orientation of this joint may predispose to a varus deformity of the first metatarsal (387). The literature is inconsistent in identifying an association between adductus of all of the metatarsals and juvenile hallux valgus (379).

The second angle that is important in quantifying the hallux valgus deformity is the hallux valgus angle defined by Hardy and Clapham (380). This angle is measured by the

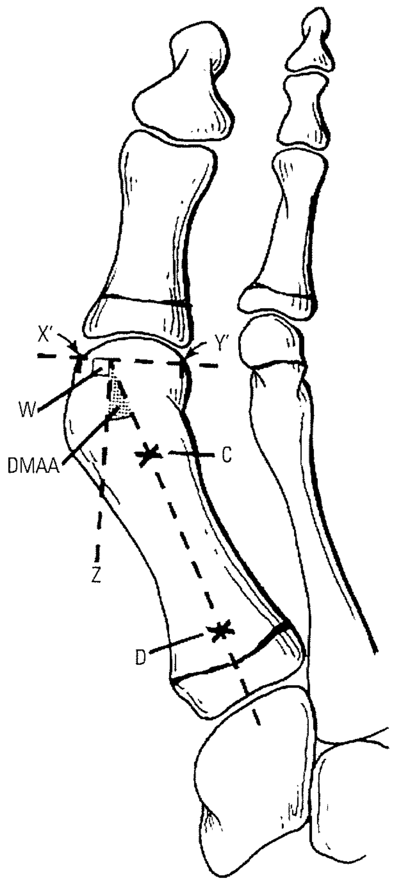


FIGURE 29-101. The distal metatarsal articular angle (DMAA) quantifies the angular relation between the articular surface and the shaft of the metatarsal. The DMAA is the angle between the metatarsal shaft (*C–D*) and the line (*W–Z*) that is perpendicular to the articular surface (*X'–Y'*). (From Coughlin M. Juvenile hallux valgus. In: Coughlin M, Mann R, eds. *Surgery of the foot and ankle*, 7th ed. St. Louis, MO: Mosby, 1999:270, with permission.)

intersections of the longitudinal axis of the proximal phalanx and the first metatarsal. The normal hallux valgus angle is <15 degrees (394).

The shape of the first metatarsal may be an etiologic factor in the development of juvenile hallux valgus. The articular cartilage on the distal end of the first metatarsal normally aligns almost perpendicular with the long axis of the bone. Lateral deviation, or orientation, of the articular cartilage may exist, thereby effectively creating a very distal valgus deformity of the metatarsal. The DMAA quantifies this alignment (378, 379, 395, 396) (Fig. 29-101). A higher angle indicates greater valgus deformity of the metatarsal. Coughlin (379) reported that 48% of juveniles with hallux valgus had an increased DMAA with a congruent first metatarsophalangeal joint, significantly greater than the percentage of adults with this finding (395). The remainder of his juvenile patients had lateral joint subluxation with a near normal DMAA, the usual finding in adults (Fig. 29-102). He noted that the DMAA was significantly higher in patients with a positive family history, in

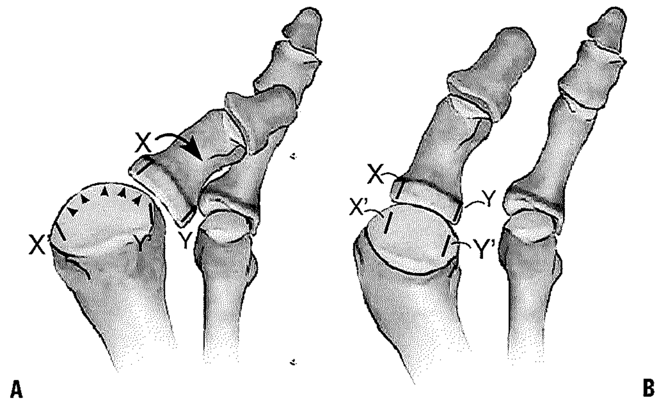


FIGURE 29-102. Incongrous **(A)** and congruous **(B)** first metatarsophalangeal joint. X' and Y': extent of metatarsal articular surface; X and Y: extent of proximal phalanx articular surface. (From Coughlin M. Juvenile hallux valgus. In: Coughlin M, Mann R, eds. *Surgery of the foot and ankle*, 7th ed. St. Louis, MO: Mosby, 1999:270, with permission.)

those with early onset of hallux valgus (younger than 10 years of age), and in those with a long first metatarsal (379).

As the deformity of hallux valgus progresses, the flexor tendons and sesamoids sublux laterally; the adductor of the great toe inserting on the proximal phalanx increases the deformity, and finally, once the hallux valgus deformity is present, the abductor hallucis with its medial insertion on the proximal phalanx has no ability to adduct the great toe.

Natural History. The natural history of juvenile hallux valgus is not known. Piggott (395) believed that juvenile hallux valgus deformities with congruous joints were stable and less likely to progress than those with subluxation.. In this situation, the degree of hallux valgus is equal to the DMAA. A hallux valgus deformity with a congruent first MTP joint may, nevertheless, require surgical correction if the severity of deformity creates disability. A congruous first MTP joint is found in 9% of adults (395) and 47% of juvenile patients (379) with hallux valgus. Joint incongruity leads to progressive deformity and degenerative arthrosis at an unpredictable rate.

Treatment. The reason for seeking consultation must be ascertained. The natural history of juvenile hallux valgus is not known, though it is considered to be favorable, and the complication rate from surgery is high. Cosmetic surgery is, therefore, contraindicated. Such treatment could be far worse than the condition itself.

Treatment can be divided into those methods that relieve pain and those that relieve pain through deformity correction. Nonoperative and operative modalities may be successful in relieving pain. Deformity correction can obviously be achieved through operative means. Contrary to expectations, Kilmartin et al. (397) found that hallux valgus deformity increased more in patients who used rigid, thermoplastic, biomechanical foot orthoses than in those who did not. There is only one report indicating a possible nonoperative means for correcting hallux valgus deformity. Groiso (398) demonstrated improvement in the hallux valgus and 1 to 2 intermetatarsal angles in approximately 50% of feet that were treated with a moldable thermoplastic night splint in combination with daytime active and passive stretching exercises. Others have not reproduced this experience. Conservative measures will relieve symptoms without correcting deformity in most patients with juvenile hallux valgus. The object is to make the shoe look like the foot rather than vice versa. Shoes with an adequate toe box, a soft upper, and a low heel are most likely to provide pain relief. An arch support can be used to decrease the tendency for valgus eversion of the hindfoot. A running shoe is the most acceptable shoe for this age group that meets these requirements, though it is not appropriate for all social situations. Bunion stretchers are available where shoes are sold and repaired. When contemplating purchase of a pair of shoes, the right shoe should be turned upside down and pressed against the sole of the left foot (and vice versa). One should be able to see the sole of the shoe extending beyond both sides of the forefoot when viewed from above. If not, the shoe is too narrow. The weight-bearing foot can also be traced on a piece of paper and compared with the outline of the shoe.

Surgery is indicated when prolonged attempts at conservative management have failed to relieve the pain over the first metatarsal head. The age of the patient at the time of surgery is an additional consideration. Poor results with high complication rates have been consistently reported in 30% to 60% of cases of surgery for juvenile hallux valgus (385, 399–402). These results have been attributed to several factors including recurrence of deformity due to further epiphyseal growth (403), growth arrest secondary to injury to the growth plates at the proximal ends of the first metatarsal and proximal phalanx, and the application of a single technique that did not take into consideration the unique pathoanatomy of each foot (401). Coughlin (379) and others (391, 402) have performed successful surgical reconstruction with few complications in adolescents with juvenile hallux valgus with open growth plates. These authors have stressed, however, that there is rarely urgency in performing surgery and that it should be delayed until the end of growth if possible. Perhaps the most challenging management decision to be made is in the adolescent athlete who is performing at a high level, albeit with pain. Surgery, with its known risks and complications, could have a deleterious effect on future performance.

No single surgical procedure is suitable for all patients with a juvenile hallux valgus deformity because of the many individual pathoanatomic deformities that might or might not exist in a particular foot. All elements and components of the deformity must be analyzed clinically and radiographically. The goal is to correct the deformities to relieve pain and functional disability while maintaining a flexible first MTP joint and a normal weight-bearing pattern of ambulation. The principle is to correct all components of the deformity at the site(s) of deformity without creating compensating deformities. Knowledge of the DMAA and the congruency of the first MTP joint are central to appropriate surgical planning, for it is this information that determines whether the correction will be intra-articular or extra-articular. The surgeon must have the knowledge and skills to perform the many and varied techniques that may be needed to address the pathoanatomy at all sites.

Soft-tissue realignment of the MTP joint by means of lateral release and medial capsule advancement should not be performed in isolation because recurrent deformity will almost uniformly result (379, 385), though hallux varus has also been reported following this procedure (402, 404).

Surgical treatment for a juvenile hallux valgus deformity with a normal DMAA and a subluxated MTP joint starts with distal soft-tissue realignment along with excision of the medial eminence on the first metatarsal head (the Silver procedure) (405) (Figs. 29-103 to 29-105, 29-107).

In adolescents, hallux valgus is more often accompanied by metatarsus primus varus than in adults (379). It is generally accepted that metatarsus primus varus is almost always present in adolescents with hallux valgus, and its correction should be a part of any surgical plan to correct hallux valgus. Correction usually entails the removal of the exostosis, with care taken not to remove the joint itself; correction of the hallux valgus; and realignment of the first metatarsal.

Although the removal of the exostosis and the soft-tissue repair to correct the valgus of the great toe are standard, many methods are described for correction of the DMAA and the metatarsus primus varus. Most surgeons seem to have their favorite method, but other considerations, such as whether the metatarsal is short or long, should also play a role in the choice of the procedure.

A medial cuneiform or base of first metatarsal osteotomy should be combined with the distal soft-tissue realignment if the intermetatarsal angle is >8 degrees, that is, metatarsus primus varus (378, 379, 400) (Figs. 29-106, 29-108, 29-111). The advantages of the proximal osteotomies are that, in contrast to distal osteotomies, there is no possibility of creating avascular necrosis of the metatarsal head, and they either maintain length of the ray or desirably lengthen it. The risk is damage to the proximal first metatarsal growth plate, which must be protected. This can of course be avoided by delaying surgery until skeletal maturity.

An opening-wedge osteotomy of the medial cuneiform is a particularly good choice if the MTC joint is medially deviated, the metatarsal growth plate is open, and the first metatarsal is shorter than the second (Fig. 29-108).

The treatment of a juvenile hallux valgus deformity with an increased DMAA and a congruous or incongruous MTP joint involves osteotomies to correct the bone deformities and realign both the joint and the first ray. A distal metatarsal osteotomy is used to correct the DMAA, while a proximal metatarsal osteotomy or medial cuneiform osteotomy is used to correct the metatarsus primus varus (378, 406) (Fig. 29-108). In some cases, an additional osteotomy at the base of the proximal phalanx, the Akin procedure (407), is indicated. The distal metatarsal osteotomy can be a simple closing wedge or a more complex biplanar chevron (378) or

Text continued on page 1491

Bunionectomy and Osteotomes for Juvenile Hallux Valgus (Figs. 29-103 to 29-112)

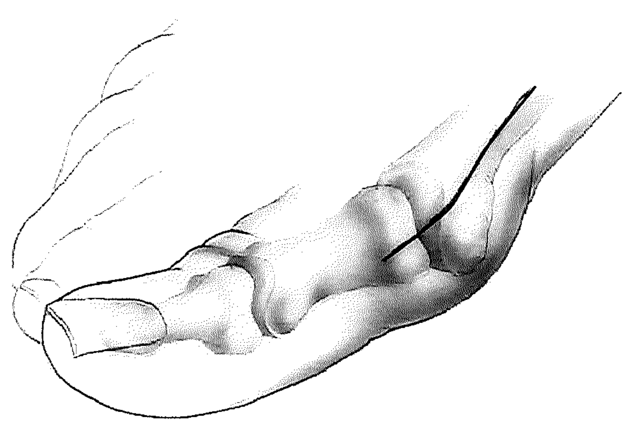


FIGURE 29-103. **Bunionectomy and Osteotomes for Juvenile Hallux Valgus.** The incision is placed on the dorsomedial side of the first metatarsal. It should extend from the flare of the proximal phalanx proximally three-fourths of the way up the metatarsal. The incision is deepened directly down to the periosteum and capsule, with care taken not to harm the dorsal or plantar branches of the nerves.

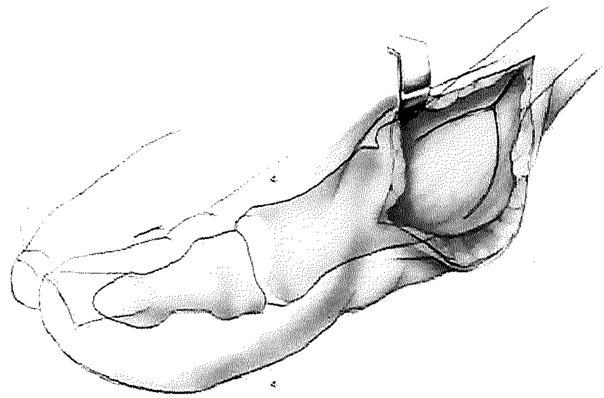


FIGURE 29-104. A V incision with the base on the medial side of the proximal phalanx is made in the capsule of the metatarsophalangeal joint. The two limbs of the V should be far enough apart and positioned such that when the capsule is repaired it will not pull the toe into dorsiflexion or plantar flexion, which can occur if the base of the V on the phalanx is too far dorsal or plantar. This flap is elevated from proximal to distal by blunt and sharp dissection. In addition, the periosteum is elevated from the distal half of the metatarsal. Care should be taken to leave the lateral attachments of capsule and periosteum because this provides the sole blood supply of what will become the distal fragment.

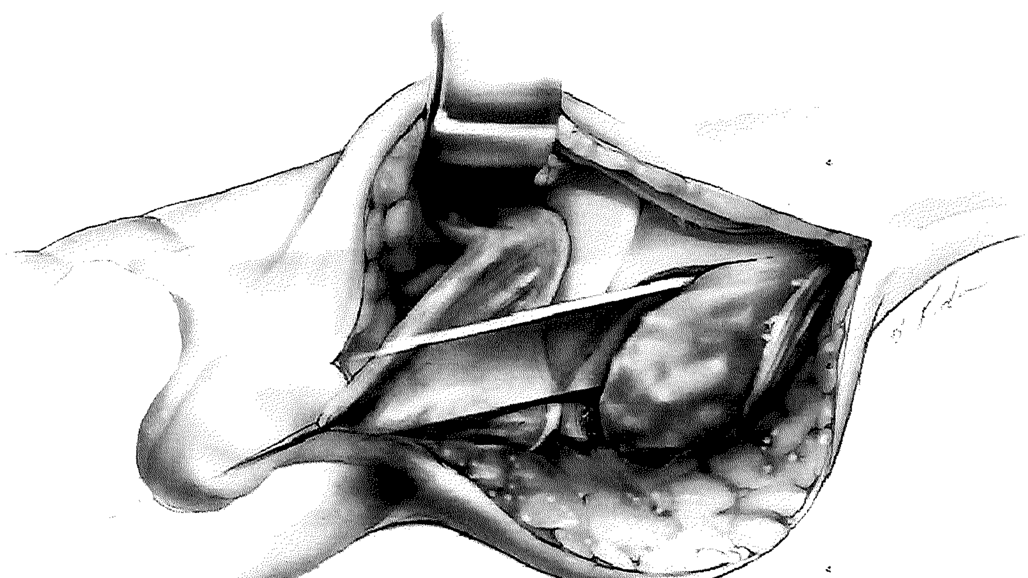
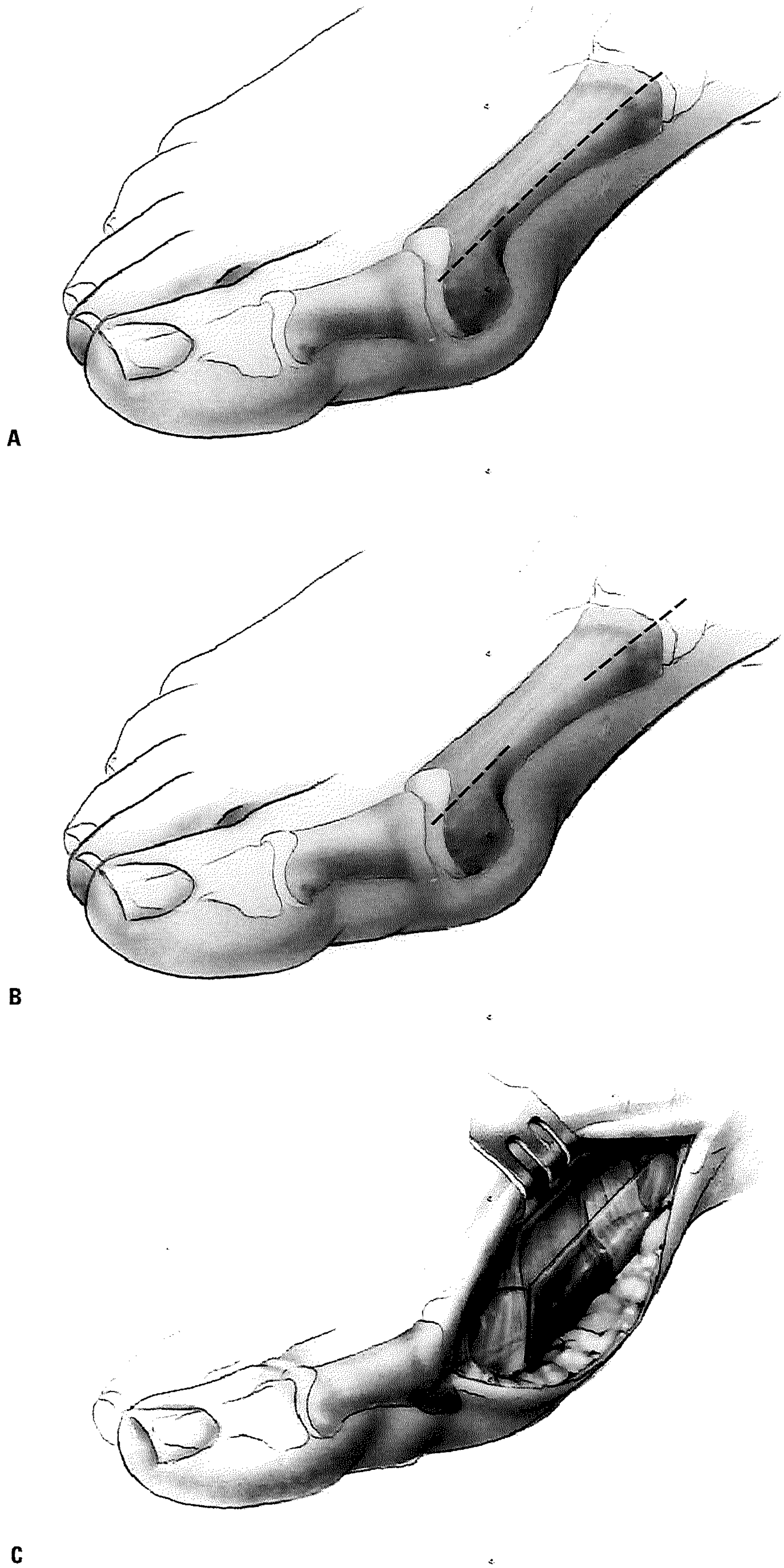


FIGURE 29-105. At the completion of the elevation of the capsular flap, the joint will be open and the exostosis will be exposed. There is usually a clear demarcation between the exostosis and the actual metatarsal joint surface. This demarcation is a groove, often referred to as Clark groove. It is important to resist the temptation to remove too much bone with the exostosis because this may leave the medial side of the metatarsal head deficient. A 1/2-inch osteotome is placed at the medial edge of Clark groove and directed proximally in line with the metatarsal shaft. In adolescents, this exostosis is not usually large, and a good portion of it consists of cartilage and fibrous tissue. This is a potential problem if a proximal opening-wedge osteotomy is planned using the exostosis as graft. A distal metatarsal osteotomy to correct a high DMAA is also performed through this exposure.

