FOOT & ANKLE INTERNATIONAL

The Subtle Cavus Foot, ''the Underpronator,'' a Review

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ABSTRACT

Subtle cavus foot deformity is ubiquitous, yet it continues to be commonly missed. Simple physical examination maneuvers can provide information that allows well-planned nonoperative care and selection of operative procedures to correct the underlying cause as well as presenting pathology.

INTRODUCTION

Interest in relating the structure of the foot to pathologic conditions has existed for many years.[15,28] Most of what has been written is about flatfoot and its resultant pathologic conditions, such as posterior tibial tendon insufficiency, bunions, clawtoes, metatarsalgia, and ''idiopathic'' lesser toe synovitis.[12,31,34,47] At the opposite end of the spectrum, however, the cavus or high-arched foot has received much less emphasis.[19] It is somewhat puzzling why this is so, because cavus foot deformities probably are almost as common as flatfoot deformities. With a careful, simple clinical examination, a cavus foot can be readily identified, and the presenting pathological conditions can be easily related to the foot type.

REASONS FOR MISDIAGNOSIS OF CAVUS FOOT DEFORMITY

Three factors contribute to the failure to recognize this type of foot deformity. First, there seems to be a belief, probably fostered in the pediatric rotations of the orthopaedic residency programs, that almost all cavus feet are the result of neurologic causes manifesting themselves in the childhood years.[45] As a result of this training, the diagnosis may not be considered in an adult patient, particularly if the deformity is subtle. Certainly, the most severe cavovarus deformities occur in the pediatric population, but a much more subtle type, which appears to be nonneurologic, probably is genetic and seems to be a familial form that is commonly present in adults. It usually presents in a subtle form, making it difficult to diagnose. To confuse matters, types of cavus feet that bridge from childhood into adulthood also exist, as seen in Charcot-Marie-Tooth disease, but these neurologically-produced types usually are diagnosed readily by the extreme deformities, typical severe muscle imbalances, and very strong family histories.

Second, it is somewhat difficult to objectively look at ''arch height'' or even heel varus during physical examination. Extremes of flatfeet usually are quite obvious, and even very high arches and varus heels may be easily diagnosed. The very common subtle cavus foot (SCF), however, is more difficult to identify and therefore often overlooked.

Last, no simple clinical sign has been widely recognized to identify the SCF. The late Ken A. Johnson, MD, popularized the ''too-many-toes'' sign and made the diagnosis of the flat, posterior-tibial-tendon-insufficient foot commonplace. In fact, he stated that ''when this material is presented at a meeting someone invariably states that they have never seen one. A couple of weeks later they identify their first one.''[16] His efforts in popularizing this sign are greatly responsible for many of the recent advances in the treatment of this disorder. He emphasized the importance of observing the foot morphology with the patient standing.

THE PEEK-A-BOO HEEL SIGN

In 1993, the ''peek-a-boo heel'' sign was first described in an article about lower leg contractures after compartmental syndrome of the leg.[25] The heel pad could be seen easily from the front with the patient

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standing and feet aligned straight ahead (Figures 1 and 4). In a normal foot, the heel pad is not visible on the medial side of the foot when viewed from the front because of the slight amount of valgus positioning of the average heel, which places the heel pad behind the normal hindfoot. When viewing from the rear, it is somewhat difficult to tell if heel varus exists, as there are no nearby landmarks (Figures 2 and 5). With heel varus it is relatively easy to see if the heel pad sticks out medially when viewing from the front, and how much of it is visible.[4] The two sides also can be compared. Extremely small degrees of heel varus can be detected in this manner. This sign appears to be much more sensitive than the more routine observation of heel morphology from the rear. We have used this sign for the past 10 years and have found it to be just as valuable for diagnosis of SCF as the ''too-many-toes'' sign is for the posterior-tibial-tendon-deficient foot. Using this sensitive sign to identify even very mild cases of cavus feet has enabled us to observe the association of a SCF to many of the common pathologic orthopaedic foot and ankle conditions (Table 1).

