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The Use of Arthrodesis to Correct Rigid Flatfoot Deformity

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Abstract

Rigid adult flatfoot deformity ranges in severity and is caused by a variety of conditions. Treatment is based on the etiology, the severity of symptoms, the stage of the deformity, and patient goals. Posterior tibial tendon pathology, osteoarthritis, posttraumatic arthritis/deformity, inflammatory arthropathy, and neuropathic arthropathy are all known causes of adult flatfoot deformity. Regardless of the cause, treatment goals are the same—restore a plantigrade foot, decrease symptoms, and increase function. When nonsurgical modalities have failed, many surgical reconstructive options are available to restore anatomy and function.

Instr Course Lect 2011;60:311-320.

Anatomy and Pathophysiology

Rigid adult flatfoot deformity (AFD) can evolve over time from a flexible flatfoot deformity, beginning either in childhood or acquired later in adult life, commonly from a rupture of the posterior tibial tendon (PTT). Rigid hindfoot deformity in the adult can also be the result of trauma, osteoarthritis, inflammatory arthropathy, neuromuscular imbalance, or neuroarthropathy. In the child, this deformity results from various types of tarsal coalition or a congenital oblique or vertical talus. It has been shown that the triceps surae has the most significant arch flattening effect in the sagittal plane and also contributes largely to the abduction of the forefoot in the transverse plane.[1,2] As the anatomy of the foot changes, the weight-bearing axis is shifted medially as the hindfoot progresses into more valgus. The cumulative increase of force of the tight triceps results in an increased force across the arch, which weakens, leading to stretching or tearing of the spring ligament, the PTT, and the midfoot joint capsules.[3]

As the arch flattens, the talus plantar flexes and the calcaneus subluxates posteriorly. Consequently, the anterior process of the calcaneus does not support the talar head, and the forefoot and midfoot rotate dorsally and laterally around the talus, leading to a lack of coverage of the talus by the navicular. Continued dorsolateral peritalar subluxation leads to increased stress on the PTT. Whether a weak PTT leads to a deformity or is caused by a deformity is unclear, although it is known that the PTT weakens and may rupture through a degenerative process.[4] However, flatfoot deformity is not solely caused by a weak or ruptured PTT. As the talus assumes a more plantar-flexed position, the spring ligament attenuates or ruptures, leading to a nonlinear talar-first metatarsal axis. Although this deformity occurs predominantly at the talonavicular joint, similar subluxation may occur at either the naviculocuneiform or the tarsometatarsal joints. The plantar-flexed talus pushes the calcaneus further laterally and posteriorly, and the cuboid

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slides with the calcaneus, bringing with it the forefoot and therefore increasing abduction. As the deformity progresses, the calcaneus impinges against the fibula, which leads to another source of stress and lateral foot and ankle pain.[5] Combined with all these described changes, the added deformity leads to deltoid ligament attenuation, causing the ankle to tilt into valgus.[3] It is not clear why a rupture of the deltoid ligament develops in some ankles but not in others. Based on the experience of the senior author (MSM), when the talonavicular joint is severely subluxated, the stress on the ankle (and hence the deltoid ligament) may be minimized because most of the force on the medial ankle is directed across the talonavicular joint. With more rigid deformities, the valgus load on the ankle is greater, and the deltoid is subjected to greater stress and may be more prone to attenuation or rupture.

A rigid deformity implies that the hindfoot cannot be reduced into a neutral position with manual manipulation. The degree of rigidity varies; in some instances, there is absolutely no movement of the subtalar or transverse tarsal joint; in others, some flexibility remains at one of the joints. Also, when manually correcting the heel into neutral position from valgus, there is a very fixed supination deformity of the forefoot. This adaptive forefoot supination compensates for the fixed hindfoot valgus because the forefoot has to progressively supinate to maintain a plantigrade position.[6,7] This forefoot supination deformity may be associated with arthritis or instability of the first tarsometatarsal or the naviculocuneiform joint or with a fixed elevation of the first metatarsal or the entire medial column.

Flatfoot rigidity associated with tarsal coalition, trauma, and arthritides is easy to explain mechanically. The transition from a flexible deformity into a rigid deformity is poorly understood but is likely to represent a gradual mechanical change resulting from increased tension on the triceps surae that leads to flattening of the arch.[1-3] In 1939, Todd[8] suggested that the change from a flexible to a rigid deformity was caused by habitual overstrain in patients who are developmentally weak. In 1948, Lapidus[9] stated the transition was caused by injury to the interosseous ligament of the subtalar joint. The long-lasting incongruity of the affected joints leads to arthrosis, soft-tissue contractures, and, finally, a rigid deformity. It is likely that the gradual attenuation of the medial soft-tissue structures, including the PTT, the spring ligament, and the talonavicular capsule, is followed by contraction of the lateral soft tissues, including the peroneal muscles and the interosseous ligament. This is followed by adaptive changes in the periarticular capsuloligamentous structures, ultimately leading to the rigid deformity.