FIGURE 29-106. The proximal metatarsal osteotomy can be performed through one long incision that is simply a proximal extension to the incision used for the Silver procedure **(A)** or through two separate incisions with the removal of the exostosis and repair of the hallux valgus performed through a distal incision and the proximal osteotomy done through a separate, more dorsally placed proximal incision **(B)**. The incisions in the periosteum through the single-incision approach are illustrated **(C)**.



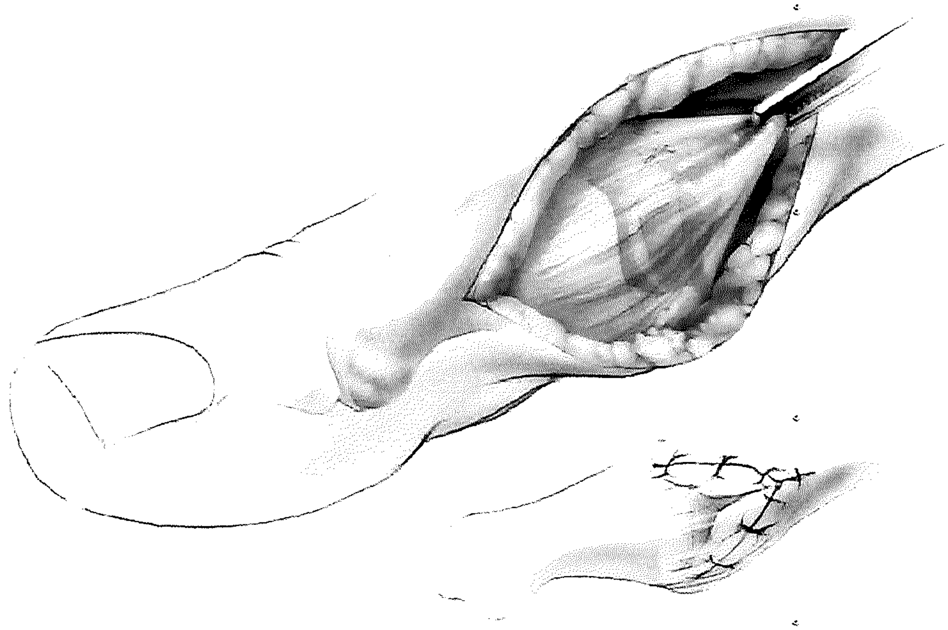


FIGURE 29-107. The metatarsophalangeal joint capsular flap is pulled proximally, and the correction of the hallux valgus is observed. This flap is, in essence, a Y-to-V advancement. It is sutured to the more proximal periosteum on the medial shaft of the metatarsal. It should not require excessive tension on this flap to correct the hallux valgus. If it does, a short incision can be made in the first dorsal web space for release of the adductor hallucis and, if necessary, the lateral joint capsule. There is risk for avascular necrosis of the metatarsal head if a distal metatarsal osteotomy is made concurrently. A short-leg cast is applied. It should be molded around the forefoot and hold a soft bolster between the first and second toes to take any tension off the capsular repair. This cast is worn for 6 weeks, at which time the osteotomy is usually healed sufficiently to permit full, unprotected weight bearing. While in the cast, the patient may be permitted crutch-protected weight bearing.

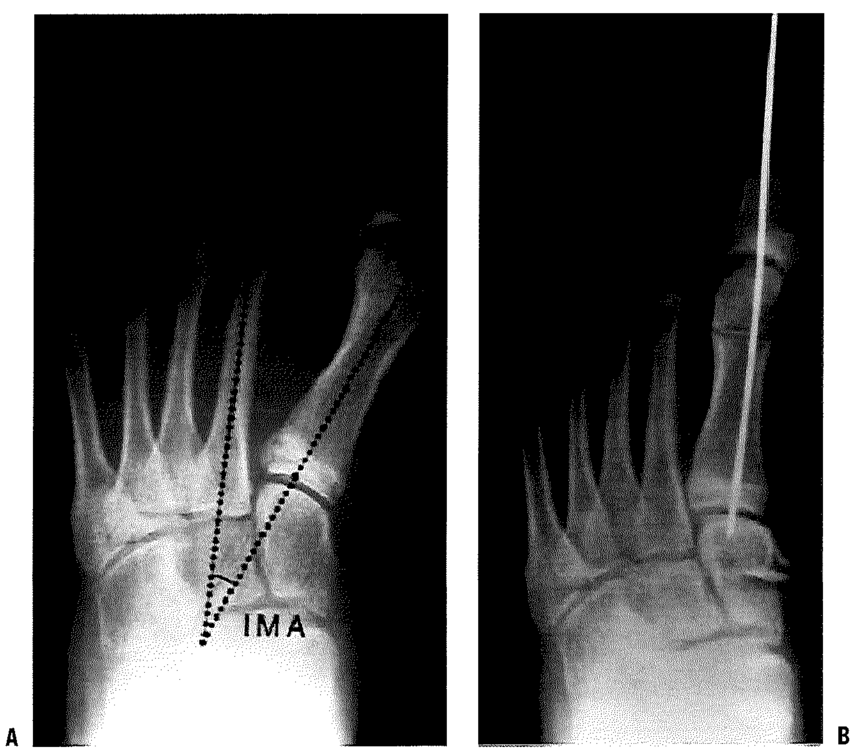


FIGURE 29-108. **A:** Preoperative radiograph of juvenile hallux valgus. *IMA*, intermetatarsal angle. (From Mosca VS. Ankle and foot: pediatric aspects. In: Beaty J, ed. *Orthopaedic Knowledge Update 6*. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1999:583, with permission.) **B:** Radiograph after medial cuneiform opening-wedge osteotomy and distal first metatarsal closing-wedge osteotomy. (From the private collection of Vincent S. Mosca, MD.)

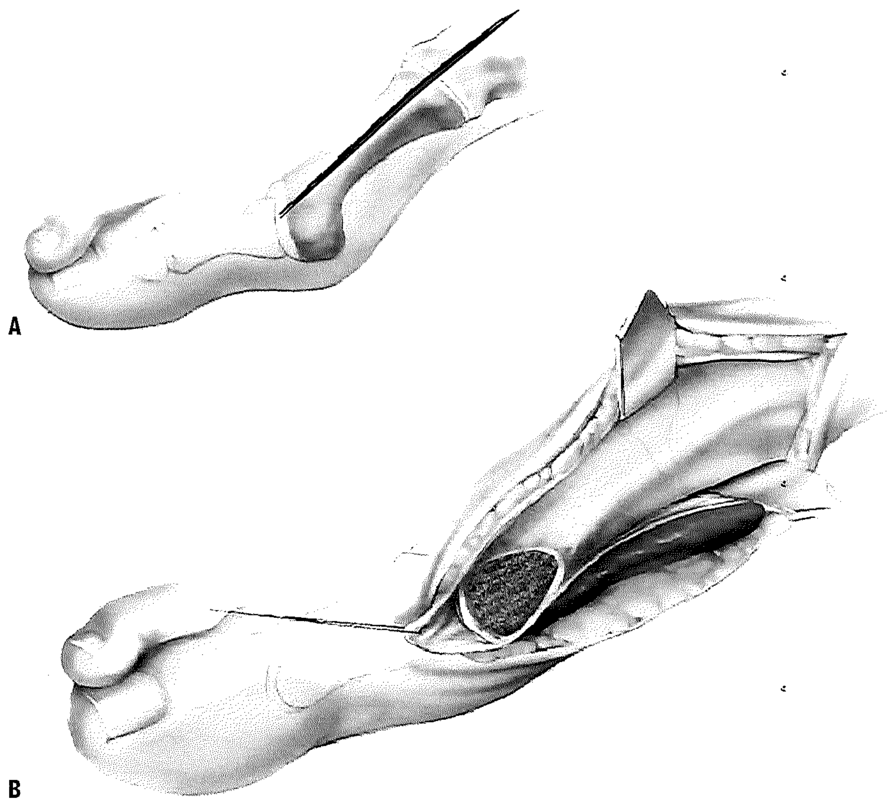
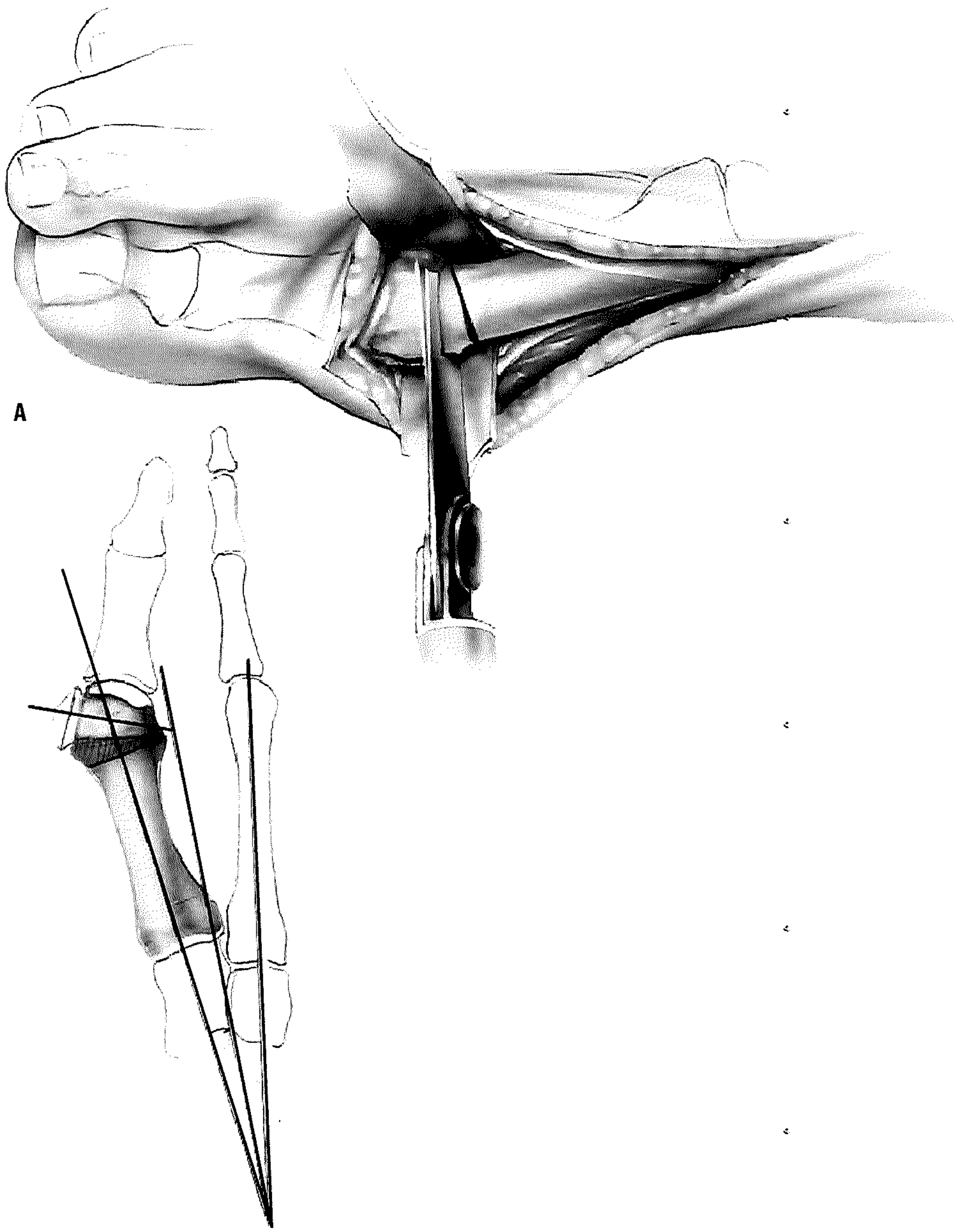


FIGURE 29-109. The first metatarsal is exposed **(A)**. The metatarsal is stripped subperiosteally, with care taken to preserve the most lateral attachments to bone. The capsule is opened with a distally based Y flap. The medial prominence of the metatarsal or bunion is excised with an osteotome, as described for the Silver bunionectomy **(B)** (see Fig. 29-105). Small metatarsal retractors are placed to aid the proximal exposure.



A

B

FIGURE 29-110. A small microsagittal saw is used to remove a medially based wedge of bone from the distal aspect of the metatarsal where the head and neck join **(A)**. The size of this wedge depends on the DMAA. The proximal cut is perpendicular to the metatarsal shaft, and the distal cut is nearly parallel to the joint surface **(B)**. Steinmann pins can be inserted proximally and distally to act as alignment guides for the osteotomies. The wedge should be removed, preserving the periosteum and a small connection of cortical bone on the lateral side to lend stability. If rotational correction of the toe is necessary, the bone is divided completely to permit rotation.

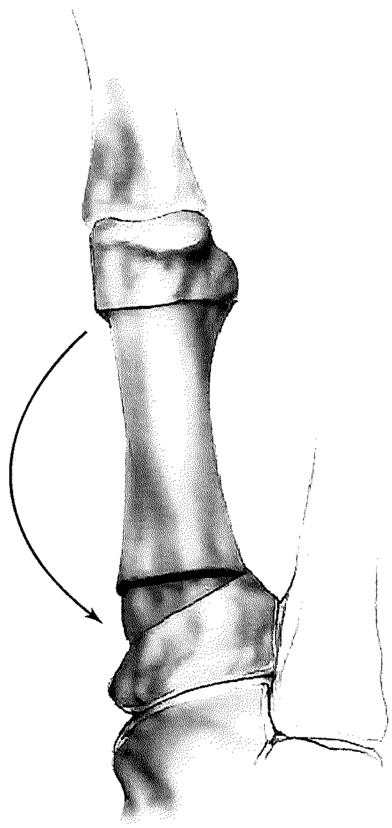


FIGURE 29-111. The microsagittal saw is used to create an osteotomy in the proximal metaphysis of the metatarsal. The wedge of bone that was removed distally is inserted into this osteotomy.

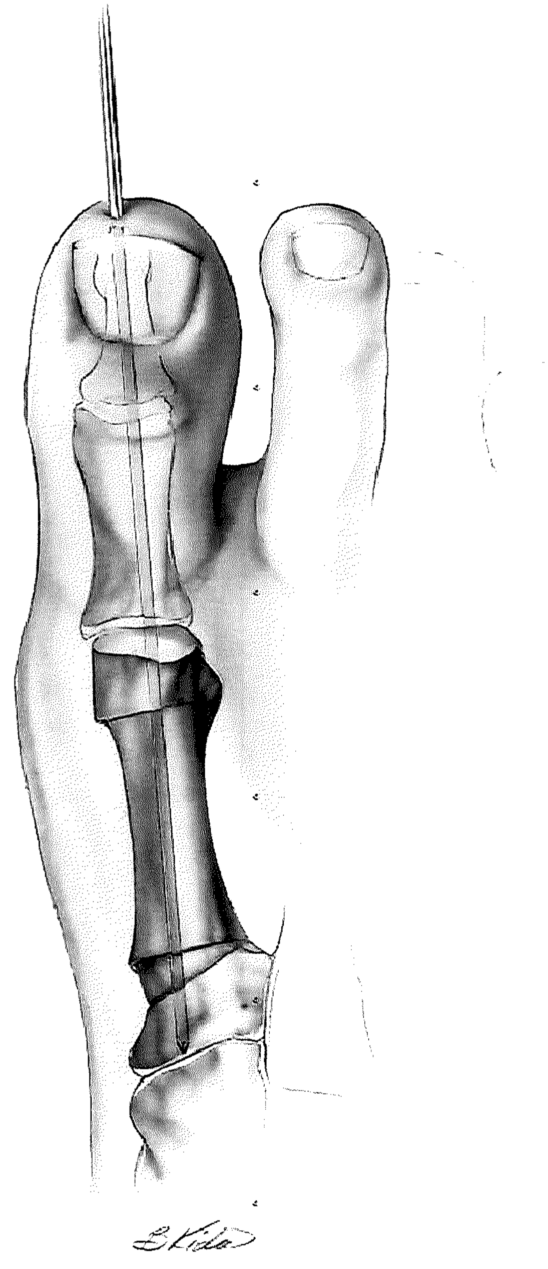


FIGURE 29-112. With the osteotomies held closed, a smooth Steinmann pin is passed retrograde from the tip of the distal phalanx to the medial cuneiform, thus fixing both of the osteotomies. Alternatively, the starting point for the pin can be on the plantar aspect of the metaphysis of the proximal phalanx with the MTP joint slightly dorsiflexed, or crossed Steinmann pins be used at the osteotomies.

Mitchell osteotomy (378, 389, 399, 401, 403, 408–411, 532). Standard uniplanar chevron and Mitchell osteotomies do not correct the DMAA. There is a risk of interrupting the blood supply to the metatarsal head, with resultant avascular necrosis, when a lateral soft-tissue release is combined with a distal metatarsal osteotomy (412).