After the diagnosis of a varus heel is made in this manner, it should be confirmed by looking at the patient from the rear. Almost universally, observers are more comfortable making the diagnosis of heel varus when they view the ''peek-a-boo heel'' from the front rather than the rear (Figures 1, 2, 4 and 5). Confirmation by viewing from the rear is particularly valuable when a false positive ''peek-a-boo heel'' sign may be present in an individual with a very large heel pad or severe metatarsus adductus who externally rotates the lower extremities through the hips to stand facing ''straight ahead.'' This compensatory maneuver allows the heel pad to be seen medially, but the heel may not actually be in varus.

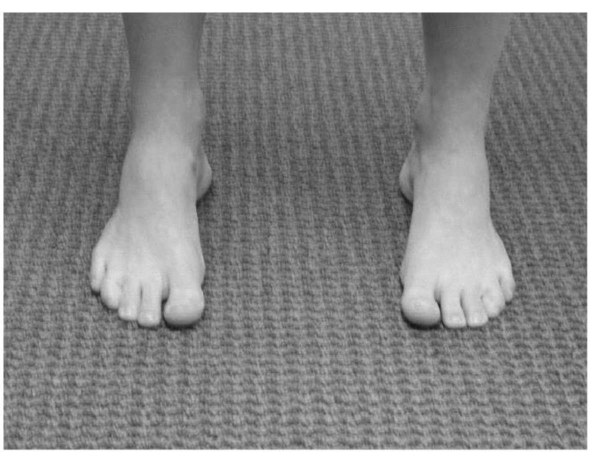

Fig. 1: Case 1. A moderately severe case of familial foot cavus in a 22-year-old woman is shown which illustrates bilateral peek-a-boo heels.

Fig. 2: Case 1. Bilateral heel varus is evident when the patient is viewed from behind.

Fig. 3: Case 1. Excellent correction of heel varus using the Coleman block test is seen. This illustrates the concept of forefoot-driven-heel varus, as the plantarflexed first ray tips the heel into varus. The effect if the plantarflexed first ray is negated by dropping it off of the side of the block.

INCIDENCE

Although the real incidence of cavus feet is currently unknown, a bell-shaped curve probably exists with high-arched cavus feet on one side and flatfeet on the other. Improved recognition of the radiographic and clinical signs of the SCF (the ''peek-a-boo heel'' sign, heel varus) should increase the recognition of this type of foot posture, and make possible improved epidemiological studies.

A preliminary study of a year-long patient log of a certified pedorthotist (BG), who fabricates foot orthotics for eight members of the American Orthopaedic Foot and Ankle Society and others, revealed that slightly over half of all patients were fitted with cavus foot orthoses.[23]

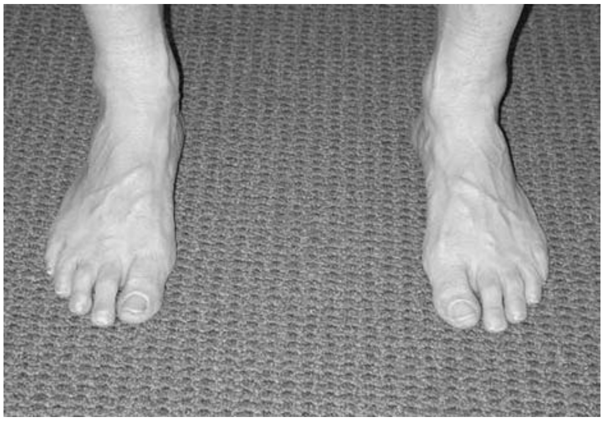

Fig. 4: Case 2. A typical patient with subtle cavus feet is shown. His feet demonstrate peek-a-boo heels bilaterally.

Fig. 5: Case 2. Bilateral heel varus is seen. It is easier to visualize the heel varus using the peek-a-boo heel technique seen in Figure 4 than in looking at the heels from the rear.

Ledoux, et al.[20] reviewed clinically and radiographically the foot posture of 2047 diabetic patients and found that 57% of patient had neutral feet, 24% had pes cavus, and 19% had pes planus. Surprisingly, more cavus feet than flatfeet were seen in this diabetic population.

EVALUATION

After the diagnosis of heel varus is made, a simple standard technique, generally first learned in pediatric orthopaedics, is necessary to further understand the characteristics of the cavus foot. Even if the patient is over adolescent age, a Coleman block test should be done.[10] In a recent discussion of this subject with an ''adult foot surgeon,'' he expressed shock that this test would be used in an adult. He stated that ''you can tell the same thing by just moving the foot around.''[36] A weightbearing evaluation is preferable.