Patient Evaluation

It is useful to examine the patient while he or she is standing and walking. The entire lower extremity should be visible, and the foot should be inspected from the front, above, and behind the patient. With the patient standing and the examiner viewing from behind the patient, the patient should be asked to stand up on the toes of both feet and then one foot (a double- and single-limb heel rise). Patients with a rigid deformity are unable to perform a single-limb heel rise, and even a double-limb heel rise may be impossible because of weakness or pain. Regardless of the magnitude of the deformity, if the hindfoot is flexible, during the heel rise the hindfoot will transition into varus and the arch will reconstitute. The strength of the PTT is not relevant in the management of a rigid deformity, but the location of pain and tenderness is important. The range of motion of the ankle and the subtalar, transverse tarsal, and first tarsometatarsal joints must be evaluated because each component of the deformity, stiffness, and compensatory motion must be addressed surgically. Additional associated features of a rigid valgus deformity are subfibular impingement between the tip of the fibula and the lateral margin of the calcaneus and varying degrees of fixed lateral subluxation or abduction of the talonavicular joint, referred to as uncovering of the talar head. In a long-standing deformity, this may lead to callus formation under the plantar medial head of the talus as well as the navicular. These fixed articular deformities are in addition to the contracture of the peroneal tendons and the Achilles or the gastrocnemius muscle. With repetitive subfibular impingement, the fibula is compressed; this, in addition to the fixed valgus deformity of the hindfoot, can lead to a stress fracture of the fibula, which is generally approximately 6 cm proximal to the tip. The fibula usually heals in slight valgus, further perpetuating the valgus deformity of the hindfoot but now also potentially causing a valgus deformity of the ankle joint. Additional medial ankle pain can result from stretching the tibial nerve and tarsal tunnel syndrome.

In these patients, it is important to evaluate ankle stability in the coronal plane for both medial and lateral instability. The medial instability is straightforward and is associated with attenuation or rupture of the deltoid ligament. With chronic, rigid, hindfoot valgus deformity, the lateral aspect is compressed against the fibula, which can lead to erosion of the calcaneofibular ligament and ultimately to multiplanar coronal plane instability. The texture of the skin is important be-

cause patients with chronic, fixed, hindfoot valgus deformity, particularly those with any rheumatologic disease and any venous stasis, have taut lateral skin. When the foot is corrected from fixed valgus to a neutral position of the hindfoot, there is marked stretching of the lateral skin, which can lead to wound dehiscence and infection. If the skin is very taut laterally, it is preferable to use a medial approach to correct the hindfoot deformity, avoiding any lateral incision.

Weight-bearing radiographs are required, including AP and lateral views of the foot, a hindfoot alignment view, and an AP view of the ankle.[10] On the AP radiograph of the foot, the talonavicular coverage, the extent of forefoot abduction, and any secondary changes in the midfoot, including arthritis and/or deformity of the tarsometatarsal and naviculocuneiform joints, are evaluated. On the lateral foot radiograph, the talometatarsal angle (normal angle, 0° to 10°) and the distance of the medial cuneiform from the floor should be measured (normal distance, 15 to 25 mm), along with careful inspection for a subtalar coalition and any changes of the talonavicular joint, such as talar beaking. The oblique foot radiograph also should be inspected for a calcaneonavicular coalition, which can lead to a rigid deformity. The ankle series should be evaluated for any valgus tilt in the tibiotalar joint. Fluoroscopic examination is useful to evaluate the mobility and stability of the ankle joint, particularly in a patient with a valgus deformity of the ankle with or without associated arthritis. It is important to determine if the ankle valgus deformity is passively correctable because this may determine the type of surgery needed; ideally, this examination should be performed fluoroscopically. MRI has no value in preoperative planning, unless severe osteonecrosis of the talus is present and associated with a rigid ankle and hindfoot deformity. A CT scan may be useful to determine the alignment of the calcaneus relative to the talus and confirm the extent of peritalar subluxation as well as fracture of the sustentaculum, which occurs in severe cases of peritalar subluxation. These scans are rarely taken with any weight or pressure on the subtalar joint and should be carefully interpreted.[11]

Classification

In 1989, Johnson and Strom[12] described three clinical stages of PTT dysfunction. This classification was modified in 1997 by Myerson[13] by adding a fourth stage, which is defined as the presence of ankle valgus caused by a rupture of the deltoid ligament with or without arthritis of the ankle joint. The classification of flatfoot deformity was further refined by Bluman et al[14] in 2007. In the Myerson classification, although stage III is still characterized by rigid hindfoot valgus, it is further defined by the presence of forefoot abduction. In stage IIIA, the deformity is corrected by a triple arthrodesis. In stage IIIB, the forefoot abduction is so severe that to correct the deformity, the triple arthrodesis is combined with bone graft lengthening of the calcaneocuboid joint. Additional procedures, such as Achilles lengthening, medial cuneiform osteotomy, medial column arthrodesis, and lengthening or transfer of the peroneal or anterior tibial tendons, are performed as necessary.