Results of the Mitchell osteotomy vary among series. Ball and Sullivan (399) reported a recurrent valgus deformity in 11 of 17 patients or 61%. Canale et al. (389) reported 31% of patients in their series with a fair or poor outcome; the less than satisfactory results related primarily to poor position of the displaced distal fragment, resulting in recurrent deformity, or plantar angulation resulting in transfer lesions to the second metatarsal head. Such problems can be decreased with appropriate use of internal fixation.

A number of very positive series, using the Mitchell osteotomy, have been reported, with positive outcomes ranging from 81% to 95% (403, 408, 532). Positive outcome from this osteotomy related to preserving the length of the first metatarsal and never dorsiflexing the metatarsal head while stabilizing the osteotomy with a screw or K-wire.

The chevron (411) osteotomy is a transverse osteotomy through the distal portion of the metatarsal with a chevron shape. The apex of the chevron osteotomy is at the midportion of the metatarsal head, and the angular limbs traverse the dorsal and plantar cortices of the metatarsal, proximal to the capsular insertion (413). Good results from this osteotomy have been reported by Zimmer et al. (411) in 85% of adolescents despite a recurrence rate of 20%. This intrinsically stable osteotomy avoids the problem of metatarsal shortening. The DMAA can be corrected by creating medially based closing-wedge chevron cuts, that is, a biplanar osteotomy.

Peterson and Newman (406) described a two-level first metatarsal osteotomy for adolescent bunions that consists of a distal medially based closing-wedge osteotomy and a proximal medially based opening-wedge osteotomy. The DMAA and the primus varus deformity are corrected, and the length of the metatarsal is preserved (Figs. 29-109 to 29-112).

In the presence of cerebral palsy, bunion deformities are quite common, both dorsal bunions and hallux valgus. Because of exceedingly high recurrence rates, fusion of the first metatarsal–phalangeal joint is the procedure of choice (414–416).

Postoperative complications are frequent after correction of juvenile hallux valgus. Recurrence, overcorrection to hallux varus, avascular necrosis of the metatarsal head, metatarsalgia, joint stiffness, and growth arrest are among the most serious.

The most reasonable approach to the adolescent with symptomatic hallux valgus is to exhaust all modalities of conservative management to treat the pain before considering surgery. Then, carefully assess the deformity both clinically and radiographically, and choose the combination of procedures that addresses each of the segmental deformities in that individual. Pay particular attention to the DMAA and the congruity of the MTP joint. Have a plan for the potential complications.

Kohler Disease

Definition. In 1908, Kohler described a self-limited painful condition of the tarsal navicular in young children that was characterized on radiographs by flattening, sclerosis, and irregular rarefaction (417). Diagnosis is dependent on the clinical and radiographic findings.

Epidemiology. This condition is uncommon. It occurs four times more frequently in boys than in girls (418, 419) and may be bilateral (419, 420).

Etiology. The etiology of Kohler disease remains unknown. It is considered to be an osteochondrosis, an idiopathic condition characterized by disorderliness of endochondral ossification, including both osteogenesis and chondrogenesis, that arises upon a previously normal growth mechanism (369). Tsirikos et al. (421) have reported bilateral Kohler disease in identical twins, suggesting a genetic predilection for this relatively rare condition.

Clinical Features. The typical child with Kohler disease is a boy under age 6 years who walks with an antalgic gait, tending to bear weight on the lateral border of the foot. There may be tenderness, swelling, redness, and warmth, signs that might suggest infection or inflammation. Range of motion of the joints is normal.

Radiographic Features. Standing anteroposterior and lateral radiographs of the foot reveal the characteristic findings of sclerosis, fragmentation, and distal-to-proximal flattening of the navicular bone (Fig. 29-113). The tarsal navicular is the last bone of the foot to ossify. The average age of appearance of its ossific nucleus is 18 to 24 months in girls and 30 to 36 months in boys (422). Irregularity in ossification of this bone is common and may occur as multiple ossification centers that subsequently coalesce (422). This should not be mistaken for Kohler disease if the clinical picture does not correlate. Abnormalities of ossification are more frequent in boys and are more common in naviculars that ossify late. Radiographs of both feet should be obtained for comparison if the changes are subtle.

Other Imaging Studies. No other imaging studies are indicated when the clinical presentation and radiographic findings are typical, although the use of a bone scan has been reported. An MRI scan is too expensive to use as a test to identify this completely benign and self-limiting condition. The clinical findings may suggest infection, which is extremely unlikely in this location without a penetrating injury. If, however, there is clinical concern for infection, a complete blood count, sedimentation rate, and C-reactive protein should be obtained, rather than an MRI.

Pathoanatomy. Kohler disease has been classified by Siffert (369) as a secondary articular osteochondrosis because involvement of the articular and epiphyseal cartilage, if any, is a consequence of avascular necrosis of the subjacent bone.

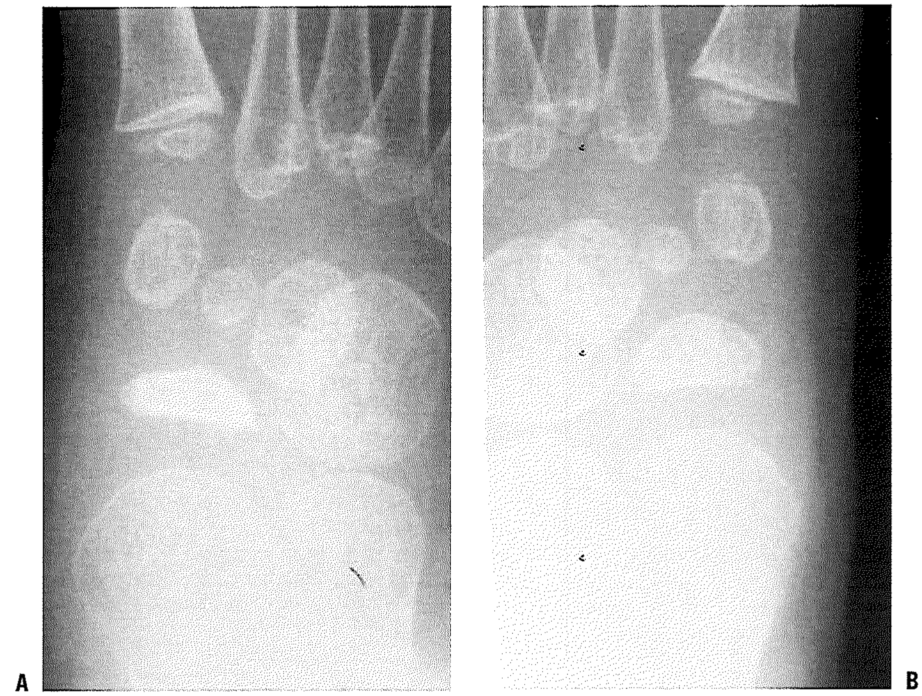


FIGURE 29-113. **A:** Kohler disease manifested as sclerotic and flattened right tarsal navicular. **B:** Healthy left navicular. (From the private collection of Vincent S. Mosca, MD.)

The navicular is located at the apex of the arch of the foot and is subjected to compressive forces during weight bearing that could disrupt its blood supply. There is evidence that the disease develops in navicular bones that are constitutionally and biologically inferior and, therefore, vulnerable to damage by mechanical forces that normal bone is able to withstand (370). Karp (422) found that ossification of the navicular occurs earlier in girls than in boys. Half of the girls studied had a navicular that was ossified by the age of 2 years, and one-third of the boys were more than 3½ years of age by the time ossification occurred. Karp's feeling was that the delay in ossification predisposed boys to mechanical injury at the time of early ossification of the cartilaginous navicular.

In addition to the effects of mechanical stress at the time of ossification, avascular necrosis appears to play a role in the development of Kohler disease. The blood supply to the navicular bone is significant, with a network of perichondrial vessels. However, at the time of early ossification, arteries penetrate the cartilaginous navicular without their mature anastomotic network, predisposing them to vascular injury. Vascular theories are supported by biopsy studies showing areas of necrosis in the navicular (417).

Waugh (423) investigated the vascular anatomy of the navicular and found two patterns of blood supply. The most common pattern was a diffuse network supplied by five or six arteries. A less common pattern was a single dorsal or plantar artery. He felt that compressive forces could occlude the vessels and produce avascular necrosis of the bone. Histologic examination of the affected bone has disclosed areas of necrosis, resorption of dead bone, formation of new bone, and interference with normal ossification.

Natural History. This is a self-limiting condition with onset in early childhood. The navicular reconstitutes itself in 4 months to 4 years after onset and is normal at skeletal maturity (418–420). There is no residual deformity or disability in adults who were affected as children. Apparent avascular changes in the navicular of an adolescent or adult represent a different condition with an unpredictable outcome.

Treatment. Treatment is symptomatic. An over-the-counter longitudinal arch support may relieve mild symptoms. More intense pain can be relieved with a below-knee cast. Borges et al. (420), Ippolito et al. (418), and Williams and Cowell (419) found that treatment in a below-knee cast for a minimum of 8 weeks reduced the duration of symptoms to approximately 3 months. The duration of symptoms was 7 to 15 months for those casted <8 weeks or those treated by other regimens. A walking cast was as effective as a non–walking cast. And except for the duration of symptoms, treatment had no effect on the final outcome of the disease (418–420). There is no role for biopsy or surgery.

Macrodactyly

Definition. Macrodactyly is the term used to describe enlargement of the digits of the feet or hands. The term means large digit, but the metatarsal or metacarpal may also be enlarged.

Epidemiology. Macrodactyly may occur as an isolated condition or as part of a syndrome, such as neurofibromatosis, Klippel-Trenauny-Weber, lymphangioma, and Proteus (424). In 1988, Kalen et al. (425) reported the largest series

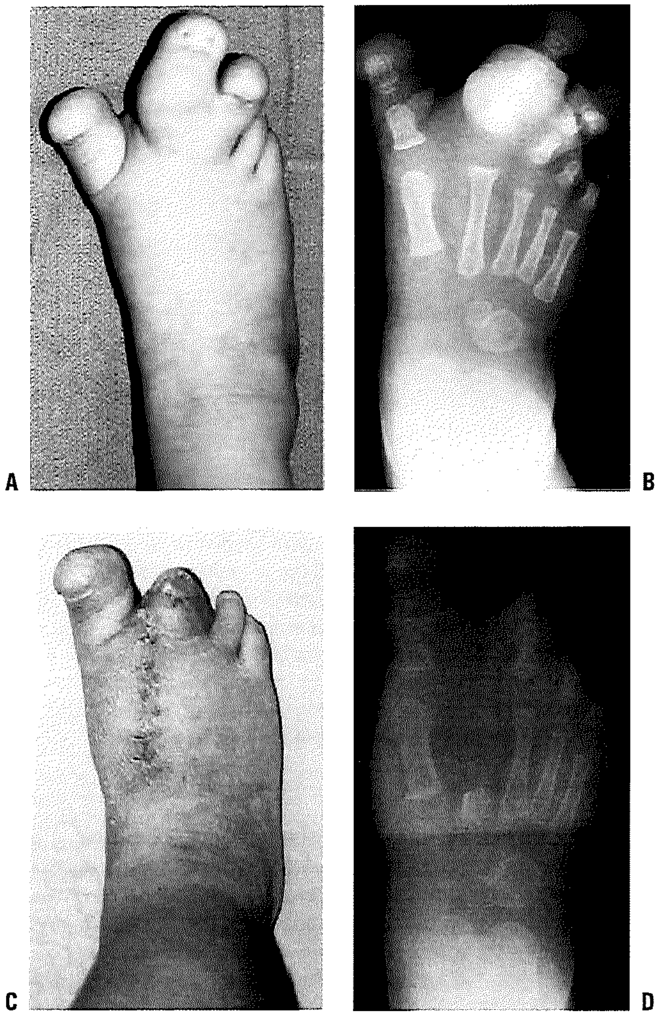


FIGURE 29-114. **A:** Macrodactyly most commonly involves the second ray; in this case, the hallux and third toe are involved to some degree. **B:** Radiographic appearance demonstrates enlargement of bone as well as soft tissue. **C:** Clinical appearance after second ray resection and third toe interphalangeal joint disarticulation. **D:** Radiographic appearance 1 year later. (From the private collection of Vincent S. Mosca, MD.)

and reviewed the English language literature to date on the isolated type that is the focus of this discussion. The incidence is extremely low. There is a slight male predominance. The second digit is most commonly involved (Fig. 29-114A,B), followed by the third. Multiple digit involvement is seen in approximately 50% of cases.

Etiology. The etiology is unknown. There is no evidence that inheritance plays a role (425). Turra et al. (426) and others hypothesized a nerve trunk disease as the cause for macrodactyly, but this theory has not been confirmed (425).

Clinical Features. The enlarged digit or digits are apparent at birth. Features of Klippel-Trenauny-Weber syndrome and neurofibromatosis should be sought, although the latter are rarely present at birth. Surprisingly, in Klippel-Trenaunay-Webber, a syndrome of venous lymphatic malformation, ipsilateral macrodactyly is frequently present with a vascular component, and contralateral macrodactyly is present as a fibrofatty disorder. In Proteus syndrome, a cerebriform skin pattern on the plantar surface of the foot as well as asymmetries of growth and nevi are present. The relative size of the entire extremity should also be assessed to rule out hemihypertrophy as the underlying disorder. Fifty percent of patients with foot involvement in macrodactyly have a dorsally angled digit with weak toe flexors (427).

Radiographic Features. Standing anteroposterior and lateral radiographs of the foot are useful for monitoring the relative growth rates of the digits and for surgical planning. MRI (428) is of value in macrodactyly in order to differentiate cases of vascular malformation in association with macrodactyly from true fibrofatty disorders or lymphedema.

Pathoanatomy. There is enlargement in length and circumference of the involved bones. An overabundance of fibrofatty tissue makes up the bulk of the soft-tissue enlargement.

Natural History. Macrodactyly may be static, in which the digit is enlarged at birth and growth is proportional to the normal digits. Alternatively, it may be progressive, in which case the involved digit grows disproportionately faster than the normal ones (429). The latter type is more common in the foot (425). Although the appearance is often grotesque, the main disability is with shoe fitting.

Treatment. Treatment must be individualized. The goal is not cosmesis, per se, but the ability to wear similar size shoes on both feet comfortably. Surgical options include soft-tissue debulking, ostectomy, epiphysiodesis, complete or partial toe amputation, and ray resection, either as isolated procedures or in combination (425, 426, 430–433). Ray resection has had the most successful reported results for decreasing the rate and risk of recurrence and for achieving the goal of improved shoe fitting (425, 426, 433, 434) (Fig. 29-114C,D). Most patients, even those who undergo ray resection, will need more than one operative procedure because all of the pathologic soft tissue cannot be removed. A more aggressive approach is, therefore, desirable.

A combination of soft-tissue debulking with epiphysiodesis of the proximal phalanx or metatarsal or both is recommended for mild, static deformities. Repeated debulking procedures may be necessary. Try to avoid multiple minimal resection procedures. It is unlikely that too much tissue can be removed! Large residual circumference of the foot, rather than length, is often the greater problem for shoe fitting.

Metatarsus Adductus

Definition. Medial deviation of the forefoot on the hindfoot with neutral or slight valgus alignment of the hindfoot is the most common congenital foot deformity (Fig. 29-115).

FIGURE 29-115. Metatarsus adductus in an infant. Note convex lateral border and neutral hindfoot alignment. (From the private collection of Vincent S. Mosca, MD.)

The terminology used to describe this deformity has been inconsistent and confusing and has included metatarsus adductus, metatarsus varus, metatarsus adductovarus, and skewfoot.

Epidemiology. Ruth Wynn-Davies reported the incidence of metatarsus varus at 1 in 1000 live births and 1 in 20 in siblings of patients with metatarsus varus (94). Hunziker et al. (435) documented an overall frequency of 12% in full-term single births and even higher for twin birth. The actual incidence is unknown because of the lack of a strict definition of the condition. An increased reported incidence during the past century is probably due to an increased awareness of the condition by primary care physicians (5, 436–438). Although earlier studies (439, 440) indicated an association of metatarsus adductus with hip dysplasia, more recent studies (441, 442) have shown no significant association between the two conditions.

Etiology. The cause of metatarsus adductus is unknown. The theory that it is the result of *in utero* positioning is supported by the high rate of spontaneous resolution (6) and the strong association with twin pregnancies (435, 443). Variations in anatomy have also been proposed as possible etiologies.

Clinical Features. Adduction of the metatarsals creates a concave medial border of the foot, a convex lateral border, and prominence at the base of the fifth metatarsal. There may also be varying degrees of forefoot supination. The hindfoot is in neutral or slight valgus alignment, and there is full and free motion at the ankle and subtalar joints.

Bleck (444, 445) published two classification systems: one based on the severity and one on the flexibility of the deformity. The severity of metatarsus adductus is determined with the use of the heel bisector method (445) applied to a weight-bearing photocopy of the child's foot (Fig. 29-116). The other classification system (444) defines a foot with metatarsus adductus as flexible if the forefoot can be passively abducted beyond the midline heel bisector while holding the heel firmly (Fig. 29-117). A partly flexible foot can be abducted only to the midline, and an inflexible, or rigid, foot cannot be abducted to the midline.

Radiographic Features. Radiographs are not necessary or indicated to diagnose metatarsus adductus in infants. Berg (446) developed a classification system for metatarsus adductus and skewfoot based on radiographs of the feet of a small group of children between the ages of 2 and 17 months. The system is inherently flawed because it is strongly dependent on assessment of the relationship between the talus and the navicular. The navicular does not ossify until age 4 to 5 years, far beyond the age of the feet in their study. Cook et al. (447) documented poor interobserver and intraobserver agreement using this system and showed no correlation between classification and response to treatment.

Radiographs are indicated for the older child and adolescent with severe residual deformity, pain, or other disability when operative intervention is being considered. A standing AP radiograph will show the trapezoidal shape of the medial cuneiform and the medial deviation, or adductus, of the metatarsals on the tarsal bones (Fig. 29-118). The severity of adductus decreases from the first to the fifth metatarsal. Normal hindfoot alignment is seen on the AP and lateral views.