The Coleman block test is performed by first observing the patient from the rear and noting the amount of heel varus.[10] The patient is then asked to stand on a 1-inch block of wood or a book. The great toe and the first metatarsal head are then dropped over the medial side of the block. Any change in the varus positioning of the heel is observed (Figures 3, 6, A and 6, B). If there is improvement of the heel varus to a normal, slightly valgus position, then two things are known: 1) the subtalar joint complex is supple, and 2) a plantarflexed first ray is ''driving'' the heel into varus, because of the tripod effect of the foot. This is termed ''forefoot-driven-hindfoot-varus.''[10] The tripod effect refers to the first and fifth metatarsal heads and the heel as points of a triangle in a common plane. Deviation of one of the points affects the plane. Here, a

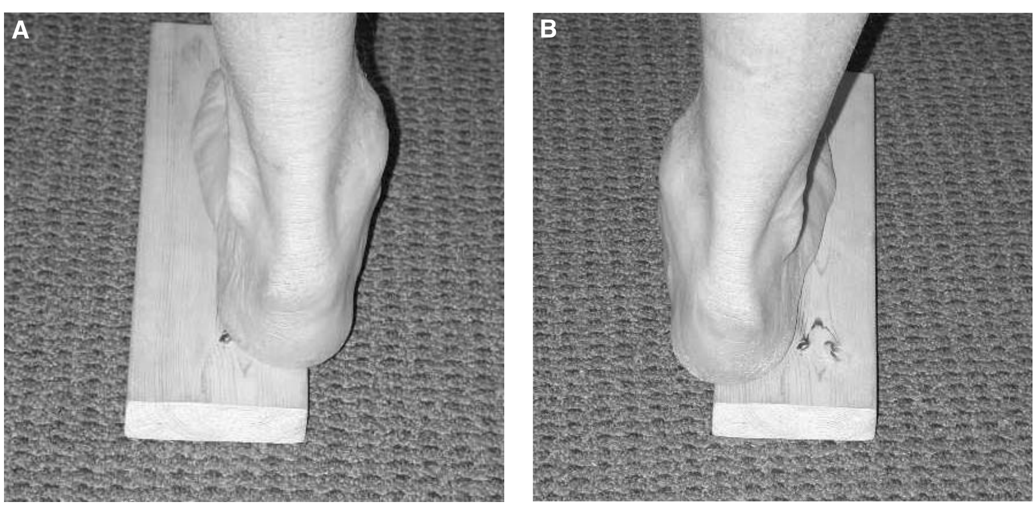

Fig. 6: A and B: Case 2. There is good correction of the heel varus bilaterally using the Coleman block test.

plantarflexed first metatarsal hits the floor first and tips the entire plane into varus.

ETIOLOGY

From our clinical observations and demographic data, this entity is believed to be idiopathic, familial, and having poorly delineated genetic determinants. This may even be considered a ''normal variant,'' except that there are a number of pathologic conditions associated with this type of foot. Other more obvious causes that also are seen include old clubfeet, polio, rheumatoid arthritis, residuals of compartmental syndromes, and sequelae of midfoot, talar, or calcaneal fractures. Rarely, talocalcaneal, or calcaneonavicular coalitions may be associated with a subtle cavus foot deformity.[2,46]

Severe cavus foot deformity associated with neurologic disturbance is relatively unusual in adults. The volume of neurologically-caused cavus deformities seems to be dependent on referral patterns and varies from clinic to clinic. The neurologic syndromes of Charcot-Marie-Tooth disease, other central and peripheral degenerative neurologic syndromes, spinal cord neoplasms, or even a herniated nucleus pulposus may cause extreme, progressive deformities.