Treatment

Nonsurgical treatment can be successful despite the rigidity of the deformity. Although an orthotic arch support cannot correct the fixed deformity, a soft, multilayered, arch support may provide relief of the bone prominence of the head of the talus. If more support is required, a custom, molded, leather, ankle gauntlet referred to as a Baldwin or Arizona brace should be considered. The brace fits into a comfortable shoe and stabilizes the ankle area and the talocalcaneal, midtarsal, and subtalar joints. It provides medial and lateral stability to minimize sinus tarsi impingement and reduce forefoot motion. The brace improves the function of the limb for most patients but does not correct the deformity, which can progress if the brace is not worn.

Most patients eventually stop wearing the brace and elect surgery to correct the deformity. The goal of surgery is to provide a plantigrade foot, decrease pain, and increase function. Because there are many surgical options available, choosing the procedure(s) to correct the deformity is dependent on the stage of deformity and the patient's goals, age, weight considerations (such as obesity), and the presence of arthritis. Usually, a rigid flatfoot deformity must be treated with an arthrodesis of some type, supplemented with osteotomy and tendon transfer as required. It is important to recognize the characteristics of a deformity that is too stiff or "not flexible enough" to correct with tendon transfer or osteotomy, the latter of which is always preferable to maximize and maintain motion in the hindfoot. If the hindfoot is stiff, adequate deformity correction is unlikely without arthrodesis, and the option of tendon transfer should not be advocated. The hindfoot can often be manually reduced to neutral; however, this is accompanied by severe forefoot supination deformity. In some instances, the "feel" of this examination may help the examiner determine that arthrodesis is preferable, has a greater degree of predictability, and will adequately meet the patient's needs. Although arthrodesis is generally used to correct a rigid deformity, under certain circumstances it may also be indicated in a pa-

tient with a flexible flatfoot. For example, in an obese patient, a tendon transfer and hindfoot osteotomies have a higher chance of failure. In some patients with severe laxity of the hindfoot (whether associated with generalized ligamentous laxity, hypermobility, or a rupture of the spring ligament), a talonavicular arthrodesis may be a more predictable procedure.

Several procedures are available for treating a rigid flatfoot, and should be added in sequence in a systematic approach commencing with reduction of the subtalar joint and then moving distally depending on the presence of additional deformity. The heel should be reduced to a more physiologic valgus, the subfibular impingement should be corrected, and the medial arch pain and deformity eliminated. The surgical options listed in this chapter include the type of procedure along with a description of the technique and indications. In all cases, equinus should be evaluated, and an Achilles lengthening procedure should be performed (gastrocnemius recession versus tendon Achilles lengthening if appropriate).

Triple Arthrodesis

Triple arthrodesis is a very common procedure for correcting a rigid flatfoot deformity. The phrase "triple arthrodesis" was first used by Ryerson[15] in 1923. This procedure was traditionally performed with joint preparation without any internal fixation and with a long-leg plaster cast. By the early 1980s, there was less reliance on cast immobilization and various types of more rigid internal fixation became more commonly used for correction. With these changes in fixation methods, there was a marked increase in the rate of union, but there were also potential disadvantages, including an increase in varus malunion from overcorrecting the talonavicular joint.[16] Although the surgical goal is to create a functional plantigrade foot, preserving motion is also important. In some instances, a modification of the triple arthrodesis procedure is used on the hindfoot joints, such as a talonavicular and subtalar arthrodesis or a subtalar and calcaneocuboid arthrodesis. This approach must be carefully considered because a single or double arthrodesis cannot correct deformity as reliably as a triple arthrodesis. Although the approach to the procedure may have changed over the decades, triple arthrodesis has remained a standard for correcting severe deformity regardless of the etiology.

Surgical Approaches

Single-Incision Lateral Approach

The traditional triple arthrodesis was originally performed through a single-incision lateral approach through the sinus tarsi, but the incidence of complications, including persistent deformity and nonunion, was common with this approach because of limited visualization of the talonavicular joint. A cadaver model evaluating preparation of the three joints using the single lateral approach showed that the cartilage can be successfully removed in 90% of the calcaneocuboid joint, 80% of the subtalar joint, but only 38% of the talonavicular joint. Additional reported complications included obliteration of the talonavicular joint, inadvertent division of the talar neck or talar head, removal of excess bone, medial skin punctures, and an iatrogenic cut through the talar dome.[17] Over the past two decades, the two-incision technique has become far more popular because it allows the surgeon to better visualize the adequate preparation, reduction, and alignment of the joints.