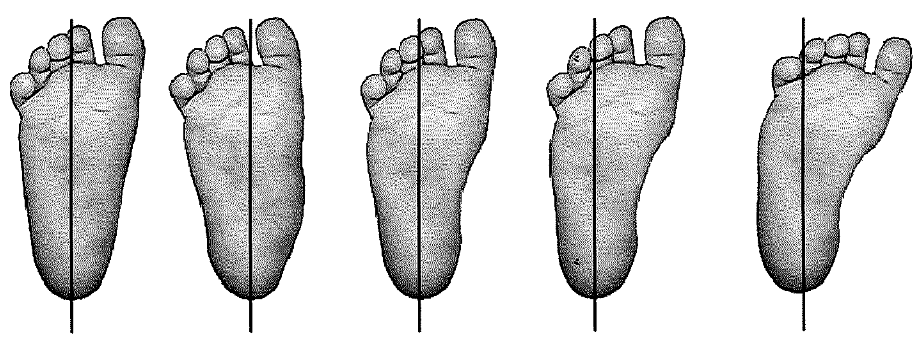


FIGURE 29-116. The heel bisector method. The severity of metatarsus adductus is determined by the relation between the toes and the distal end of the line bisecting the heel. The severity does not correlate with prognosis. (From Bleck EE. Developmental orthopaedics. III. Toddlers. *Dev Med Child Neurol* 1982;24:533, with permission.) (533)

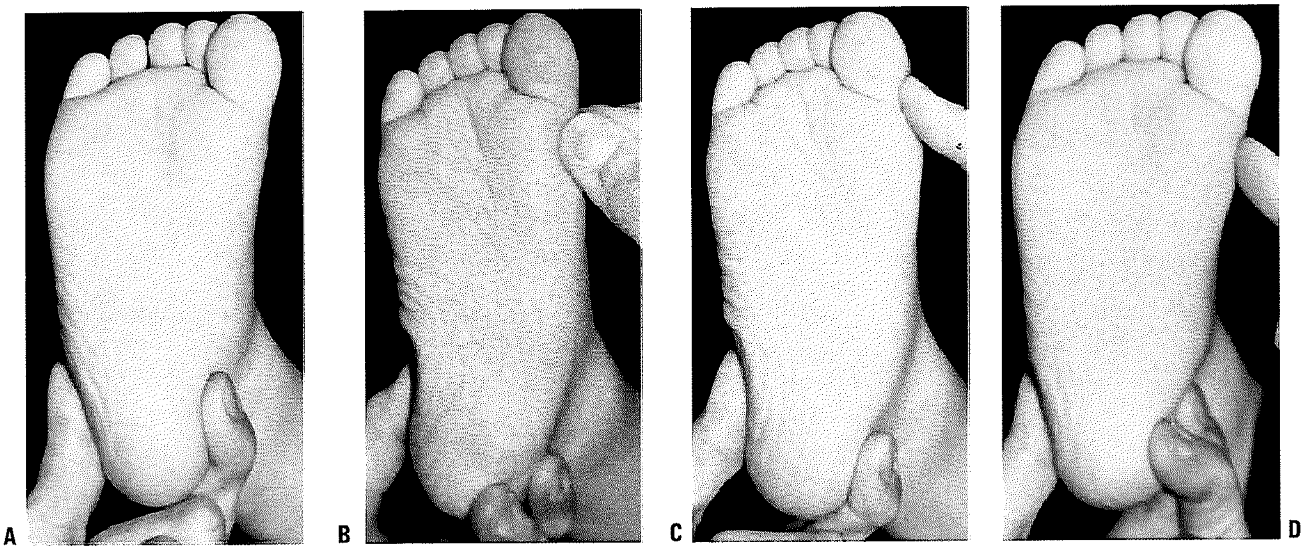


FIGURE 29-117. Demonstration of Bleck's flexibility classification of metatarsus adductus. **A:** Metatarsus adductus in an infant. **B:** A flexible foot can be passively overcorrected into abduction with little effort. **C:** A partly flexible foot can be passively corrected only to the midline. **D:** An inflexible foot cannot be passively corrected to the midline. (From Cappello T, Mosca VS. Metatarsus adductus and skewfoot. *Foot Ankle Clin* 1998;3:683–700, with permission.) (529)

There is no indication for routine ultrasound screening of hips in infants with metatarsus adductus.

Pathoanatomy. Whereas some authors have proposed the etiology to be joint malalignment deformity secondary to *in utero* positioning, others have proposed the etiology to be muscle imbalance resulting from contracture and anomalous insertion of the tibialis anterior (437, 448, 449) or tibialis posterior (450). Two studies on cadavers with metatarsus adductus have documented an abnormality in the shape of the medial cuneiform (451, 452). The bone is trapezoid shaped and the first metatarsal–medial cuneiform joint is tilted medially, that is, in varus alignment, deformities that are better seen on the radiographs of older children and adults (Fig. 29-118). It may be that the position theory applies to those feet that correct spontaneously and the anatomic theories apply to those that do not.

Natural history. Rushforth prospectively studied the natural history of metatarsus adductus in 83 children with 130 affected feet who received no treatment (6). Eighty-six percent were normal, 10% were moderately deformed and asymptomatic, and 4% were deformed and stiff at an average follow-up of 7 years. He stated that it was not possible to determine prognosis before the age of 3 years.

Ponseti and Becker (5) followed 379 children with metatarsus adductus and documented improvement by age 3 to 4 years in 335 patients who had flexible feet, as defined by Bleck (444). Forty-four patients (11%) with partly flexible and rigid deformities underwent treatment with corrective plaster casts. Farsetti et al. (4) rated 26 of 29 feet (90%) in this treated group as good at an average follow-up of 32 years. There were no poor results or long-term functional disabilities in patients with mild or moderate residual deformity. No patient required surgical correction and hallux valgus was not an identified problem.

The percentage of feet with metatarsus adductus that undergo spontaneous correction without treatment may actually be even higher than reported in these studies, because of the likelihood of underreporting of mild, flexible cases.

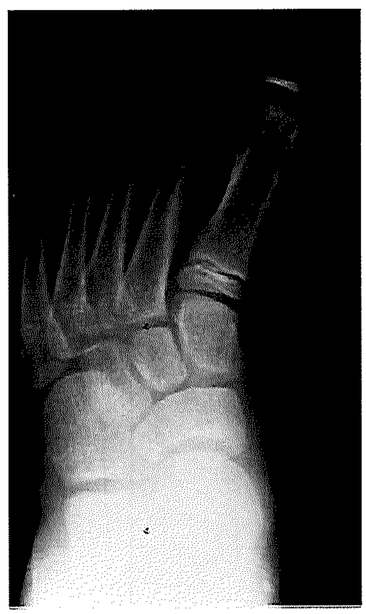


FIGURE 29-118. Metatarsus adductus in an older child with trapezoidal-shaped medial cuneiform. (From Cappello T, Mosca VS. Metatarsus adductus and skewfoot. *Foot Ankle Clin* 1998;3:683–700, with permission.)

Treatment. Proposed nonoperative management for metatarsus adductus includes observation, stretching exercises, splints/braces, corrective shoes, and stretching casts. Many types of operative procedures have been recommended for resistant deformities, including soft-tissue releases and osteotomies.

The prognosis for spontaneous correction of flexible deformities without treatment is excellent (4, 5, 448). The efficacy of passive stretching exercises is not documented. Kite (437) believed that stretching exercises performed by the parents were not effective, and Ponseti and Becker (5) believed that they were potentially harmful.

The efficacy of shoes, braces, and splints in correcting foot deformities in children has never been demonstrated. The Denis-Browne bar has no ability to concentrate corrective forces at the site of deformity, the tarsometatarsal joints. Furthermore, some authors believe that it can do harm by creating valgus deformity of the hindfoot (5, 446).

Ponseti (4, 5), Bleck (444), Berg (446), and others have documented the efficacy of manipulation and serial casting for the correction of partly flexible and inflexible deformities. The upper age limit for this treatment modality is not known, but most authors recommend initiation under the age of 1 year (5, 444, 446). Anecdotal experience indicates no need to begin this treatment under the age of 6 months. The details of the casting technique are important. Care must be taken to avoid excessive valgus stress on the hindfoot, which could create an iatrogenic skewfoot (5, 437). Long-leg casts are preferred. Holding casts or postcasting splints and shoes have been recommended to decrease the risk of recurrence after casting, which has been reported at 8% to 37% (437, 444, 453).

Surgery is rarely, if ever indicated for metatarsus adductus (4). Spontaneous resolution of the deformity can occur up to age 4 years (4, 5), and minor residual deformity does not necessarily lead to disability (4, 6). There are no reported series on long-term disability from residual deformity. Nevertheless, many different operative procedures have been proposed to correct the deformity. Release of the abductor hallucis has been associated with the development of hallux valgus (454). Medial midfoot capsulotomies have been reported without clearly stated indications or natural history controls (448, 455).

Heyman et al. (456) described mobilization of the forefoot by capsulotomy of the tarsometatarsal joints and release of the intermetatarsal ligaments. Long-term follow-up studies (457, 458) showed a 41% failure rate with complications including skin slough, avascular necrosis of the second and third cuneiforms, dorsal prominence of the first metatarsal–cuneiform joint, and early degenerative arthrosis of those joints with pain. Osteotomies at the base of the metatarsals have been utilized as an extra-articular alternative approach to avoid the complications of capsulotomies (459, 460). However, shortening of the first metatarsal from a nonunion or physeal injury, a devastating complication, has been reported in 5% to 30% of patients (459, 461, 462).

In the rare situation of an older child with disability related to residual deformity, it seems logical to perform the operative correction at the site of deformity. An opening-wedge osteotomy of the medial cuneiform will change the malformed bone from a trapezoid to the normal rectangular shape and, thereby, correct the orientation of the first metatarsal–cuneiform joint (77). This procedure can be combined with a closing-wedge osteotomy of the cuboid (Fig. 29-119; see also Figs. 29-55 to 29-61) or with osteotomies at the base of metatarsals two through four in the more severe and resistant case (223, 224, 463, 464). These osteotomies have been shown to be safe and effective, though rarely indicated. Careful preoperative assessment of the hindfoot is necessary to determine if the apparent metatarsus adductus is, in fact, a skewfoot deformity.

FIGURE 29-119. Correction of symptomatic metatarsus adductus in an older child with an opening-wedge osteotomy of the medial cuneiform and a closing-wedge osteotomy of the cuboid. (From the private collection of Vincent S. Mosca, MD.)

Polydactyly and Polysyndactyly

Definition. Polydactyly is a congenital condition in which one or more toes are duplicated. The corresponding metatarsal may be fully or partially duplicated as well. With polysyndactyly, the duplicate toe is joined to the more normal toe by soft tissue (simple) or bone (complex).

Epidemiology. The incidence of polydactyly is 0.3 to 1.3 per 1000 live births in whites and 3.6 to 13.9 per 1000 live births in blacks (465, 466). There is no sex predilection.

FIGURE 29-120. Bilateral preaxial and postaxial polydactyly. (From the private collection of Vincent S. Mosca, MD.)

Approximately 50% of cases are bilateral and 62% of bilateral deformities are symmetric (467). There is polydactyly of the hands in 34% of patients with polydactyly of the feet (467). Polydactyly may be inherited as an autosomal dominant trait with variable penetrance (468), but it occurs most often as an isolated trait.

Etiology. The cause of polydactyly is unknown. Presumably, there is failure of differentiation in the AER during the first trimester of pregnancy, leading to polydactyly and polysyndactyly (467). Experimentally, polydactyly can be produced by radiation, cytotoxins, and folic acid deprivation.

Clinical Features. Temtamy and McKusick (468) classified polydactyly as preaxial if the hallux was duplicated, postaxial if the fifth toe was duplicated, and central if there was duplication of the second, third, or fourth toe. Phelps and Grogan (467) found that 79% were postaxial, 15% were preaxial, and 6% central in their review of 194 supranumery toes in 125 patients. More than one type may exist in a foot (Fig. 29-120). Polydactyly can be further classified as well-formed and articulated (type A) or rudimentary and vestigial (type B). The duplicate toe may be entirely separate, or there may be simple or complex syndactyly. The toenails may be separate or conjoined in cases of polysyndactyly.

The central and postaxial duplications are usually well aligned with the other toes. The preaxial duplicate toe is often deviated medially. One must consider the possibility of a longitudinal epiphyseal bracket of the first metatarsal in the presence of preaxial polydactyly and polysyndactyly (257, 259) (see section on congenital hallux varus).

Radiographic Features. Venn-Watson (469) proposed a morphologic classification of the abnormalities of the metatarsals and phalanges in polydactyly of the foot (Fig. 29-121). Unfortunately, there is not enough ossification of the phalanges even in the first few years of life to accurately classify the

FIGURE 29-121. Venn-Watson classification of polydactyly. **A:** Postaxial. **B:** Preaxial. (From Venn-Watson EA. Problems in polydactyly of the foot (469). *Orthop Clin North Am* 1976;7:909–927, with permission.)

deformity before surgical treatment. There is clearly no indication for a radiograph at birth. To help with surgical planning, an AP radiograph is obtained immediately prior to surgical ablation. It will reveal a metatarsal abnormality and may suggest the true pathoanatomy of the phalanges.

Natural History. Untreated polydactyly will commonly cause shoe-fitting problems, particularly when the hallux is duplicated.

Treatment. A family may choose to retain the duplicate digit if it is well formed, well aligned, and does not extend beyond the border of the foot. Wide shoes may be all that is required.

Surgical treatment performed at about 1 year of age is indicated to improve shoe tolerance. Improved cosmesis is a byproduct. The most malaligned toe is resected, which is usually the medial duplication in preaxial polydactyly and the lateral duplication in postaxial cases (467, 470). Division of a synchondrosis at the base of the proximal phalanges is quite safe with little risk of growth arrest of the retained phalanx. Likewise, an enlarged, partially duplicated and unsegmented metatarsal head can be safely reduced in size by performing a transphyseal longitudinal osteotomy (467). One may, however, choose a safer approach and shave down the cartilaginous epiphysis with care taken to avoid the perichondrial ring. The metatarsophalangeal joint capsule should be repaired if possible. A duplicate metatarsal as well as the abnormal limb of a Y-shaped metatarsal should be resected.

In cases of polysyndactyly, the most malaligned phalanges and the corresponding toenail are removed through a dorsal racket-handle incision (467, 469, 470). The soft-tissue nail fold must be carefully recreated to prevent chronic toenail ingrowth. A common pattern of postaxial polysyndactyly involves duplication of the middle and distal phalanges of the fifth toe in which neither middle phalanx is axially aligned with the normal proximal phalanx. Simple syndactyly of this partially duplicated fifth toe to the fourth toe is commonly seen (Fig. 29-122). If surgery is elected, the most poorly aligned toenail and phalanges are removed (sometimes requiring longitudinal osteotomy/resection of part of a middle phalanx rather than removal of the entire bone), while preserving the simple syndactyly to the fourth toe. Lateral deviation of the fifth toe might result if the toes are separated (470).

One can expect close to 100% good and excellent results with surgical treatment of polydactyly and polysyndactyly. Most of the reported poor results were in patients with residual hallux varus and a short first metatarsal following resection of a preaxial duplication. Some or all of these patients may have had a longitudinal epiphyseal bracket that, with our present knowledge, should have undergone resection and interposition grafting (257) with a better expected outcome. Resection of central ray duplication does not reliably narrow the foot (467).

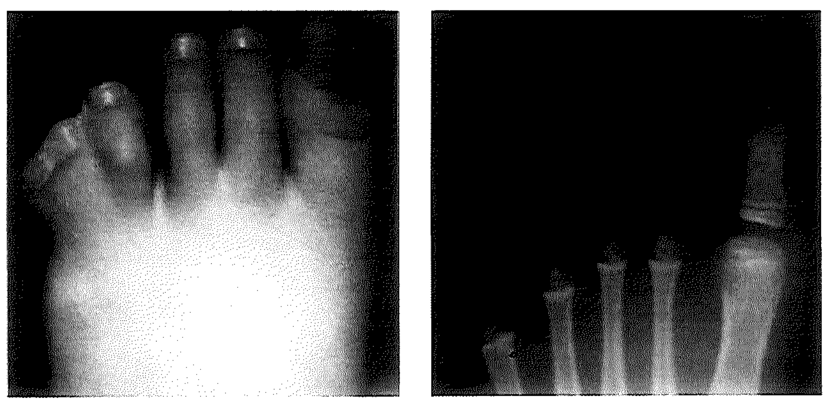
Positional Calcaneovalgus Foot

Definition. Positional calcaneovalgus deformity is characterized by marked dorsiflexion of the entire foot at the ankle joint with mild and flexible eversion of the subtalar joint (Fig. 29-123). The dorsal surface of the foot rests on the anterior surface of the lower leg. The soft tissues on the dorsal aspect of the foot and ankle are contracted and limit plantar flexion and inversion.

Epidemiology. Wetzenstein (471) reported the incidence at 30% to 50%, and Wynne-Davies et al. (443) reported it at 1 per 1000 live births. The true incidence figures are not known, but positional calcaneovalgus may be the most common deformity of the foot seen at birth. It is more common in girls, first-born children, and children of young mothers.

Etiology. The probable cause of this deformity is intrauterine malpositioning, rather than a truly congenital deformation.

Clinical Features. The importance of discussing this condition is in the differentiation from other more serious deformities. Congenital vertical talus is the most important condition from which to differentiate positional calcaneovalgus. In contrast to the latter condition, congenital vertical talus is characterized by fixed equinus and valgus of the hindfoot, rigid dorsiflexion of the midfoot on the hindfoot, and the inability to create a longitudinal arch by manipulation (Fig. 29-76). Congenital posteromedial bowing of the tibia may also be confused with positional calcaneovalgus, but physical examination and radiographs can easily differentiate a bowed tibia with a flexible ankle joint from a straight tibia with limitation



A B

FIGURE 29-122. Postaxial polysyndactyly. Clinical (**A**) and radiographic (**B**) appearance. (From the private collection of Vincent S. Mosca, MD.)

FIGURE 29-123. Positional calcaneovalgus foot deformity. (From the private collection of Vincent S. Mosca, MD.)

of passive ankle plantar flexion. Paralytic calcaneovalgus, due to weakness of the triceps surae, can be seen at birth in children with myelomeningocele. The underlying diagnosis should be apparent from the medical history, the general physical exam, and the specific physical exam.

Radiologic features. If the foot is sufficiently flexible for the examiner to be confident with the diagnosis of positional calcaneovalgus foot deformity, no x-ray films are necessary. In cases in which there is confusion between a calcaneovalgus foot deformity and a congenital vertical talus, lateral radiographs obtained with the foot in maximum plantar flexion and maximum dorsiflexion will differentiate the two entities (Fig. 29-77). In most cases, x-ray films are not required.

Natural history. The prognosis for spontaneous correction of positional calcaneovalgus foot deformity is excellent (7).