FOOT MORPHOLOGY AND BIOMECHANICS

The SCF has a number of definite characteristics. The primary deformity is a plantarflexed first metatarsal.[29] In addition to increasing arch height, this plantarflexed position results in the medial aspect of the forefoot striking the ground first during the foot-flat and heel-rise portions of the gait cycle. When the head of the first metatarsal strikes the ground, the hindfoot can no longer evert at the subtalar and midtarsal articulations as it does immediately after heel strike. Because of the tripod effect, the foot and ankle tip into varus and lateral ''ankle'' instability is felt. Mosca suggested that the plantarflexed first metatarsal probably is caused by hyperactivity of the peroneus longus muscle and is ''flexible'' initially.[29] We call this ''peroneal overdrive.'' With time, the deformity becomes ''stiff'' then ''rigid.'' The subtalar complex of the hindfoot lags behind the ''flexible-stiff-rigid'' pattern in the forefoot, but gradually the same sequence occurs. A fixed heel varus is the ultimate final stage. The foot eventually becomes stiff and loses the ability to absorb shock. With time, the entire forefoot develops a ''pronated'' position, and the hindfoot becomes fixed in varus. In flatfoot deformity, the opposite is seen: as the forefoot is supinated and the heel is in valgus.

Clinically, most patients have a tight gastrocnemius muscle. Using the Silverskiöld test, the gastrocnemius muscle can be isolated from the remainder of the triceps surae complex. If the patient has no passive ankle dorsiflexion with the knee extended, and the ankle can be dorsiflexed to approximately 5 degrees above neutral with the knee flexed, gastrocnemius muscle tightness exists.[11]

Forefoot pronation also has a deleterious effect on ankle dorsiflexion: with the first ray plantarflexed, there is a functional forefoot equinus. The plane of the weightbearing portion of the foot is more plantarflexed than normal because the plantar aspect of the first metatarsal head is plantar to the heel.

Finally, as the ankle is plantarflexed by the tight gastrocnemius muscle, the vector line of action of the peroneus longus tendon becomes more advantageous to plantarflexing the first ray than does the vector line of pull of the antagonist muscle-tendinous unit, the anterior tibial tendon (Figure 7).[44] The chronic muscle imbalance that exists as the peroneus longus overpowers the anterior tibial tendon is thought to be the reason that mild cavus deformities may progressively worsen in patients with equinus deformities.[3]

ASSOCIATED PATHOLOGY

Commonly, SCF results in recurrent inversion sprains of the ankle and occasionally the subtalar joint. Surgical reconstruction may be necessary, and the SCF may require correction in addition to reconstructing the lateral ligaments. In fact, a feeling of ankle instability may be present without actual loosening of the ligaments. This may be the situation that exists when people complain of instability and radiographic stress tests are normal.

A person with SCF walks on the outer border of the foot and may develop a proximal diaphyseal-metaphyseal fracture of the fifth metatarsal. Less commonly, stress fractures of the other lesser metatarsals, especially the base of the fourth occur.[42] Associated peroneal tendon pathologies include recurrent dislocation or subluxation, tendinitis, splitting, and os peroneum syndrome with either an ossified or nonossified os peroneum becoming fragmented and causing symptoms.[7] In addition, an enlarged, painful peroneal tubercle on the lateral calcaneus may be present.

Overload calluses under the base or head of the fifth metatarsal, metatarsalgia, and hallux sesamoiditis also may occur. Calluses under the first and fifth metatarsal heads may be indications of a SCF.

Excessive external rotation of the talus and tibia may result in varus strain at the knee joint, increased lateral collateral knee ligament strain, and iliotibial band friction syndrome.[26,27,37] Medial compartmental knee joint arthritis may develop in long-standing cases.