Two-Incision Approach

With the patient supine, a lateral incision is made, extending from the tip of the fibula to the base of the fourth metatarsal. The sural nerve is retracted plantarly, the peroneal tendons are protected, and the extensor digitorum brevis is elevated dorsally and preserved. The sinus tarsi is opened, débrided, and distracted with a laminar spreader to visualize the subtalar joint. Care must be taken to remove all the cartilage from the entire posterior, middle, and anterior facets, followed by perforation of the subchondral plate with systematic drilling of both the talus and the calcaneus with a 2.0-mm drill bit at 2-mm intervals, generating abundant bone slurry. A 5-mm, curved osteotome is then used to shingle the joint surfaces to further generate a good cancellous bed of bone. The calcaneocuboid joint is prepared in a similar manner. Next, a dorsomedial incision just medial to the anterior tibial tendon is made. This joint is much more difficult to visualize, and although a laminar spreader can be used to try to twist open the joint for distraction, the talar bone quality may be poor, causing the head of the talus to be crushed by the spreader. It may be easier to use a pin distractor to open the joint, which is then prepared as previously described, along with drill holes, which are particularly important if the navicular is sclerotic. It is essential to preserve the bone on both joint surfaces, maintaining the contour of the talonavicular joint. If bone is inadvertently removed, the medial column of the foot will shorten, followed by a varus malunion.

The sequence of fixation is subjective, but this chapter's authors believe that the talonavicular joint should be fixed first because this joint functions as the hinge to the hindfoot. If the deformity is mild to moderate, the talonavicular joint is always corrected first, followed by the subtalar joint, which "falls into place." With the talonavicular joint held reduced, the first ray is plantar flexed by dorsiflexing the hal-

lux, which further corrects the forefoot relative to the hindfoot. If there is a complete peritalar dislocation, the subtalar joint is reduced first because it is difficult to translate the subtalar joint medially and simultaneously correct heel valgus in these very severe deformities. In contrast, if the subtalar joint is reduced first, it is easy to overcorrect the talonavicular joint; this overcorrection must be avoided to prevent a varus or adductus malunion. Two points of fixation of the talonavicular joint are recommended. This chapter's authors use one 5.0-mm screw from distal to proximal in compression mode along with a two-hole locking compression plate placed more dorsolaterally. The subtalar joint is fixed next with one 7-mm screw, followed by fixation of the calcaneocuboid joint. It is useful to notch the side of the calcaneus for insertion of the 5-mm screw into the calcaneocuboid joint to prevent splitting the distal calcaneus. Alternatively, a plate or staples can be used quite effectively to compress the calcaneocuboid joint. If a gap is present in the calcaneocuboid joint following correction of pronounced forefoot abduction, it may be necessary to lengthen the lateral column through the calcaneocuboid joint using a structural bone block graft. The results of simultaneous triple arthrodesis and lateral column lengthening are favorable.[18]

Single-Incision Medial Approach

Variations of standard triple arthrodesis have been described for correcting rigid hindfoot deformity, including more limited fusions of either the talonavicular and the subtalar joints or the subtalar and the calcaneocuboid joints. A single-incision medial approach also has been used with a predictable outcome to perform triple arthrodesis in patients who are at risk for wound healing complications associated with correcting a hindfoot valgus deformity.[19] This approach can be accomplished through a rather small incision (**Figure 1**). Jeng et al[19] treated 17 patients with a rigid hindfoot valgus deformity using triple arthrodesis with a single medial incision. The indication for surgery was refractory pain associated with hindfoot valgus deformities in patients with taut lateral skin and poor skin conditions laterally because of contracture. The severity of the hindfoot deformity itself was not the indication for this procedure. A subtalar and talonavicular arthrodesis was achieved in all patients and an asymptomatic nonunion of the calcaneocuboid arthrodesis was reported in 2 of 17 patients. In a cadaver study, Jeng et al[20] showed that through the single medial incision, 91% of the subtalar, 91% of the talonavicular, and 90% calcaneocuboid joints could be prepared. The medial approach to either a triple or a hindfoot double arthrodesis is a reliable procedure that can be used in patients with poor-quality lateral skin and a fixed hindfoot valgus deformity and in those in whom correction with a two-incision approach could lead to a lateral wound complication. Brilhault[21] performed a subtalar and talonavicular arthrodesis procedure in 11 patients and reported the occurrence of wound healing and arthrodesis as well as an asymptomatic calcaneocuboid joint in all patients. More importantly, significant radiographic improvements were reported in the AP talonavicular coverage angle (from 38.5° to 7°), the lateral talonavicular–first metatarsal angle (from 21° to 0°), and the hindfoot-frontal alignment angle (from 18° to 7.5°).