Treatment. Larsen et al. (7) found no difference between calcaneovalgus feet that underwent manipulation and bandaging versus observation alone when assessed at 3 to 11 years follow-up. The majority of the feet were normal. The severity of contractures found at birth appeared to have no influence on the final results. Wetzenstein (471) noted a high degree of correlation between the severity of calcaneovalgus deformity in the newborn and flexible flatfoot in the older child. Flexible flatfoot is a normal foot shape, so there should be no negative implication from this finding. Based on this information, one can conclude that positional calcaneovalgus is a benign deformity with excellent prognosis without treatment. Certainly no treatment is required for a mild deformity in which the foot can be plantarflexed and inverted beyond neutral position. In an attempt to hasten correction, passive stretching exercises can be performed by the parents for a moderate deformity in which there is initial difficulty in manipulating the foot to the neutral position. It is a rare foot that requires serial casting to hasten correction of the contracted dorsal soft tissues. Surgery is never required.

Sever Apophysitis

Definition. In 1912, Sever (472) described, what he thought was, an inflammatory disorder of the apophysis of the os calcis in the growing child that caused heel pain.

Epidemiology. Sever disease (calcaneal apophysitis) is the most common cause of heel pain in the immature athlete (473). The average age of clinical presentation is 11.5 years with the majority of patients presenting between 10 and 12 years of age. It is two to three times more common in boys. Bilateral involvement occurs about 60% of the time (473).

Etiology. The cause of Sever apophysitis is unknown. It is considered to be a nonarticular osteochondrosis (369). Repetitive microtrauma and overuse lead to this "apophysitis" in constitutionally susceptible children (473).

Clinical Features. The typical patient with Sever apophysitis is a 10- to 12-year-old avid male soccer player with activity-related heel pain who has recently undergone a growth spurt. The child continues to play despite the pain. There is rarely redness, swelling, or warmth, and there is no night pain. The classic physical finding is pain with medial-to-lateral compression of the apophysis. Other possible causes of heel pain can usually be diagnosed with careful and specific palpation (474) (Fig. 29-124). The child with calcaneal apophysitis will usually have mild contracture of the Achilles tendon.

Radiologic Features. The diagnosis of Sever apophysitis is a clinical one, because there are no diagnostic or pathognomonic radiographic features. Irregularities of ossification with sclerosis and fragmentation represent the normal radiographic appearance of the apophysis of the os calcis in the growing child (475) (Fig. 29-125). Lateral and axial (Harris) radiographs are not necessary in the face of a classic history and physical examination, but can be used to rule out other causes of heel pain, particularly if there is local swelling, redness, warmth, or a history of night pain suggesting infection or tumor.

Other imaging studies. A bone scan can be helpful in localizing the site of pathology in cases of heel pain when symptoms, physical findings, and radiographs are nondiagnos-

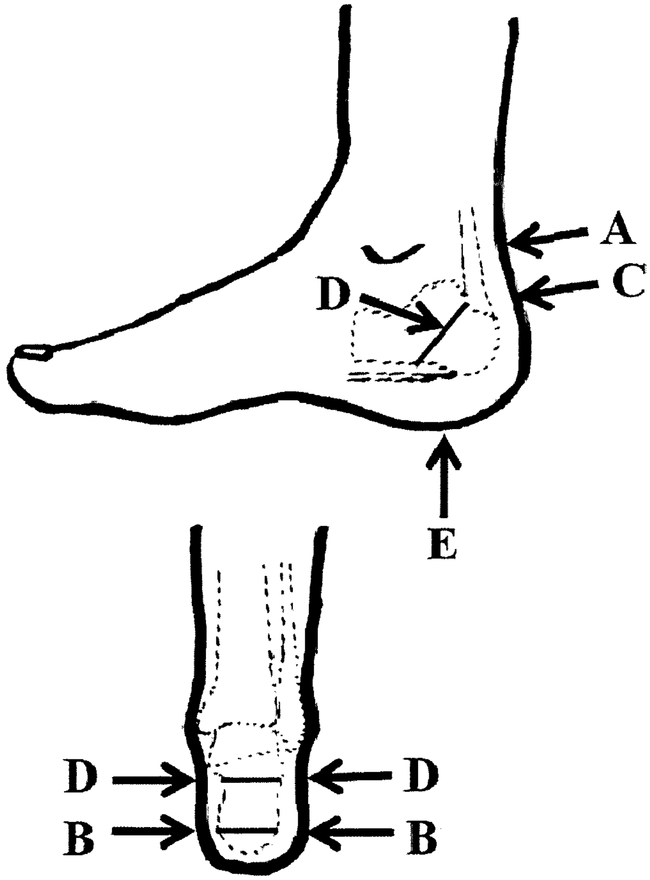


FIGURE 29-124. Sites of heel pain: (A) Achilles tendinitis; (B) calcaneal apophysitis (Sever's disease); (C) retrocalcaneal bursitis; (D) calcaneal stress fracture; (E) plantar fasciitis/calcaneal bursitis (extremely rare in children and adolescents). (From the private collection of Vincent S. Mosca, MD)

FIGURE 29-125. Lateral radiograph of the hindfoot showing the normal irregularities of ossification of the apophysis of the os calcis in the growing child. (From the private collection of Vincent S. Mosca, MD.)

tic. It is particularly helpful to rule out a stress fracture. An MRI scan is a more expensive alternative study that should rarely be obtained.

Pathoanatomy. The apophysis of the os calcis experiences opposing traction forces from the Achilles tendon and the plantar fascia during weight bearing (369, 476, 477). It is also subjected to powerful compressive forces at right angles to the traction forces during heel strike. Siffert (369) believed that, in constitutionally susceptible children, mechanical disruption of the endochondral mechanism might be evident as microfractures that do not heal because of repeated trauma. He felt that the disruption of chondrogenesis and osteogenesis could account for the clinical symptoms and the radiographic changes that, although not diagnostic, are often seen with Sever apophysitis. Liberson et al. (476) had the opportunity to study pathologic specimens of the apophysis of the os calcis in children. Their histologic and computer-aided analyses supported the hypothesis of a stress-remodeling process that occurs subclinically in every child at a certain stage of apophyseal development. They determined that it is due to bending of the apophysis under repetitive stresses of traction and impact. They concluded that pain, radiographic changes, or both result when remodeling exceeds certain rates.

Natural History. Sever apophysitis is a self-limited and an age-limited condition. It cannot occur after maturation and closure of the apophysis of the os calcis.

Treatment. Treatment is symptomatic. It includes restriction of activities that cause pain, Achilles tendon stretching exercises, strengthening of the anterior compartment muscles, and the addition of a soft heel pad and lift. Nonsteroidal anti-inflammatory medications and/or a short-leg cast can be used for a short time if the pain is significant. This is the same treatment regime recommended for most causes of heel pain in the child. The average time to symptomatic relief using this regimen is 2 months with a range of 1 to 6 months (473). Recurrence of symptoms is possible prior to skeletal maturation. There is no evidence that continued participation in painful activities has any long-term sequelae. There is no role for surgery in this condition.

Skewfoot

Definition. Skewfoot is the term used most commonly to designate a rare and poorly defined foot shape that combines adduction deformity of the forefoot with valgus deformity of the hindfoot, that is, metatarsus adductus plus flatfoot (Fig. 29-126). This is a consensus definition that has been recently adopted in the medical literature (237, 308, 478–480), but has not been officially adopted in medical dictionaries. It is not known how much valgus deformity of the hindfoot is necessary to reclassify a foot with presumed metatarsus adductus as a skewfoot, or how much forefoot adductus is required to reclassify a presumed flatfoot as a skewfoot. Skewfoot is generally discussed in the literature in relation to metatarsus adductus; however, disability caused by this con-

FIGURE 29-126. Probable skewfoot in an infant. **A, B:** Apparent metatarsus adductus, but with the head of the talus visible and palpable medially. This indicates coexistent eversion of the subtalar joint with abduction of the navicular on the head of the talus. **C:** Posterior view reveals hindfoot valgus/eversion. (From Mosca VS. Flexible flatfoot and skewfoot. In: Drennan JC, ed. *The child's foot and ankle.* New York, NY: Raven Press, 1992:355, with permission.)

dition is most often related to the hindfoot deformity (237). Inconsistent terminology was used in the three seminal articles on this deformity in the English literature. Peabody and Muro (449) labeled it congenital metatarsus varus, McCormick and Blount (438) coined the term skewfoot, and Kite (436) called it serpentine metatarsus adductus. Interestingly, McCormick and Blount (438) used the term skewfoot to describe a whole group of deformities of the foot that included the shape that is now called skewfoot. Consistency in these articles was found in the reported rarity of the deformity and the difficulty in correcting and maintaining correction of the deformity.

Epidemiology. The lack of a strict definition has contributed to the lack of information on this deformity, including its incidence, etiology, natural history, and treatment. It has been stated, without verification, that the diagnosis cannot be made in the newborn. Some researchers have stated that the deformity occurs as a result of improper cast treatment of metatarsus adductus and clubfoot. There are, however, clearly idiopathic cases.

Etiology. The etiology is unknown. Some authors believe that a skewfoot deformity can be created in a foot with metatarsus adductus by applying abduction pressure to the forefoot without stabilizing the hindfoot when manipulating, casting and bracing these feet (5, 446). Most cases, however, are idiopathic. The medial cuneiform in a skewfoot is trapezoid shaped, as it is in metatarsus adductus (308, 478). A thickened portion of the tibialis anterior courses along an oblique dorsal-to-plantar groove on the concave medial border of the medial cuneiform (308, 478). The etiologic significance of these findings is unknown.

Clinical Features. Little has been written on the clinical features of skewfoot deformities, so I will present my personal observations on a fairly large number of these deformities. It is challenging to differentiate skewfoot from metatarsus adductus in an infant, but certain characteristics are helpful. In the skewfoot, the forefoot is adducted on the midfoot, a prominent dorsolateral convexity exists over the cuboid, there is a vertical medial midfoot skin crease, and the head of the talus can be visualized and palpated immediately proximal to the medial midfoot skin crease (Fig. 29-126). The plantar surface of the skewfoot is S-shaped, whereas the foot with metatarsus adductus is C-shaped. In the infant and young child with skewfoot deformity, the Achilles tendon has full flexibility and the ankle can be easily dorsiflexed. The hindfoot is in significant valgus alignment, and there is lateral displacement of the navicular on the head of the talus, yet the arch usually appears *higher* than normal. This creates discordance in the clinical appearance of the foot in the frontal and sagittal planes, a feature that changes with age in some children. Young children with persistent and rigid forefoot adductus deformity occasionally present with pain and callus formation at the base of the fifth metatarsal or the medial side of the hallux. They do not report, nor do they manifest, hindfoot symptoms. Parents report that the children do not like to stay in their shoes.

Valgus deformity of the hindfoot with flattening of the longitudinal arch and adductus of the forefoot can be better appreciated in older children, adolescents, and adults with skewfoot, although the deformity is often misclassified, even in the orthopaedic literature. In these older individuals, the hindfoot has usually converted to the typical valgus deformity seen in a flatfoot, with full eversion of the subtalar joint and loss of the longitudinal arch with a midfoot sag (Fig. 29-127). There is now concordance in the clinical appearance of the foot in the frontal and sagittal planes. Shortening of the tendo Achillis is noted in the older child, adolescent, and adult with symptomatic skewfoot (237, 308, 478, 479). Their symptoms are identical to those seen in individuals with flexible flatfoot with a short Achilles tendon, that is, pain and callus formation under the head of the talus (Fig. 29-128), and, occasionally, impingement pain in the sinus tarsi region.

A careful clinical examination of the hips of a child with an apparent skewfoot should be performed, because of the

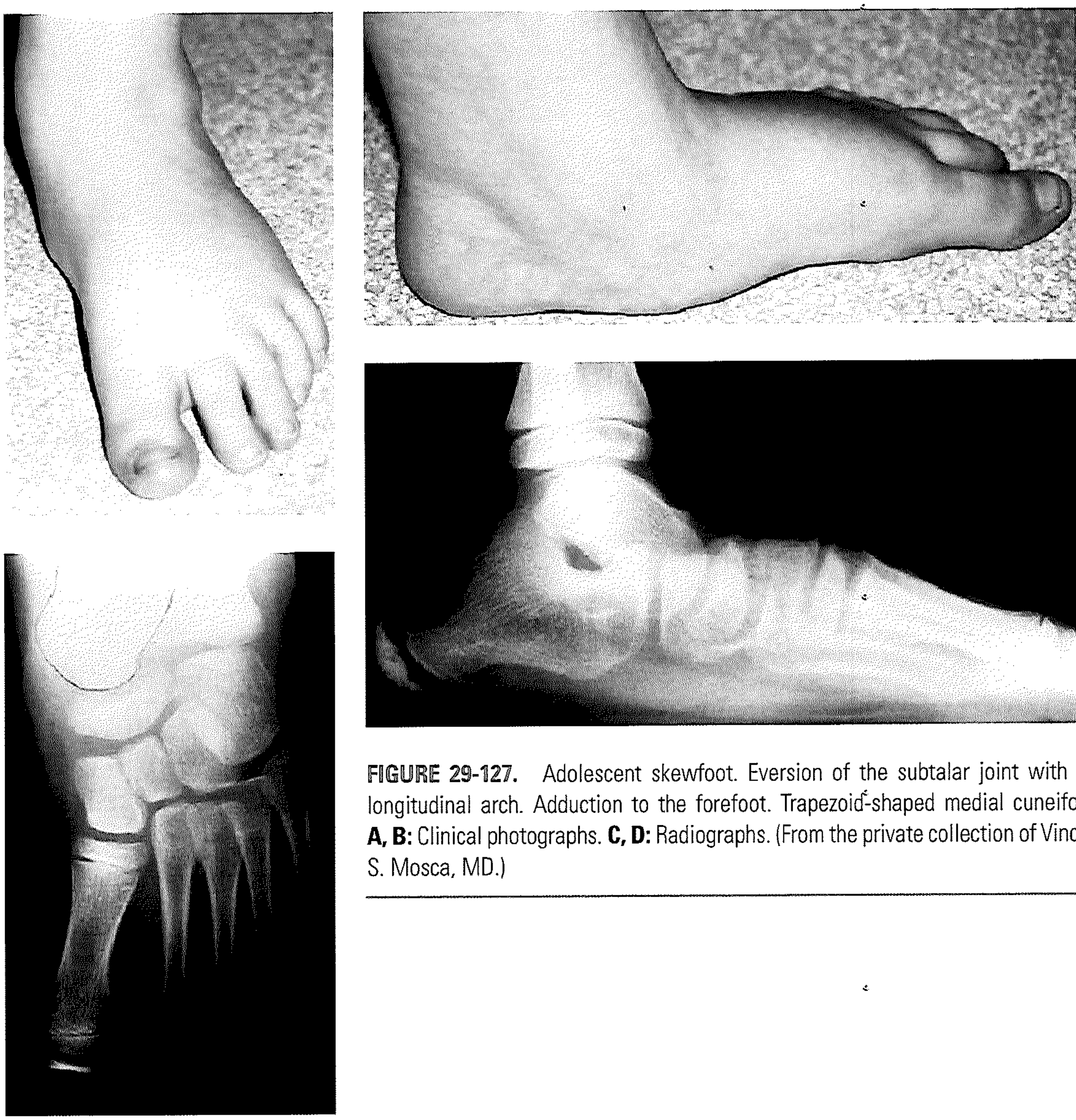


FIGURE 29-127. Adolescent skewfoot. Eversion of the subtalar joint with flat longitudinal arch. Adduction to the forefoot. Trapezoid-shaped medial cuneiform. **A, B:** Clinical photographs. **C, D:** Radiographs. (From the private collection of Vincent S. Mosca, MD.)

FIGURE 29-128. Painful callus that developed under the head of the talus in a skewfoot with contracted Achilles tendon. (From the private collection of Vincent S. Mosca, MD.)

reported 1.5% incidence of congenital hip dysplasia in children with metatarsus adductus (440). Because of the difficulty in differentiating these two foot deformities in babies, some of the so-called metatarsus adductus feet in these studies might have actually been skewfeet.

Radiographic Features. Radiographs are not indicated for the diagnosis of skewfoot in the infant. Berg (446) attempted to classify metatarsus adductus and skew foot radiographically, but his system was based on assessment of the relationship of the navicular to the talus at a time in life when the navicular is not ossified. The classification system was found to have poor interobserver and intraobserver reliability by Cook et al. (447).

Standing AP and lateral radiographs of the foot in the older child, adolescent, and adult will confirm the deformities that

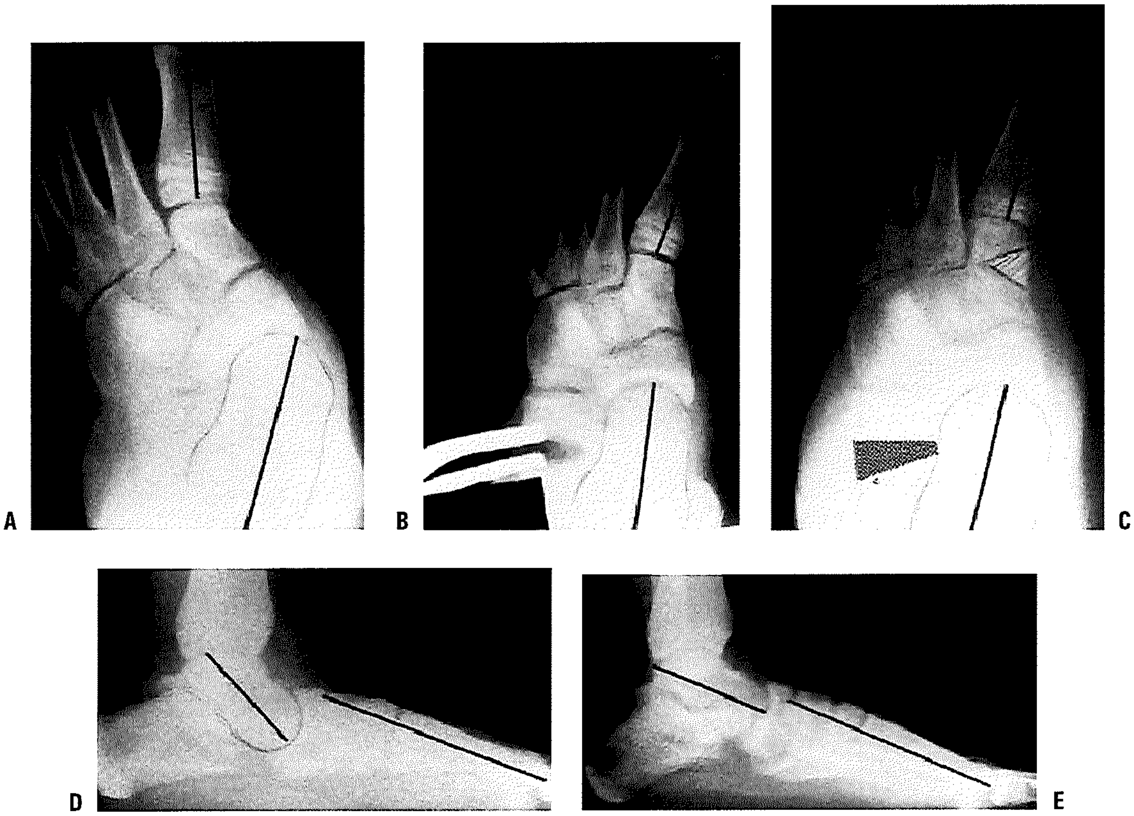


FIGURE 29-129. Preoperative, intraoperative, and postoperative radiographs of a painful skewfoot in a 13-year-old adolescent. **A:** Preoperative anteroposterior view. **B:** Intraoperative distraction of calcaneal osteotomy. **C:** Corrected deformity on anteroposterior radiographs with grafts in place. **D:** Preoperative lateral view. **E:** Postoperative correction. Calcaneal lengthening osteotomy, medial cuneiform opening-wedge osteotomy, and Achilles tendon lengthening were used. (From Mosca VS. Flexible flatfoot and skewfoot. In: Drennan JC, ed. *The child's foot and ankle.* New York, NY: Raven Press, 1992:355, with permission.)

are appreciated clinically, that is, adductus of the forefoot on the midfoot and valgus deformity of the hindfoot. Mosca (308) was the first to stress that the skew, or zigzag, deformity is present in both the frontal and sagittal planes (Fig. 29-129A-D). Previously, only the frontal (AP) plane deformity was assessed and discussed in the literature. He also identified the flaw in using the standard talus–first metatarsal angle to assess deformity between the forefoot and the hindfoot (237). The skewfoot has two deformities in opposite directions from each other between the talus and the first metatarsal in both the frontal and sagittal planes. These angular deformities tend to cancel each other out when the talus–first metatarsal angle is measured. For that reason, a skewfoot with severe valgus deformity of the hindfoot will appear less deformed than a flatfoot with less valgus deformity when both are assessed clinically and radiographically.