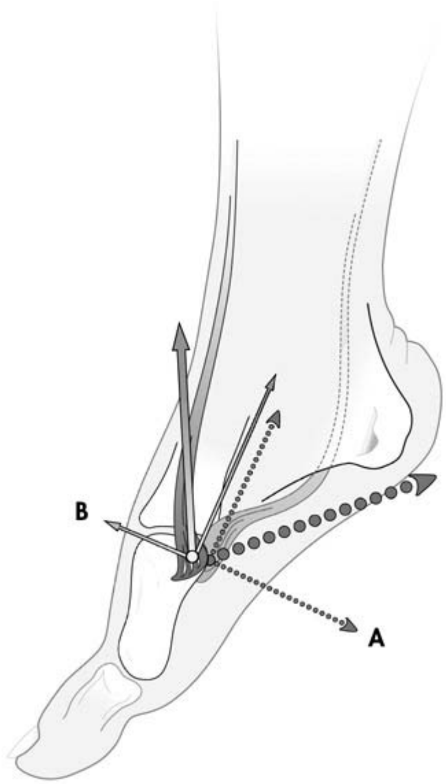

Fig. 7: Peroneal overdrive secondary to equinus deformity. The foot is in excessive equinus for illustrative purposes. The resultant forces in the anterior tibial muscle and the peroneus longus muscle are shown and are approximately equal (thick arrows).[43] Vector components demonstrate long peroneal muscle's (dotted large arrow) domination over the anterior tibial muscle (solid large arrow) on the sagittal motion of the first metatarsal. The plantarflexion vector of the long peroneal muscle (**A**) greatly exceeds the dorsiflexion vector of the anterior tibial muscle (**B**) when the foot is in equinus. The other component vectors simply act to compress the medial joints of the foot and the forces are wasted.

Table 1: Conditions Associated with the Subtle Cavus Foot

ankle instability
posterior fibula
recurrent instability after a lateral ankle ligament reconstruction
subtalar instability
peroneus brevis tendon split
peroneus longus tendon split
recurrent dislocation of the peroneal tendons
enlarged peroneal tubercle
painful os peroneum syndrome
enlarged distal fibula
Jones fracture of the 5th metatarsal
stress fracture of the base of the 4th metatarsal
callus under base of 5th metatarsal
calluses under 1st and 5th metatarsal heads concurrently
sesamoidal overload, chondromalacia, avascular necrosis
plantar fasciitis
vertical stress fracture, medial malleolus
metatarsus adductus with bean-shaped foot
midfoot arthritis
varus ankle arthritis
varus total ankle positioning postoperatively
medial compartmental knee arthritis
iliotibial band friction syndrome
stress fractures, tibia, fibula
exertional compartmental syndrome of leg, foot
tight gastrocnemius muscle

Because SFC frequently is associated with a tight Achilles tendon and tight plantar fascia, a painful plantar fasciitis may develop.[8,26] If ankle arthritis develops from talar tilt, ankle reconstruction may be necessary. SCF usually is present in patients with long-standing recurrent ankle sprains, and varus ankle arthritis.[14]

These stiff feet, without the usual shock-absorbing mechanisms, also may produce a vertical stress fracture of the medial malleolus, tibial or fibular stress fractures, leg or foot exertional compartment syndromes, shin splints, and other stress-related disorders of the ankle, knee, hip, and spine (Table 1).

RADIOLOGY

Routine radiographic examination should consist of standing anteroposterior (AP) views of both ankles (same cassette), both feet (same cassette), and lateral views of each foot and ankle together on the same cassette.[9]

Radiographic abnormalities are common with SCF. The intricate research parameters are extensively reviewed in a recent article by Ledoux et al.[20] In common practice, however, more simple measurements are necessary. In the lateral view, the axis of the talus, the medial tarsal bones, and the first metatarsal normally are aligned (Meary's line). In the SCF, the first metatarsal is plantarflexed. Other parameters easily seen are a high arch, with an increased distance seen between the bottom of the medial cuneiform and the bottom of the fifth metatarsal base;[9,13] posterior positioning of the fibula relative to the tibia as the axis of ankle motion is externally rotated (the ''sagittal breech'' as described by Lloyd-Roberts in the radiographs of clubfeet)[18,21,43] and dorsiflexion of the calcaneus.

Standing AP radiographs of the feet reveal hindfoot supination with a diminution of the normal talocalcaneal angle, with the long axis of both bones nearly parallel to each other. The metatarsals may overlap and metatarsal adductus is common.

The standing AP views of the ankles, taken together, allow comparison of the height of the feet measured from the floor to the top of the talar dome.[33] With a unilateral deformity, the cavus foot is taller in the arch. The talus is seen in an externally rotated ankle mortise, with the fibula being positioned posteriorly. Special views and additional studies may be needed to examine the foot further. Because a calcaneonavicular coalition may be present, an internal oblique view of the foot is needed. The internal oblique view also allows identification of a Jones-type fracture of the fifth metatarsal. Stress radiographs of the ankle and subtalar joint are needed to evaluate for chronic instability.

A CT scan may be needed if a talocalcaneal coalition or any other abnormality of the subtalar joint is suspected, as in patients with rheumatoid arthritis or old trauma. The CT planes should be in the semicoronal plane, perpendicular to the posterior facet of the subtalar joint, and the axial plane, parallel to the plantar surface of the foot. Occult stress fractures can be seen on bone scanning, which also is useful to identify painful arthritic conditions, such as degenerative arthritis in the tarsometatarsal area that may develop in a high arch.