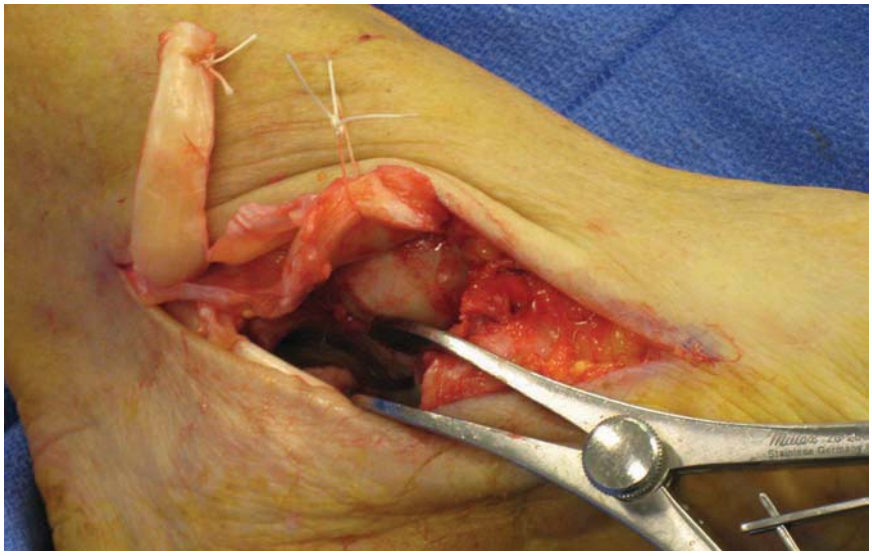

Figure 1 Intraoperative photograph of the medial approach for a triple arthrodesis to correct a hindfoot deformity.

As this chapter's authors gained more experience with the medial approach to correct deformity, it became apparent that the calcaneocuboid joint does not always need to be included in the arthrodesis. More recently, this chapter's authors have attempted to treat most rigid AFDs with a single medial incision, either including the calcaneocuboid joint or not including that joint, depending on the ability to completely correct the deformity. The isolated subtalar and talonavicular arthrodesis must be performed with caution because inferior subluxation of the cuboid relative to the calcaneus

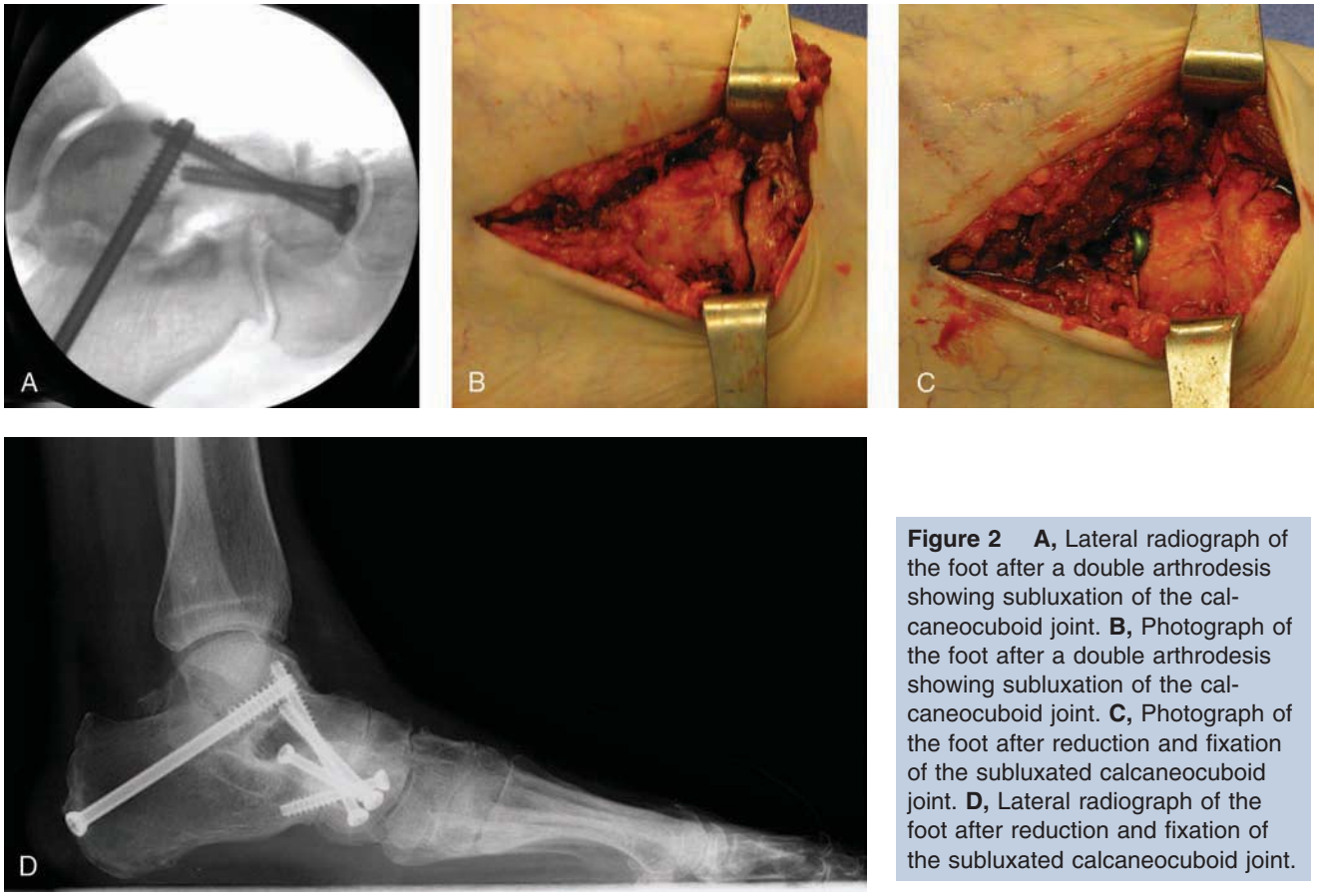

Figure 2 **A,** Lateral radiograph of the foot after a double arthrodesis showing subluxation of the calcaneocuboid joint. **B,** Photograph of the foot after a double arthrodesis showing subluxation of the calcaneocuboid joint. **C,** Photograph of the foot after reduction and fixation of the subluxated calcaneocuboid joint. **D,** Lateral radiograph of the foot after reduction and fixation of the subluxated calcaneocuboid joint.