Natural History. The natural history of skewfoot is unknown. One would assume that some children undergo spontaneous correction of their skewfoot deformities with age, as occurs with isolated metatarsus adductus (5, 6) and flexible flatfoot (9, 10). The prevalence of long-term disability due to residual deformity is unknown, but some children have pain, callosities, and difficulty wearing shoes as early as the end of the first decade of life (237, 308, 436–438, 449, 478–480).

Treatment. Despite our inability to definitively differentiate metatarsus adductus from skewfoot in infancy, it is reasonable to treat all feet with partly flexible and inflexible forefoot adductus with serial long-leg casting. Several authors have reported success with this approach, noting that it takes longer to correct a skewfoot and that additional care must be exercised to avoid valgus stress on the already deformed hindfoot (5, 436–438, 444, 446). Berg (446) cautioned against the use of reverse last shoes and Denis-Browne bars for the same reason.

Rarely, a child in the middle of the first decade of life will present with pain and callus formation at the base of the fifth metatarsal or the medial side of the hallux, due to a severe and rigid adductus component of a skewfoot deformity. The arch is elevated, despite valgus angulation of the heel, and the tendo Achillis is not contracted. If shoe modifications cannot relieve the symptoms, surgical correction is indicated. Recommendations in the literature for correction of the forefoot adduction component of skewfoot in this age group include tarsometatarsal capsulotomies (456), metatarsal base osteotomies (459), and medial cuneiform opening-wedge osteotomy (77, 223), possibly combined with closing cuboid wedge osteotomy (224). Considering the reported risks and complications of the procedures, a closing-wedge osteotomy of the cuboid with an opening-wedge osteotomy of the medial cuneiform produces the best clinical results with the least morbidity (224). The hindfoot can usually be ignored at this age.

Some older children, adolescents, and adults with skewfoot deformity will report pain and callusing under the prominent head of the plantar-flexed talus (237, 308, 478, 479). Invariably, they have contracture of the Achilles tendon and symptomatically resemble patients with flexible flatfoot with a short Achilles tendon (237, 308, 478, 479). Attempts can be made to stretch the Achilles tendon by means of exercises or casts. Rigid orthoses increase the pressure under the head of the rigidly plantar-flexed talus and should be avoided. Nonoperative management generally holds little hope for relieving symptoms. Less commonly, children with skewfoot will present with isolated or coexisting pain and callosities at the head of the first metatarsal or the base of the fifth metatarsal (479).

An operation is indicated when nonoperative management fails to relieve the pain and callosities (237, 308, 478, 479). Suggestions for operative management can be found in the literature, but most are based on theory and not on a review of operative results. Historical recommendations have been for tarsometatarsal capsulotomies or osteotomies at the base of the metatarsals to correct the forefoot deformity (449) with subtalar or triple arthrodesis for the hindfoot (458, 459, 480). Reported complications from these procedures on the forefoot are enumerated in the section of this chapter on metatarsus adductus (457–459, 461, 462). Reported complications and disability from subtalar and triple arthrodesis are enumerated in the section of this chapter on flatfoot (19–27). Mosca (478) proposed correction of symptomatic skewfoot by combining the best and safest methods for correcting the individual deformities of the forefoot and hindfoot. In 1993, he reported the short-term results of the largest series of operatively treated skewfoot deformities using a single technique. The technique consists of a calcaneal lengthening osteotomy, conceptualized by Evans (236) and elaborated by Mosca (237, 238); a medial cuneiform opening-wedge osteotomy, according to Fowler et al. (77); and lengthening of the tendo Achillis (Fig. 29-129). Nine of ten severe skewfoot deformities achieved a satisfactory clinical and radiographic outcome while maintaining joint mobility.

Syndactyly

Definition. Syndactyly of the toes is a failure of segmentation of adjacent digits involving soft tissues alone (simple syndactyly) or soft tissues and bones (complex syndactyly). Complex syndactyly is most commonly seen in cases of polysyndactyly and in children with syndromes, particularly Apert syndrome (256). The most common simple syndactylized digits are the second and third, which may be either complete or incomplete (Fig. 29-130).

Epidemiology. Zygosyndactyly, the term used for simple syndactyly between the second and third toes, is a common and often inherited trait that is frequently bilateral.

Etiology. Pathologenesis is unknown, but presumably in early fetal development there is a failure of separation of cells in the AER.

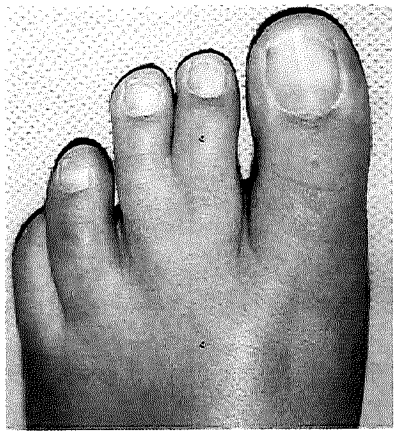


FIGURE 29-130. Clinically benign zygosyndactyly. (From the private collection of Vincent S. Mosca, MD.)

Clinical Features. The webbing may be complete to the ends of the toes or it may be extremely shallow and subtle. There is rarely deviation or deformity of the toes and there is no widening of the forefoot. Simple versus complex syndactyly can usually be differentiated on physical exam. Occasionally, differential length of the toes may result in a flexion deformity of the longer toe and a callus over the PIP joint with accompanying pain. This is rarely seen when the syndactyly is between the second and third toes.

Radiographic Features. Radiographs are rarely indicated, as there will be no findings. They should be performed if deformity, from differential length of the toes, is present and surgical management is planned.

Natural History. In general, syndactyly of adjacent digits is asymptomatic throughout life. Toes function together as a unit, unlike fingers that function independently. Surgical treatment and adaptive shoe wear are rarely needed.

Treatment. Surgical treatment in general is not warranted for syndactyly, as comfort and function are not impaired. The surgical scars are less cosmetic than the condition itself. Occasionally, the syndactyly exists between the great and second toes. Since these toes frequently grow at different rates and result in toes of unequal length, surgery is often warranted at this location. Caution must be exercised, however, if the indication for separation of the toes is the ability to wear sandals with a strap between those toes. The surgical scars will often be irritated by the strap, making it uncomfortable to wear the shoes for which the operation was performed.

Tarsal Coalition

Definition. Tarsal coalition is a fibrous, cartilaginous, or bony connection between two or more tarsal bones that results from a congenital failure of differentiation and segmentation of primitive mesenchyme.

Epidemiology. Tarsal coalition was described in the archaeologic remains of several civilizations since pre-Columbian times (481). The association of the anatomic abnormality with the clinical syndrome of a painful flatfoot occurred 26 years after the introduction of radiographic imaging in 1895. In 1921, Slomann (482) linked the so-called peroneal spastic flatfoot with calcaneonavicular coalitions seen on radiographs. Almost 3 decades later, Harris and Beath (483) linked peroneal spastic flatfoot with talocalcaneal coalition. Tarsal coalition has also been linked with the infrequently occurring tibialis spastic varus, or cavovarus, foot since 1965 (530, 531).

Some tarsal coalitions are associated with other congenital disorders, such as fibular hemimelia (484), clubfoot (485), Apert syndrome (256), and Nievergelt-Pearlman syndrome. These tend to be quite extensive in regard to the number of tarsal bones involved and the percentage of involvement of the subtalar joint. The natural history and prognosis for these types, though not well studied, seem to be good.

The overall incidence of tarsal coalitions was proposed by Harris and Beath in 1948 to be 2%, on the basis of routine physical examination of Canadian Army enlistees (483). On the basis of a cadaveric study by Phitzner in 1896, the rate of calcaneal navicular synostosis was found to be 2.9%, and if talocalcaneal coalitions are included as well, its incidence might reach 6% (486, 487). More recently, a radiographic study by Lysack and Fenton (488) documented a general prevalence of calcaneal navicular coalition of 5.6%, which was significantly greater than previously reported.

The most common sites of coalition are the middle facet of the talocalcaneal joint and between the anterior process of the calcaneus and the navicular (483). Coalitions at these two sites occur with about equal frequency and, together, account for approximately 90% of all coalitions (489). Tarsal coalitions are bilateral in 50% to 60% of cases. Clarke (490) documented multiple coalitions in 6 of 30 patients on review examination of CT scans, but the incidence is believed to be much lower than that. Also reported are talonavicular, calcaneocuboid, naviculocuneiform, and cuneiform–metatarsal coalitions, all of which are uncommon (489, 491). The true incidence of tarsal coalition, as well as the relative frequency of affected joints and the frequency of bilaterality, is not known, because most affected individuals are asymptomatic and go uncounted.

Etiology. Wray and Herndon (492) suggested an autosomal dominant pattern of inheritance with variable penetrance based on a single-family study. Leonard (13) confirmed an autosomal dominant pattern with almost full penetrance in a study of 31 index patients and 98 first-degree relatives. Tarsal coalitions have been found in monozygotic twins (493).

Clinical Features. Progressive flattening of the longitudinal arch with valgus deformity of the hindfoot generally predates symptoms, but is rarely the presenting complaint. The insidious onset of vague and aching pain in the region of the sinus tarsi or the medial aspect of the hindfoot of a child between the ages of 8 and 16 years is characteristic. The pain is usually aggravated by activity and relieved by rest. Occasionally, children will report recurrent ankle sprains. Pain under the head of the plantar-flexed talus that is exacerbated by weight bearing, as occurs in a flexible flatfoot with a short Achilles tendon, is often reported in feet with the most severe valgus deformities. There is often tenderness at the site of coalition, and there may be tenderness on the dorsal aspect of the talonavicular joint.

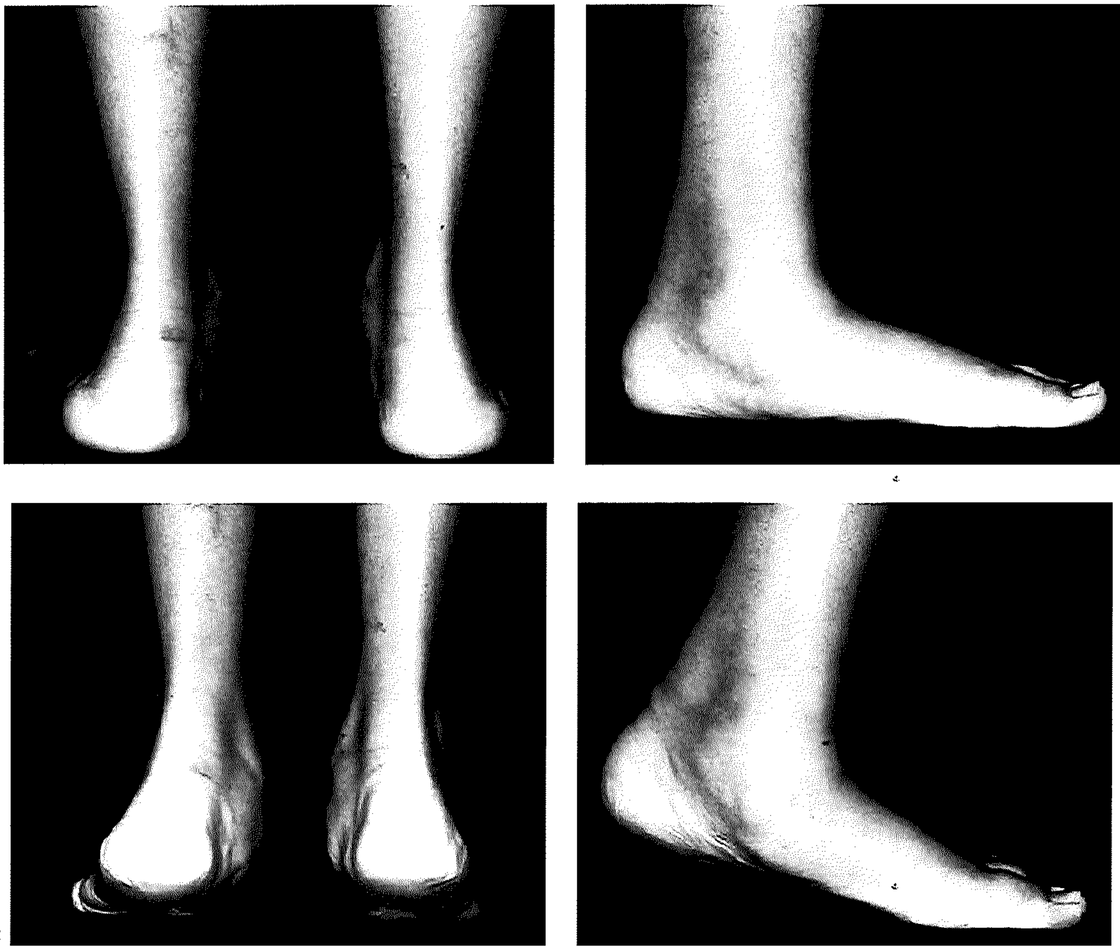
The flatfoot deformity has been variously described as rigid and peroneal spastic. Rigidity refers to restriction of subtalar joint motion, which can be assessed in several ways. It is important to isolate and manipulate the subtalar joint with the ankle joint held in neutral dorsiflexion and with care taken to ensure that the apparent subtalar joint motion is, in fact, occurring at that joint. The talonavicular and calcaneocuboid joints can develop hypermobility in some feet with long-established and solid subtalar coalitions and can give the impression of subtalar joint motion when none exists. In the typical situation, the subtalar joint will not invert and the arch will not elevate during toe standing (494) (Fig. 29-131) or with the Jack toe-raise test (307) in a foot with a talocalcaneal coalition. Feet with calcaneonavicular coalitions are generally less rigid and less flat than those with talocalcaneal coalitions, which makes inherent sense because the former type does not bridge cross the subtalar joint and the latter does.

The rigid flatfoot deformity, or peroneal spastic flatfoot, can also be seen with juvenile rheumatoid arthritis, bone lesions of the talus, calcaneus or midfoot, and trauma. Ruling out arthritis and the other causes of rigid flatfoot deformity is mandatory.

Radiographic Features. A calcaneonavicular coalition is best seen on an oblique radiograph of the foot (Fig. 29-132A). A cartilaginous coalition has the appearance of an articulation with somewhat undulating subchondral bone surfaces. An osseous coalition is obvious. Its presence is suggested on the standing lateral radiograph by an elongated process of the anterior calcaneus, called the anteater nose sign (495) (Fig. 29-132B).

Other radiographic findings that are best seen on the lateral view may include dorsal beaking on the head of the talus (Fig. 29-133), broadening and rounding of the lateral process of the talus, and narrowing of the posterior talocalcaneal facet joint (496, 497). The C sign, a C-shaped line formed by the medial outline of the talar dome and the inferior outline of the sustentaculum tali, is a fairly reliable indicator of a talocalcaneal coalition (498) (Fig. 29-133). It is not, however, pathognomonic. Taniguchi et al. (499) found the C-sign to have low sensitivity, meaning that the diagnosis of tarsal coalition is not negated by the absence of a C-sign. Brown et al. (500) found the C-sign to be specific for a flatfoot deformity but neither sensitive nor specific for the diagnosis of subtalar coalition. Liu et al. (501) found that the absent middle facet was a more accurate sign in the diagnosis of a subtalar coalition than either talar beaking or the C-sign.

In all cases of suspected tarsal coalition, a standing anteroposterior radiograph of the ankle should be obtained.



A B C D

FIGURE 29-131. **A, B:** Rigid flatfoot. **C, D:** The arch will not elevate, and the hindfoot valgus will not correct to varus during toe standing, because of immobility of the subtalar joint. (From Mosca VS. Flexible flatfoot and tarsal coalition. In: Richards B, ed. *Orthopaedic knowledge update: pediatrics*, Rosemont, IL: American Academy of Orthopaedic Surgeons, 1996:211, with permission).

A B

FIGURE 29-132. **A:** A calcaneonavicular coalition (*arrow*) is best seen on an oblique radiograph of the foot. **B:** Lateral radiograph demonstrating the anteater nose sign (*arrows*), indicating a calcaneonavicular coalition. (From the private collection of Vincent S. Mosca, MD.)