TREATMENT

After SCF is diagnosed, the specific problem causing the patient's complaints should be defined. Treatment of the foot deformity often is necessary in combination with treatment of the area causing specific symptoms. If the foot deformity is ignored, recurrent symptoms may develop. Lateral ankle ligament reconstructions for instability, in particular, are prone to failure if the underlying cavovarus foot is not treated.[18,43]

Nonoperative treatment

Rigid orthoses molded to the cavus usually excerbate symptoms associated with foot stiffness and reduced shock-absorbability and can cause stress-related metatarsal fractures. Nonoperative treatment should begin with a combination of gastrocnemius muscle stretching exercises and specialized foot orthoses. These modalities generally are used for 2 to 3 months.

Our experience indicates that approximately three of four patients have improved stability or pain relief with the use of the custom orthoses designed especially for SCF. However, because the widespread use of custom orthoses is limited by a practitioner's experience, resources, patient cost, and reimbursement potential, the need for a simpler, cheaper alternative was identified. To treat the SCF cost-effectively and consistently, we developed and patented the Cavusfoot Orthotic® (djortho, Vista, CA). This prefabricated orthosis was designed based on the principles proposed by Bordelon for treatment of the cavus foot in children.[5,6] The design features of the Cavusfoot Orthotic® (CFO) include an elevated heel to cushion the heel and accommodate a tight gastrocnemius muscle and a recess under the first metatarsal head to accommodate the plantarflexed first ray and allow some degree of hindfoot eversion, provided it is supple. A forefoot wedge, beginning just lateral to the first metatarsal recess, extends to the lateral border of the device to mirror the forefoot pronation. The medial arch height is actually reduced to allow hindfoot eversion.

All other custom or prefabricated orthoses that we have seen are made either to correct a pronated flatfoot or to support a cavus foot arch. Even when the forefoot portion has been correctly fashioned with a medial recess for the first metatarsal head and a lateral forefoot post, the insert is still made to fit snugly against the under-surface of the arch, negating any possible hindfoot eversion the posting might allow.

Selecting the proper footwear is an important and often overlooked aspect of treating SCF. The upper portion of the shoe should be made of a soft, flexible material with widely-spaced lace openings to accommodate the prominent midfoot. The heel should be a little higher than the forefoot and flared to accommodate the forefoot equinus and provide some inversion stability to the SCF. The forefoot should have extra depth and an oblique toebox to reduce contact with any contracted toes. The sole should be more cushioned than rigid. Athletic shoes with medial posting or firmer materials focused along the medial aspect should be avoided, because these are designed to reduce heel eversion (pronation).

Many patients with SCF already have tried several pairs of pronation-control sport shoes. They either have been diagnosed as a ''pronator'' or told that their high arch requires extra support. The recommended shoe is a neutral-cushion running shoe. A straight lateral border is preferred over an hour-glass shape. Air chambers and cosmetic cutaways or scallops significantly weaken the shoe and may add to heel strike instability.

For business or dress, lace-ups are preferred over loafers and a shock-absorbing crepe sole is preferred over leather.

Varus knee arthritis often is treated with lateral heel wedges.[17,30,41,48] While simple wedges may bring relief of the knee pain, tipping a heel into valgus when there is a fixed plantar-flexed first ray may force the medial ray plantarward, causing an excessive pronation force throughout the foot. The resulting foot pain may be so severe that the treatment is discontinued. The use of the CFO for medial knee arthritis is recommended because it allows the heel to go into valgus, while accommodating a plantarflexed first ray.

Operative Treatment

Operative correction should be considered if there is no improvement or worsening of the condition after appropriate nonoperative treatment. In addition to correction of a specific pathologic problem, SCF also must be corrected if it is a contributing factor. A tight gastrocnemius muscle may require a gastrocnemius tendon lengthening procedure. We prefer a modified Vulpius lengthening through a medial incision, cutting through the gastrocnemius tendon alone and occasionally the soleus fascia if more lengthening is required.[32,40] For peroneal overdrive with a flexible plantarflexed first metatarsal, a peroneus longus-to-brevis transfer is done at the peroneal tubercle (resecting the tubercle). The tendon is allowed to gap approximately 1.5 cm. The distal peroneus longus tendon stump is transferred to the brevis tendon. This avoids the formation of a dorsal bunion.