may occur, resulting in a fixed rotation of the transverse tarsal joint, which will then lead to pain under the cuboid and the base of the fifth metatarsal (**Figure 2**).

Adjunctive Procedures

Following any hindfoot arthrodesis, adjunctive procedures are frequently necessary to achieve the desired correction of a plantigrade foot. To some extent, these procedures must be planned ahead of the triple arthrodesis because the incisions may vary slightly as these additional osteotomies and tendon transfers are performed. With a severe abduction deformity, correction may be difficult because of peroneal tendon contracture; the tendons can be lengthened or cut or the peroneus brevis can be transferred to the peroneus longus. The latter procedure has a twofold purpose—to lengthen the lateral contracted tendon and improve the plantar-flexion strength of the first metatarsal. With very severe inferior subluxation of the talus under the navicular, there is a contracture of the anterior tibial tendon, which then elevates the first ray even further and adds to the deformity. In some instances, correction of the sagittal alignment of the first ray cannot be attained without lengthening or a lateral transfer of the anterior tibial tendon. The elevation and/or the anterior tibial tendon may need to be released if the desired correction cannot be obtained. Correcting the medial column alignment in the sagittal plane is essential to the success of a triple arthrodesis because loss of medial column support will lead to insufficient weight bearing, which forces the hindfoot into valgus and creates further deformity. As the medial column support fails, even if the talonavicular joint is fused, the subtalar joint must evert to maintain a plantigrade foot. Naviculocuneiform arthrodesis, first tarsometatarsal arthrodesis, or a medial cuneiform opening wedge osteotomy are correction options determined by the location of the deformity and the instability. If fixed forefoot supination is present following the triple arthrodesis, and no arthritis at either the naviculocuneiform or first tarsometatarsal joints is present, it is preferable to maintain as much motion in these joints as possible, performing the realignment at the level of the medial cuneiform. Although the addition of a medial column arthrodesis to the triple arthrodesis adds to the stiffness of the foot and the potential for arthritis at the remaining open medial joint, these deformities cannot be ignored. Restoring the medial column alignment after naviculocuneiform arthrodesis may

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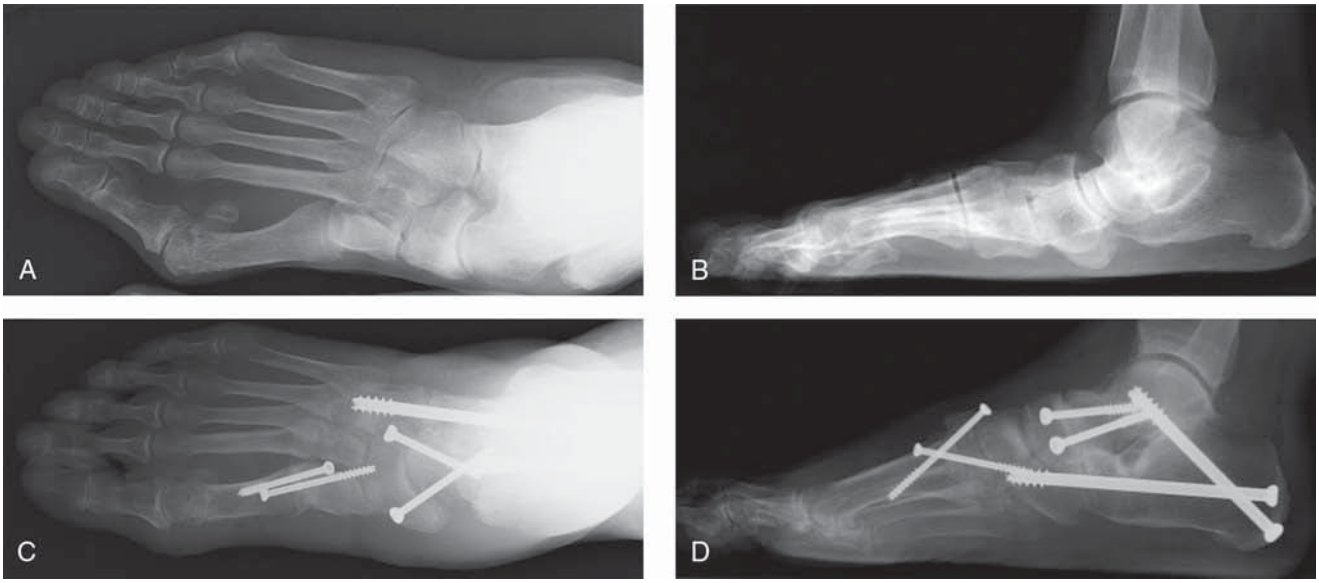