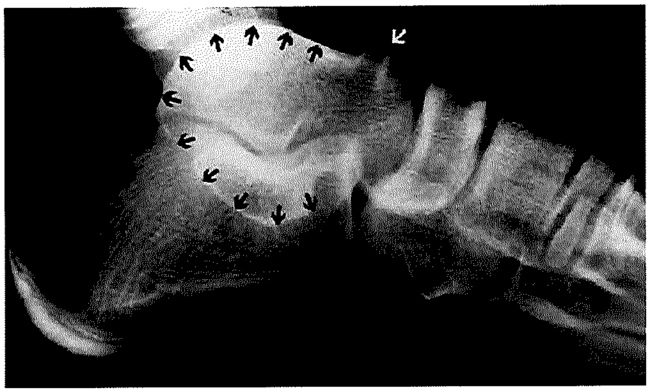


FIGURE 29-133. A dorsal talar beak (*white arrow*) in a foot with a talocalcaneal coalition. This represents a traction spur, not degenerative arthritis. The C-sign of Lateur (*black arrows*) is a nonspecific indication of a talocalcaneal coalition. (From the private collection of Vincent S. Mosca, MD.)

A ball-and-socket ankle may be seen in cases of long-standing tarsal coalition, particularly in the syndromic or the nonidiopathic types (496, 497).

A talocalcaneal coalition can be seen on an axial, or Harris (483), radiograph, but the best way to assess a coalition in this location is with a CT scan (502, 503) (Fig. 29-134). The thin slice images should be obtained in the coronal, sagittal, and transverse planes with three-dimensional reconstruction of the images.

A CT scan should also be obtained prior to resection of a calcaneonavicular coalition for two reasons. The first is to clearly define the variable pathoanatomy of the coalition that, in extensive cases, may extend further plantar-medially under the head of the talus than might be suggested by the plane radiographs (504). The second reason is to determine if there is a coexisting talocalcaneal coalition, a situation not uncommonly seen (490).

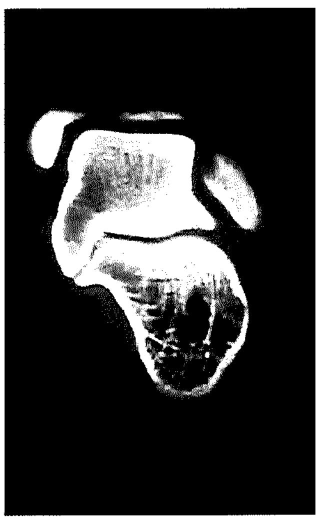


FIGURE 29-134. Talocalcaneal coalitions are best seen on computed tomography (CT) scans taken in the coronal plane. The middle facet is very narrow, irregular, and down-sloping. The posterior facet is more narrow than the ankle joint. And the calcaneus is in valgus alignment. (From Mosca VS. Flexible flatfoot and tarsal coalition. In: Richards B, ed. *Orthopaedic knowledge update: pediatrics*, Rosemont, IL: American Academy of Orthopaedic Surgeons, 1996:211, with permission.)

More recently, Emery et al. (505) showed that MRI was *nearly* as good as the "gold standard CT imaging" for subtalar coalitions. While MRI should *not* be the first-line study, it can be used to identify a symptomatic tarsal coalition that is still in the fibrous stage of differentiation if the plain radiographs and CT scan are nondiagnostic (506). A bone scan can help to identify the true cause of pain in a foot that has radiographic evidence of a tarsal coalition, but an atypical history or pain pattern (503).

Other Diagnostic Studies. Other causes for a rigid flatfoot include juvenile rheumatoid arthritis, septic arthritis, and osteomyelitis. A complete blood count with differential, estimated sedimentation rate, C-reactive protein, antinuclear antibody test, and rheumatoid factor may be warranted if evaluation fails to confirm a suspected tarsal coalition.

Pathoanatomy. In genetically programmed individuals, a tarsal coalition begins as a syndesmosis with fibrous tissue between two bones of the foot that do not joint together in at least 94% of people. The fibrous tissue undergoes metaplasia to cartilage to become a synchondrosis and then to bone as a synostosis. This process occurs during late childhood and early to middle adolescence (483, 507, 508).

Restriction of subtalar motion caused by a coalition blocks eversion of the subtalar complex that normally occurs during the early stance phase of gait. A component of eversion is dorsiflexion of the acetabulum pedis (anterior calcaneus, spring ligament, and navicular) that occurs as it rotates and glides around the head of the talus. When rotation and gliding are eliminated by the coalition, the dorsiflexion force is concentrated at the talonavicular and calcaneocuboid joints (509). They are converted to hinge joints that widen inferiorly and narrow superiorly. The dorsal proximal edge of the navicular impinges on and overrides the head of the talus. This overriding causes elevation of the talonavicular ligament and periosteum on the neck of the talus. The osseus repair of this periosteal elevation leads to the talar beaking that is visible on lateral radiographs of the foot. The reason for progressive flattening of the longitudinal arch is not established.

The site or sites of pain vary from one individual to another. The etiology of the pain is unknown (483, 489), but has been attributed to ligament sprain, peroneal muscle spasm, sinus tarsi impingement and irritation, subtalar joint irritation, fracture through the synchondrosis, and stress transfer to adjacent mobile joints with the development of degenerative arthrosis (481). Pain can also be experienced under the head of the plantar-flexed talus.

Natural History. According to Leonard (13), only about 25% of individuals with tarsal coalitions become symptomatic.

The onset of pain usually coincides with metaplasia of the coalition from cartilage to bone, but may occur earlier in its evolution. This generally occurs between 8 and 12 years for children with calcaneonavicular coalitions, and between 12 and 16 years for those with talocalcaneal coalitions. Metaplasia of the coalition also coincides with the development of progressive valgus deformity of the hindfoot, flattening of the longitudinal arch, and restriction of subtalar motion. All of these findings are more severe in feet with talocalcaneal coalitions (496, 507).

Treatment. Treatment is indicated only for painful tarsal coalitions (483, 496, 510), because there is no convincing evidence that painless tarsal coalitions cause disability. It is not clear what causes some to become painful, but inflammation clearly underlies the pain, wherever it is located. An attempt should be made to relieve symptoms by nonoperative means, which may include activity modification, nonsteroidal anti-inflammatory drugs, over-the-counter cushioned flat shoe inserts, and immobilization in a cast-type walking boot or a below-the-knee walking cast. Pain is generally relieved completely within 24 to 48 hours of cast application. Approximately 30% of patients remain pain-free following cast removal 6 weeks later (507). An over-the-counter cushioned flat shoe insert may help to maintain pain relief. A firm molded arch support will increase the pain.

Surgery is indicated for those patients with recurrent and disabling symptoms. The goal of treatment is the relief of pain, not the elimination of the coalition or the reestablishment of the longitudinal arch. Surgical options include resection of the coalition, osteotomy, and arthrodesis.

Resection of calcaneonavicular coalitions (Figs. 29-135 to 29-138) was first reported by Badgley (511) in 1927. Interposition of the extensor digitorum brevis (EDB) was added to the resection procedure and reported by Cowell (512) in 1970.

Mitchell and Gibson (535) reported on excision of calcaneonavicular bars that remain symptomatic after conservative treatment as an alternative to triple arthrodesis. A subsequent report by Cowell (512) helped to popularize this approach, and the following reports have validated the success of this operation (513–515, 520, 536, 537). Between 80% and 90% of patients who have excision can expect an acceptable result. Some surgeons believe that talar beaking represents arthritis of the talonavicular joint and therefore a contraindication to this surgery. It has been pointed out, however, that this change is actually extra-articular and probably the result of the excessive motion at this joint, producing traction on the ligaments. It would appear from the reported results that talar beaking is not a contraindication to this procedure.

Mubarak et al. (513), in 2009, reported the advantages of using free fat, rather than the EDB, as the interposition material to be lower reossification and reoperation rates and improved cosmesis. The combined procedure of resection and soft-tissue interposition, compared with resection alone, has been shown to decrease the incidence of recurrence and to increase the incidence of long-term pain relief (512–515). (Fig. 29-139).

Resection of a calcaneonavicular coalition with muscle or fat interposition is indicated in a patient younger than 16 years of age who has a cartilaginous bar with no other coalitions present and no degenerative arthrosis, and who has undergone unsuccessful nonsurgical treatment (513, 514). The upper and lower age limits, the coalition tissue type, and the influence of coexisting coalitions have not been scientifically established.

Prior to resection of a calcaneonavicular coalition, one should ensure that a second coalition is not present by analysis of a CT scan of the hindfoot. The absence of degenerative changes in the talonavicular joint and calcaneocuboid joint should be ensured. Significant degenerative arthritis is a contraindication to surgical excision. Cooperman et al. (516) demonstrated significant variation in the extent of the fusion of the anterior aspect of the calcaneus with the navicular. In his analysis of 30 specimens, the anterior facet of the subtalar joint was totally spared in 8. The anterior facet was partially replaced in 7 of 30 specimens and completely replaced in 15. This variation in the anterior portion of the subtalar joint related to calcaneonavicular coalitions may result in some variation in outcome and certainly relates to the extent and depth of the resection required to adequately treat this problem. Failure to resolve symptoms with excision is often related to inadequate resection at the time of the primary procedure (504). Upasani et al. (504) used CT scan analysis to show that calcaneonavicular coalitions are usually 25 mm deep (from dorsolateral to plantar-medial) and wrap under the head of the talus. They suggested using a preoperative CT scan for surgical planning.

The role of surgical resection of a talocalcaneal coalition is less clear. This coalition is located on the tension side of the valgus deformity of the hindfoot, and further progressive flattening of the arch may occur following resection. Investigation has only recently focused on a historically frequently quoted, but unproven, statement in the literature that a talocalcaneal coalition should not be resected if it occupies greater than one half of the width of the subtalar joint surface (517). Wilde et al. (518)reported unsatisfactory results of resection in feet in which the ratio of the surface area of the coalition to the surface area of the posterior facet was >50% (as determined by CT mapping of the entire joint). There was excessive valgus deformity of the hindfoot in all of these feet, measured on the coronal CT images as >16 degrees. Many of the feet with poor outcomes also had narrowing of the posterior facet (indicating secondary ankylosis of the largest and most important facet of the subtalar joint) and impingement of the lateral process of the talus on the calcaneus. The independent influence of the size of the coalition was not determined by this or any study to date. These are, however, the most objective criteria for determining the resectability of a talocalcaneal tarsal coalition. Luhmann and Schoenecker (519) reported that there were good postoperative results following resection in feet with valgus deformities of <21 degrees and with middle facet

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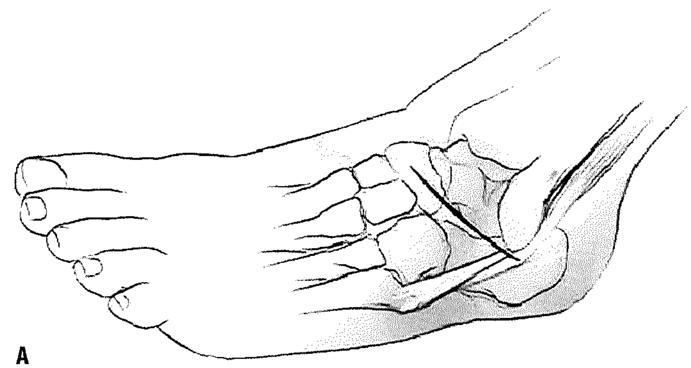
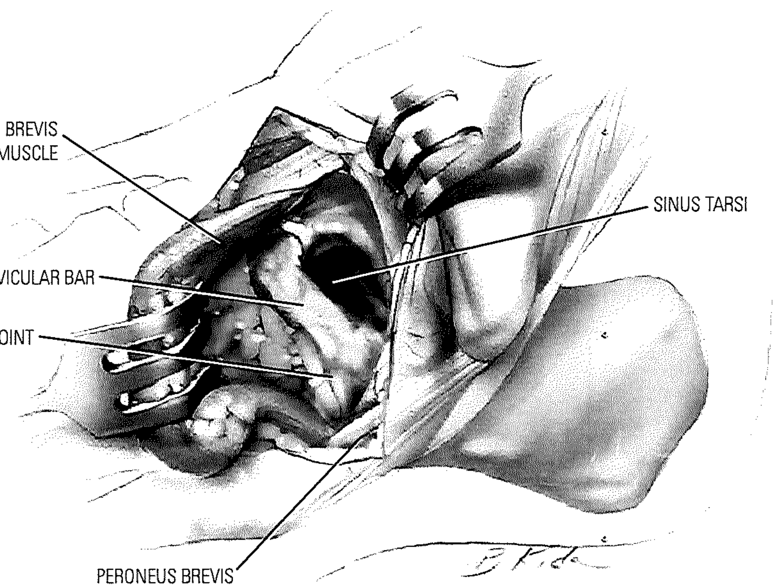
Resection of Calcaneonavicular Coalition (Figs. 29-135 to 29-138)



A



B

FIGURE 29-135. Resection of Calcaneonavicular Coalition. The calcaneonavicular bar is approached through an Ollier incision on the dorsolateral surface of the foot. The incision may extend from the extensor tendons to the peroneal tendons in a skin crease over the coalition **(A)**. This incision is placed directly over the bar that is an extension of the anterior process of the calcaneus up to the navicular. With experience, this incision can be relatively small when placed directly over the coalition. It is important that the initial incision be made through the entire layer of skin, subcutaneous tissue, and fascia overlying the extensor brevis muscle, without undermining the wound edges. This is very thin skin that must be handled with care. The fascia of the extensor brevis muscle is opened and elevated proximally off the muscle itself. After exposing the proximal origin of the extensor brevis muscle, an incision is made into the fibrofatty tissue deep into the sinus tarsi. These portions of the fibrofatty tissue and the extensor brevis muscle are dissected distally as a unit, exposing the bar connecting the anterior end of the calcaneus and the navicular, as well as the calcaneocuboid joint **(B)**. Although the illustration shows a far more extensive dissection than necessary, it is advisable to expose a small portion of the talonavicular and calcaneocuboid joints to gain proper orientation to the coalition. This distally based flap of soft tissues will either act as the interposition material or will cover a free fat graft that can be used as an alternative interposition material.

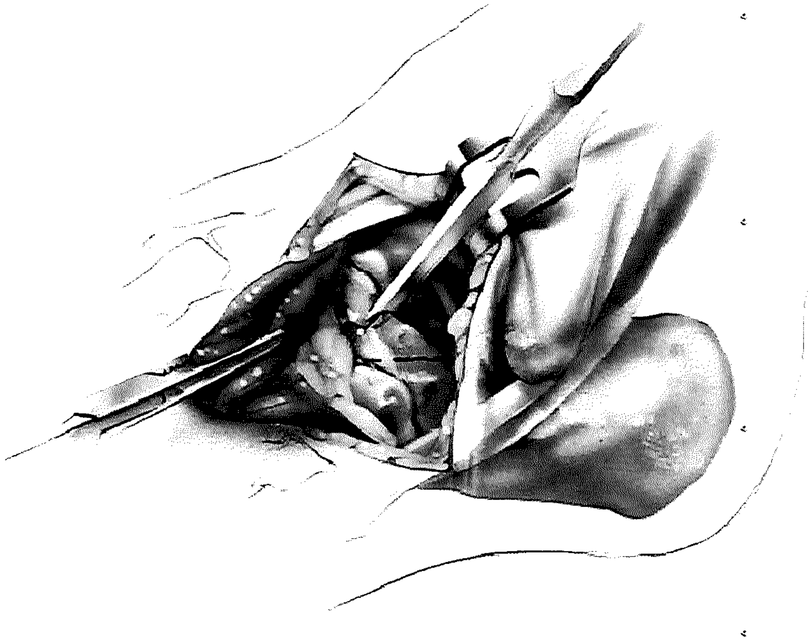


FIGURE 29-136. A hemostat or suture can be placed on the fibrofatty tissue to retract it and the extensor brevis muscle out of the way without damaging the muscle. At this point, the anatomy should be easily visible, showing the coalition. An understanding of the normal anatomy is important in planning the excision. If too much is excised, the joints will be violated. If too little is excised, motion will not be restored and the bar may re-form. The most common error is to excise too little bone from the plantar-medial corner of the bar. It is important that the piece of bone excised is trapezoidal and not triangular. A 1/4-inch or 1/2-inch straight osteotome is used to excise the bar. Good exposure of the sinus tarsi, where the calcaneus and the talus are in close approximation, will aid in directing the osteotome in the correct direction. If the surgeon is unsure, an image intensifier may be used.

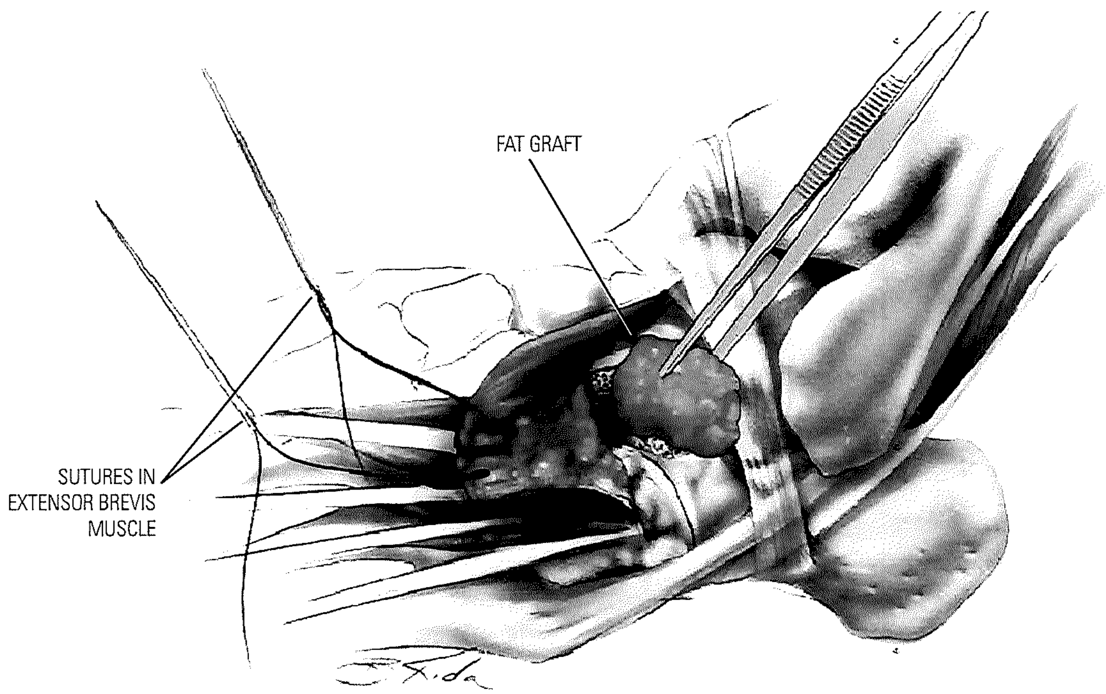


FIGURE 29-137. After the bar is excised, the surgeon should be able to see a distinct gap separating the anterior aspect of the calcaneus and the navicular. In addition, examination of the foot should confirm that subtalar motion is restored. It should be possible to displace the origin of the extensor brevis muscle into this gap between the calcaneus and the navicular that was created by removal of the bar. It is preferable to insert a free fat graft from the buttock crease area and cover it with the EDB. A heavy absorbable suture is threaded through the end of the extensor brevis muscle, and a long, heavy, straight Keith needle is threaded onto each end of the suture.