Osteotomies are preferred to fusions whenever possible.[38,39] Stiff or fixed first metatarsal plantarflexion is treated with a V-type osteotomy of the bone, just distal to the tarsometatarsal joint.[3] It is fixed with a 4.0-mm screw, notching the dorsal cortex to avoid splitting.[24] Severe, entire forefoot pronation deformities also may require osteotomies of the second and third metatarsals. In addition to the metatarsal osteotomies, a V-type osteotomy of the midtarsal bones, through cuneiforms and cuboid, may be necessary in very severe deformities. All of these osteotomies can be done in patients who have a supple subtalar joint that corrects with the Coleman block test.

If the hindfoot is stiff and does not correct with the Coleman block test, a lateralizing heel osteotomy frequently is indicated. This is done through an oblique incision through the midportion of the calcaneal tuberosity, perpendicular to the axis of the tuberosity. The heel is translated laterally from 5 to 10 mm and fixed with two vertically-stacked 6.5-mm screws. If additional heel lateralizing is needed, this can be accomplished by cutting through at a different level, approximately 1 cm from the first one, at a later date. This results in a curved-type of calcaneus, with excellent function.

A calcaneal osteotomy is particularly useful in patients with recurrent sprains of the ankle as a result of heel varus[43] and can be used with either a supple or a stiff subtalar joint.

If significant deformity and stiffness exist, a triple arthrodesis is needed. The talonavicular, calcaneocuboid, and talocalcaneal joints are denuded of their articular cartilage, and fixed with 6.5-mm lag screws in the position of mild heel valgus. The forefoot is supinated as much as possible through the Chopart joints.[22] To avoid arthrodesis, Klaue[19] recommended a medializing-lengthening osteotomy through the talar neck to reposition the foot in severe deformities, with both supple and stiff subtalar joints.

In long-standing deformities, reducing the foot into the position of mild heel valgus with a triple arthrodesis will result in further plantarflexing an already plantarflexed first ray. If this is not corrected with a dorsiflexion osteotomy, the ankle will tip into varus postoperatively. Because the hindfoot joints usually are already stiff in severe deformities, there is little, if any, motion loss after a triple arthrodesis. A satisfactory plantigrade position is essential. It is important to recognize the effects that any operative procedure will have on the other parts of the foot (the forefoot-hindfoot alignment, in particular), because severe problems can result from ill-advised operations, especially if the subtalar joint is stiff and cannot adapt.

Associated Operations

Pathologies associated with SCF need to be corrected operatively as well as the structural components of SCF. Recurrent sprains of the ankle or subtalar joint can be treated with a tightening of the lateral ligaments, with or without augmentation. Peroneal tendon pathology may require suturing of a split peroneus brevis or longus tendon. Tightening of the superior retinaculum usually is done with this or with recurrent peroneal tendon dislocation. The fibula often has compensatory enlargement and may be huge. The peroneal groove may be shallow or convex and may need to be deepened. Painful os peroneum syndrome, in which the peroneal sesamoid fragments and separates, may require removal of the fractured bone, and peroneus longus to brevis transfer.[7] A Jones fracture may require screw fixation with or without a bone graft to ensure healing. Recent evidence shows that acute fixation may be the best option.[35] Most other metatarsal stress fractures are treated nonoperatively. Great toe sesamoid injuries occasionally necessitate removal of one of the bones. Degenerative midfoot arthritis may require multiple tarsometatarsal joint arthrodeses.

Progressive varus ankle arthritis may occur with SCF. The foot shape may be unrecognized for many years, during which the patient suffers recurrent ankle sprains. This arthritis may require either tibiofibular or heel osteotomies at an early stage, or an ankle fusion in late stages for pain relief.[14] The varus ankle with an underlying SCF is one of the most difficult reconstructive problems for total ankle arthroplasty. The prostheses that are minimally constrained often tip into varus postoperatively if an underlying SCF exists.[1] At a late stage, a stiff SCF is difficult to correct fully, making total ankle arthroplasty a formidable challenge with this type of ankle and foot deformity.

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