Figure 3 **A,** AP preoperative radiograph of a rigid flatfoot with hallux valgus and instability of the first tarsometatarsal joint. **B,** Lateral radiograph of a rigid flatfoot with hallux valgus and instability of the first tarsometatarsal joint. **C,** Postoperative AP radiograph after a triple arthrodesis and first tarsometatarsal arthrodesis. **D,** Postoperative lateral radiograph of the foot after a triple arthrodesis and first tarsometatarsal arthrodesis.

provide a link between stability of the midfoot and alignment of the hindfoot.[22]

First tarsometatarsal joint arthrodesis is a reliable technique to stabilize the medial column and correct forefoot supination following a triple arthrodesis, especially in the presence of arthritis, instability, metatarsus elevatus, or hallux valgus. It is important to note that this joint is very deep, measuring up to 30 mm, and failure to prepare the plantar aspect of the joint will result in an undesirable dorsal malunion. Fixation is ideally performed with two axial compression screws, although staples or a plate have been successfully used for fixation of this joint (**Figure 3**). In 182 patients treated with a first tarsometatarsal joint arthrodesis as a part of an AFD reconstruction or correction of hallux valgus, no nonunions of the first tarsometatarsal joint were reported when the procedure was performed as part of the AFD correction.[23]

When the hindfoot is fixed in severe valgus, the medial shift of the subtalar joint in conjunction with the triple arthrodesis may not be sufficient. There may be erosion of the lateral subtalar joint, and correction cannot adequately be obtained without an additional medial translational osteotomy of the calcaneus. This procedure must be planned ahead because the incision may vary if the osteotomy is performed simultaneously, by either extending the sinus tarsi incision posteriorly or using a second oblique incision directly inferior to the peroneal tendons over the calcaneus. Following exposure, débridement, and joint preparation of the subtalar joint, the osteotomy is performed and provisionally fixed with Kirschner wires or guide pins. The screws can extend into the talus, simultaneously correcting and fixing both the calcaneus osteotomy and the subtalar joint (**Figure 4**).

Figure 4 Photograph showing the ability to achieve fixation of both a medial displacement calcaneal osteotomy and subtalar arthrodesis.

Management of the Unstable Ankle

The stability of the ankle should be checked following fixation of the triple arthrodesis, not only for attenuation or rupture of the deltoid ligament but also for lateral ankle instability (particularly for those procedures that are performed for a severe valgus deformity). Chronic valgus impingement between the calcaneus and the fibula may lead to erosion of the calcaneofibular ligament and subsequent ankle instability. If lateral ankle instability is present, it must be stabilized to prevent subsequent ankle arthritis. There is

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Figure 5 Fluoroscopic image showing an incompetent deltoid after a triple arthrodesis.

never sufficient tissue present to perform a simple reconstruction using a Broström-type procedure; therefore, some reconstruction using the peroneal tendon is preferable. This chapter's authors use a modified Chrisman-Snook procedure.[24] A rupture of the deltoid (stage IV deformity) can be corrected in a variety of ways. The ankle must be examined to determine if the deformity is passively correctable (stage IV-A) or if it is rigid (stage IV-B). Fluoroscopic examination at the time of the triple arthrodesis is helpful, but it is preferable to perform it ahead of time to anticipate the planned procedure (**Figure 5**). In stage IV-B deformity or if the ankle deformity is flexible but associated with arthritis, it should be corrected with either a tibiotalocalcaneal arthrodesis or a pantalar arthrodesis. Total ankle replacement in this setting is highly unreliable, and a fixed valgus deformity of the ankle is best treated with arthrodesis. The use of an intramedullary rod is preferred for primary and revision arthrodesis, especially in revision surgeries for correcting a stage IV deformity. Although tibiotalocalcaneal and pantalar fusions are successful in obtaining a plantigrade foot, there can be associated morbidity. Even after successful fusion, the energy expenditure of ambulation is increased, and functionality and patient satisfaction are decreased.[25] For managing a stage IV-A deformity, the ankle joint can be preserved with a variety of ligament reconstruction techniques performed following the necessary hindfoot and midfoot realignment. The correction of the hindfoot and midfoot alignment must be obtained, with particular attention to ensuring good, stable alignment of the medial column; a first tarsometatarsal arthrodesis should be performed if necessary. Studies have shown that a medial translational osteotomy of the calcaneus is also beneficial because it decreases the valgus force on the deltoid ligament.[26] If the stage IV deformity is associated with malunion of a previously performed hindfoot arthrodesis, then either the correction should be made at the ankle joint in stage IV-B deformities or a revision arthrodesis should be followed by a deltoid reconstruction.