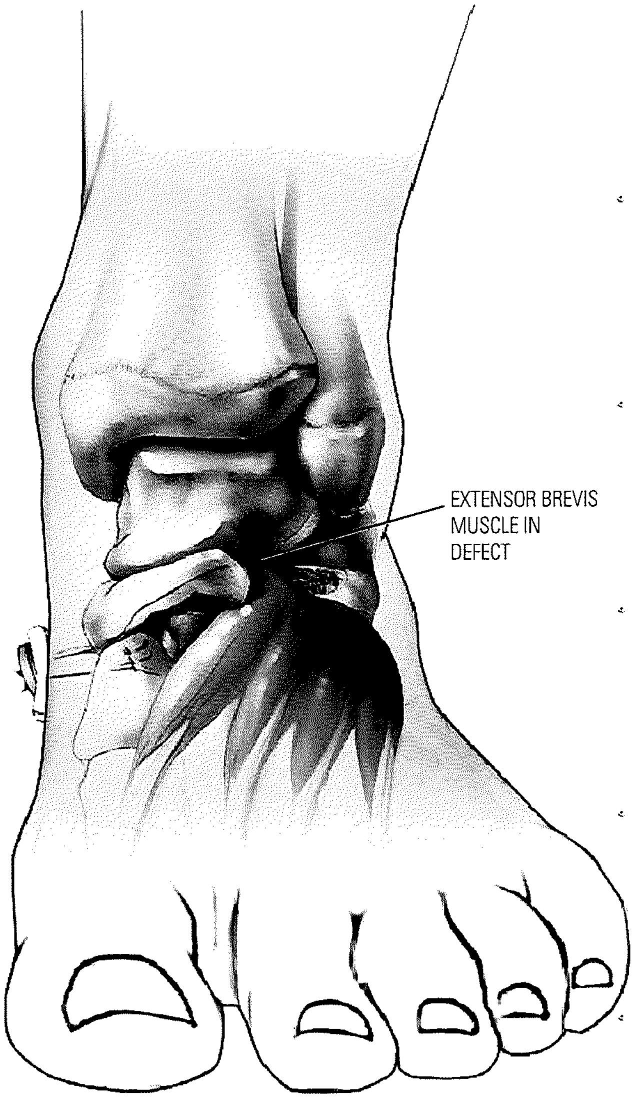


FIGURE 29-138. If the extensor brevis is used as the interposition material, two straight Keith needles are passed through the gap that was left by the excision of the bar and out through the skin on the medial side of the foot. As the needles emerge, they are passed through a small piece of sterile foam or felt and a sterile button. Bone wax may be placed on the cut bone ends. A forceps is used to guide the muscle deep into the defect while the suture is pulled through and tied over the button on the medial side of the foot. This should result in the muscle being interposed between the cut ends of the calcaneus and navicular. Placing both sutures on one needle lessens the chance that a nerve or other structure will be trapped between the two sutures. Alternatively, a free fat graft from the buttocks or elsewhere in the extremity can be obtained for use as the interposition material. The extensor brevis is then used as a cover and graft position-maintainer as it is sutured back to its origin. The wound is closed with interrupted absorbable sutures in the deep layer of muscle fascia and subcutaneous tissue that was carefully preserved at the beginning of the operation. The skin is closed with care to evert the skin edges. A short-leg cast is applied. The patient remains non–weight bearing in a lightweight short-leg cast for 2 to 3 weeks. After the cast is removed, the patient remains non–weight bearing on the operated foot for an additional 3 to 4 weeks while performing active range of motion exercises multiple times per day. Thereafter, partial weight-bearing crutch gait progresses to full weight bearing based on comfort and strength.

A

B

C

FIGURE 29-139. **A:** Oblique radiograph of the foot of a 10-year-old girl with a 1-year history of foot pain demonstrating an incomplete calcaneonavicular coalition. **B:** Note the incomplete coalition in the opposite asymptomatic right foot. **C:** One year after resection of the coalition, no reformation of the bar has occurred.

involvement of more than 50%. However, valgus deformities in excess of 21 degrees required postoperative bracing and had compromised results.

Degenerative arthrosis associated with either coalition is considered to be a contraindication to resection, but that diagnosis is difficult to establish. Historically, the presence of a dorsal talar beak was considered to be evidence of degenerative arthrosis (Fig. 29-133). That theory has been replaced with the belief that the beak represents a traction spur, since it recedes with successful resection of the coalition. Its presence is, therefore, not a contraindication to resection (517, 518, 520, 521).

Successful resection and interposition grafting of talocalcaneal coalitions (Figs. 29-140 to 29-143) has been reported in up to 89% of cases at 10 years follow-up (522), although most pub-

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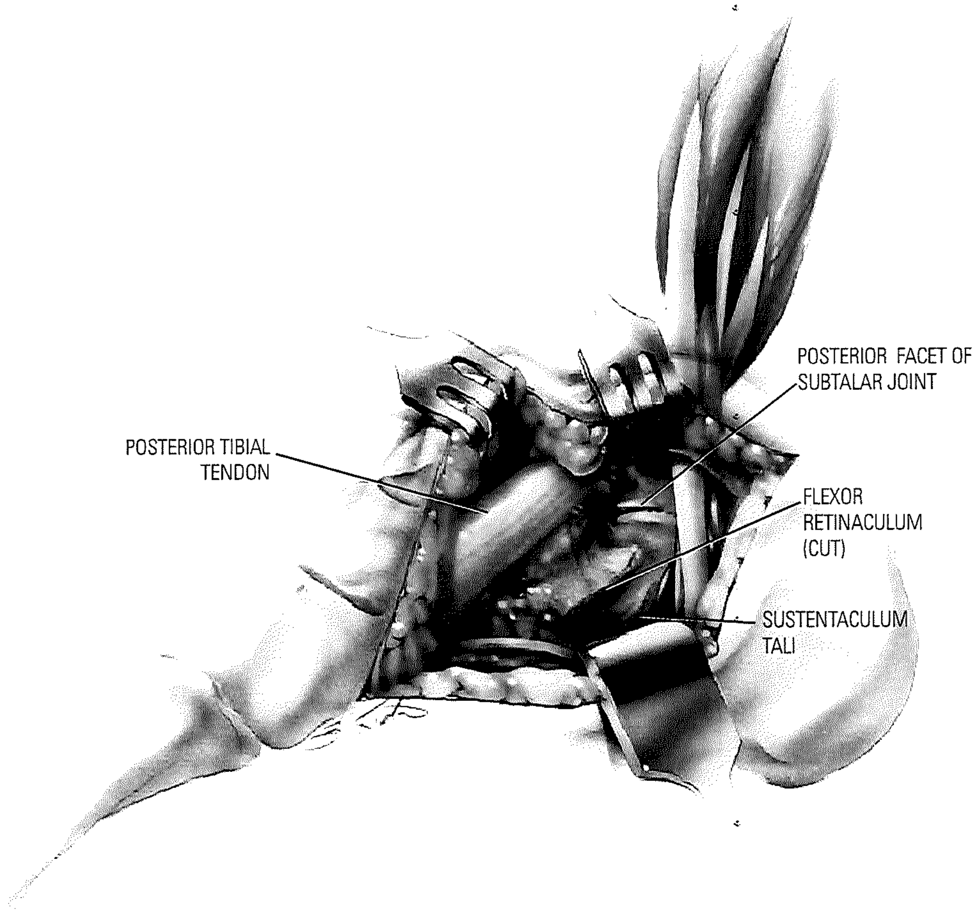
Resection of Talocalcaneal Coalition (Figs. 29-140 to 29-143)

A



B

FIGURE 29-140. Resection of Talocalcaneal Coalition. A slightly curved incision about 5 to 6 cm in length is made over the sustentaculum tali following the course of the FDL tendon **(A)**. The incision should extend from the prominence of the navicular to the area posterior to the posterior facet of the subtalar joint. If muscle fibers of the abductor hallucis are encountered, they are reflected plantarward. The flexor retinaculum, which overlies the sustentaculum tali, must be opened to allow the FDL tendon, along with the neurovascular bundle, to be retracted plantarward. The flexor hallucis longus tendon, which runs just beneath the sustentaculum tali, can also be retracted out of the way. The posterior tibial tendon can be identified running above the sustentaculum tali. At this point, the coalition will not be apparent because it lies beneath the periosteum and the sheath of the FDL **(B)**.

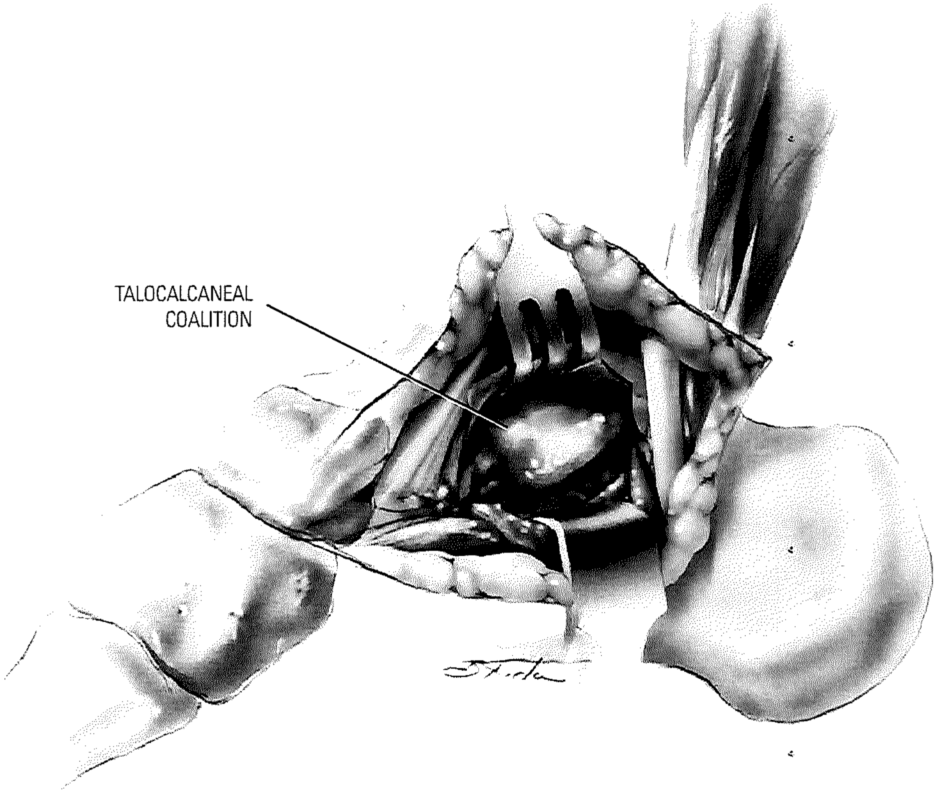


FIGURE 29-141. To expose the coalition and define its anterior and posterior boundaries, an incision is made in the periosteum slightly to the dorsal side of the prominence, which is the sustentaculum tali and the middle facet coalition. The periosteum, including the sheath of the FDL tendon, is elevated off of the bony prominence and reflected volarly. This should be done with care because, although this periosteum is often thin, it will be necessary to approximate it later to hold the fat graft in place. This dissection should be carried far enough anteriorly and posteriorly to identify normal joint space. The medial aspect of the coalition and its anterior and posterior boundaries are now identified. The lateral extent of the coalition can be judged from the preoperative computed tomographic scans. It is a good idea at this point to test the motion of the subtalar joint. Some slight motion may be observed in the normal parts of the joint that are exposed. This will be useful for comparison after excision of the coalition.

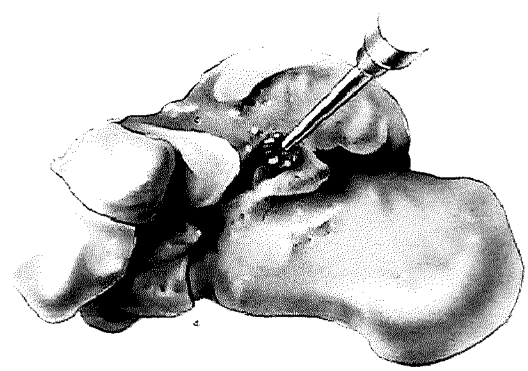


FIGURE 29-142. To begin the excision of the coalition and preserve as much of the sustentaculum as possible, it is helpful to define the exact location of the coalition within the bony mass. To accomplish this, a small osteotome can be used to shave off thin layers of bone until the fibrous or cartilaginous coalition is identified. This is possible only when the coalition is not completely ossified. If it is completely ossified, its removal can be guided by the normal joint surfaces distal and proximal. Using a small rongeur or a power burr, the coalition is excised. The excision should not be unnecessarily wide, and as much of the sustentaculum tali as possible should be preserved. The removal of synchondrosis and bone is continued until the two matching articular surfaces of the anterior facet and those of the posterior facet are seen. A laminar spreader can be inserted into the resection cavity to gently distract the subtalar joint. There should be little resistance to vertical distraction of the anterior and posterior facets. At this point, subtalar motion should be improved markedly.

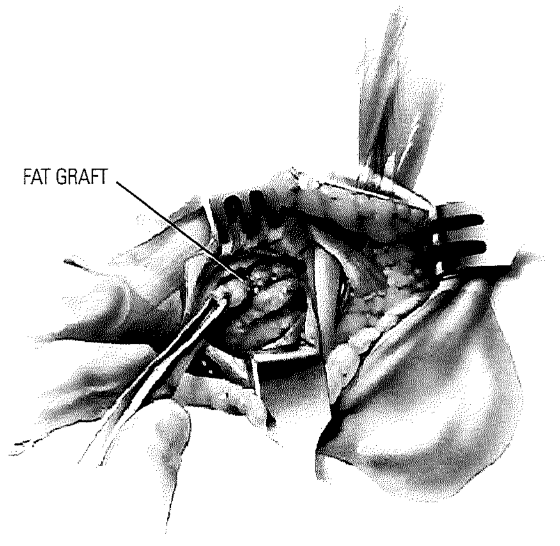


FIGURE 29-143. The final step is to interpose fat between the two bony surfaces. This can be obtained most easily from the area on the dorsal surface of the calcaneus between the posterior facet and the Achilles tendon. However, there is often not enough fat at that location. My preference is to obtain the graft through a transverse incision in the ipsilateral buttock crease where the fat supply is unlimited and the scar is cosmetic. The bony surfaces can be sealed with bone wax to lessen the bleeding that might tend to displace the fat graft. The fat is carefully pushed into the defect created by the excision, with care taken to ensure that it reaches the depth of the excision. It is held in place by approximating the periosteum with small sutures. The tendons can be returned to their sheaths, which can be approximated with fine absorbable sutures. The subcutaneous tissues and the skin are closed, and a short-leg cast is applied. The patient remains non–weight bearing in a lightweight short-leg cast for 2 to 3 weeks. After the cast is removed, the patient remains non–weight bearing on the operated foot for an additional 3 to 4 weeks while performing active range of motion exercises multiple times per day. Thereafter, partial weight-bearing crutch gait progresses to full weight bearing based on comfort and strength.

lished and unpublished studies have documented a lower success rate at even shorter follow-up (518, 520, 523). The poor results have been attributed to poor indications, although the actual reasons for poor results or early recurrence of symptoms are at best conjectural. Interposition can be with fat (517, 524) or a split portion of the flexor hallucis longus tendon (523).

Historically, resection of a persistently symptomatic talocalcaneal coalition was not popular because of the uncertainty of the outcome (507, 520). However, several reports have documented success with this procedure (517, 522, 524, 538). The use of computed tomographic scanning to determine the extent of joint involvement before undertaking surgical excision may to some extent account for the greater success of this procedure. Exactly how much of the joint may be involved and how successful a result can be achieved are not known.

Scranton (517) did not recommend excision if more than 50% of the joint was involved. Most patients with symptomatic talocalcaneal coalitions also have significant fixed valgus of the hindfoot. Excision of this coalition does not result a full restoration of subtalar motion and it does not correct the hindfoot valgus deformity. For this reason, it is worth considering an additional procedure at the same time as the excision—a valgus correcting osteotomy of the calcaneus.

Documented degenerative arthrosis (particularly in adults), persistent or recurrent pain and/or deformity following resection of a coalition, and large irresectable coalitions (based on the study by Wilde et al. (518)) with severe valgus deformity are considered by some authors to be indications for a triple arthrodesis (481, 518). However, the known poor long-term results of triple arthrodesis (19–21, 26, 27) make this an undesirable option, particularly for children and adolescents.

In feet with severe valgus deformities, the pain is often related to the deformities themselves, and not the coalitions. There is pain, tenderness, and callus formation under the head of the plantar-flexed talus, essentially identical to the signs and symptoms found in flexible flatfeet with tight Achilles tendons. These feet often have large osseus talocalcaneal coalitions along with contracture of the gastrocnemius or the entire triceps surae. Osteotomies performed to improve alignment of the foot, with or without resection of the coalition, are alternatives to triple arthrodesis. The posterior calcaneus medial displacement osteotomy, with or without a medial closing wedge, can be considered (235, 524, 525), though those procedures do not realign the talonavicular joint or correct the rotational deformity of the subtalar joint. The calcaneal lengthening osteotomy, conceptualized by Evans (236) and elaborated by Mosca (237, 238), has been shown by Mosca and Bevan (526) to correct all components of the everted/valgus deformity of the hindfoot and relieve symptoms, even in feet with large, unresected osseous coalitions in the middle facet of the talocalcaneal joint. This osteotomy should be considered for the rigid flatfoot with severe valgus deformity of the hindfoot, contracture of the Achilles tendon, pain under the head of the talus, and little-to-no degenerative arthrosis of the talonavicular and calcaneocuboid joints. According to Mosca and Bevan (526), it can be performed as an isolated procedure if the coalition is unresectable, based on the criteria of Wilde et al. (518). It can also be performed with concurrent or staged resection and interposition grafting in a foot with severe valgus deformity and a resectable cartilaginous coalition.

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