Deltoid reconstruction falls into three categories: repair of the ligament, advancement of the ligament, or the use of a tendon graft (either an autograft or an allograft).[27-30] The local remnant of the deltoid ligament, PTT, and capsule are not sufficient to maintain long-term correction, and failure of these approaches has been reported.[26] This chapter's authors recommend a technique that uses a forked semitendinosus allograft tendon in conjunction with soft-tissue interference screws to reconstruct the deep tibiotalar ligaments and the superficial calcaneofibular fibers. The graft is anchored in a tibial tunnel that is created parallel to the joint at the level of the physeal scar. After a Krackow suture is placed in the distal end of the tendon, it is then passed subcutaneously over the medial malleolus. A talar tunnel is created, and the tendon is passed, manually tensioned, then secured. Next, a calcaneal tunnel is created, and the tendon is passed, tensioned, then secured.[26]

Results

The results of triple arthrodesis for AFD have been studied extensively. A series of 32 triple arthrodeses for stage III and IV deformity (average follow-up, 4.3 years) showed improvement in American Orthopaedic Foot and Ankle Society scores by 36 points, with all but one patient reporting satisfaction with the procedure. There was one nonunion and two malunions.[31] Similarly, in a series of 44 feet (9 with AFD), 34 had good results.[32] In a study of the results of triple arthrodesis in 132 feet (average follow-up, 5.7 years), Pell et al[33] reported an overall patient satisfaction score of 8.3 of 10. Interestingly, 60% of the patients had clear radiographic progression of ankle arthritis, but this did not correlate with patient satisfaction. The longest outcome data available in the literature on triple arthrodesis shows a 95% patient satisfaction rate at 40-year follow-up.[34]

Limited Hindfoot Arthrodesis Procedures

As previously discussed, an isolated talonavicular arthrodesis cannot correct excessive hindfoot valgus or instability of the midfoot joints. It has been shown in a cadaver model that isolated talonavicular fusion was as powerful as both the triple and double arthrodesis; however, it reduced hindfoot motion by 80%.[35] An isolated talonavicular arthrodesis is occasionally indicated for managing rigid flatfoot deformity, but it may be better indicated for severe hypermobility associated with a rupture of the spring ligament and a flexible flatfoot deformity. The talonavicular joint is the apex of the deformity in AFD,[35] and certainly most of the transverse tarsal joint deformity and

abduction of the midfoot can be corrected with an isolated talonavicular arthrodesis. Residual hindfoot valgus remains a concern with this technique, and a medial displacement calcaneal osteotomy can be added if necessary to correct the heel deformity. At 27-month follow-up, 26 patients with AFD treated with an isolated talonavicular arthrodesis had favorable outcomes with no pain or pain only after heavy use. Although the procedure was performed for patients with AFD, it was not reported if the deformity was flexible or rigid. A successful fusion was achieved in all the patients and no loss of correction was reported. Mild asymptomatic adjacent joint arthritis was reported in five patients, and ankle plantarflexion was decreased by 10°.[36,37]

A double arthrodesis (talonavicular and calcaneocuboid joints) has been described with an overall satisfaction rate of 83% with the procedure.[38,39] Progressive degeneration of the surrounding joints was common, and the most frequent complication was nonunion at the talonavicular joint. The authors stressed that this procedure was indicated only in rigid flatfeet in which the principle deformity was at the transverse tarsal joints, with no subtalar arthritis present.[39]

Isolated subtalar arthrodesis is an effective procedure for stage II and some stage III deformities.[40] This approach is recommended only when most of the deformity originates from the subtalar joint, less than 30% of the talonavicular joint is uncovered, pain is isolated to the lateral foot and sinus tarsi, and arthritis is present in the subtalar joint; it can also be used as a salvage procedure for a failed prior reconstruction. A subtalar arthrodesis may be performed in conjunction with a flexor digitorum longus transfer and supplemented by a medial column procedure as necessary to correct forefoot supination and instability. In patients with a somewhat flexible deformity that could be treated with tendon transfer and osteotomy, this approach may provide more durable results, particularly if associated with inflammatory arthropathy or obesity. The benefit of isolated subtalar fusion is joint preservation of the transverse tarsal joint. A cadaver study showed a 39% loss of eversion and a 41% loss of inversion with subtalar arthrodesis, with minimal affect on dorsiflexion and plantarflexion.[41] Extending the fusion to a triple arthrodesis showed a 16% reduction in plantarflexion and a 13% decrease in dorsiflexion. The triple arthrodesis also resulted in an additional 20% loss of eversion and 22% loss of inversion. Studies evaluating isolated subtalar arthrodesis for AFD in conjunction with flexor digitorum longus transfer have reported good results.[42,43]

Summary

The surgical management of rigid AFD requires a systematic approach. A careful patient history, a thorough examination, and a detailed review of weight-bearing radiographs are paramount in determining the etiology and the stage of the deformity. After this is achieved, a well-planned surgery can be devised. Many options exist for surgical correction. Careful patient selection and meticulous technique are required for successful outcomes. Regardless of the surgical reconstruction, the goal is a long-lasting plantigrade foot.

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