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Triple Arthrodesis for the Adult-Acquired Flatfoot Deformity

Michael P. Maskill, DPM, Jeffrey D. Loveland, DPM,
Robert W. Mendicino, DPM, FACFAS*,
Karl Saltrick, DPM, FACFAS,
Alan R. Catanzariti, DPM, FACFAS

Division of Foot and Ankle Surgery, The Foot and Ankle Institute of Western Pennsylvania, The Western Pennsylvania Hospital, 4800 Friendship Avenue, North Tower, First Floor, Pittsburgh, PA 15224, USA

Triple arthrodesis is indicated for deformity, end-stage arthritis, and instability of the hindfoot. Triple arthrodesis often is the procedure of choice for end-stage adult-acquired flatfoot (AAFF). The benefits of triple arthrodesis include resolution of symptoms, hindfoot realignment, and stability. A well-positioned triple arthrodesis ultimately will result in a plantigrade foot that will support the ankle in optimal alignment. This article reviews the technical execution and realignment considerations associated with triple arthrodesis for AAFF.

Triple arthrodesis is indicated for stages 3 and 4 AAFF and for stage 2 AAFF with severe concomitant hindfoot instability, other rigid flatfoot deformities (eg, tarsal coalition), and posttraumatic hindfoot arthrosis. The goals of the procedure include deformity correction with appropriate realignment, restoration of hindfoot stability, sound arthrodesis, and pain relief. Complications such as malunion, inadequate correction, continued instability, gait disturbances, and adjacent joint degeneration result from inadequate realignment. Therefore, realignment is a critical factor for achieving acceptable outcomes with triple arthrodesis. Recently published studies report satisfaction rates of greater than 90% after a 5-year follow-up [1,2].

Triple arthrodesis has been shown to produce favorable long-term results in resolution of pain and patient satisfaction [3]. Few studies, however, discuss the effect of realignment on outcomes. Likewise, few reports discuss the

* Corresponding author.
E-mail address: rmendicino@faiwp.com (R.W. Mendicino).

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type of fixation and adjunctive procedures typically performed with triple arthrodesis for AAFF. Recent studies have begun to evaluate realignment considerations, fixation techniques, and adjunctive procedures with short-term follow-up in a small patient population [4].

Extensive literature has been published regarding triple arthrodesis. Davis [5] originally described arthrodesis of the subtalar joint (STJ) and talonavicular joint (TNJ) to provide more stability to the cavus foot. Hoke [6] later described the double arthrodesis for the treatment of talipes equinovarus. Ryerson [7] modified the surgical technique by arthrodesing the calcaneocuboid joint (CCJ) in addition to the STJ and TNJ, hence the term "triple arthrodesis." Cast immobilization was used to maintain alignment until healing was complete. Non-union rates have decreased from 7% to 23% to zero to 9%, respectively, with the evolution of osteosynthesis and postoperative non–weight bearing [8–12].

Anatomy and pathophysiology

The posterior tibial tendon (PTT) is a powerful muscle that acts as a strong supinator of the foot. The PTT passes immediately posterior to the medial malleolus and medial to the STJ axis. It functions as a pulley to plantarflex the ankle, supinate the foot, and dynamically stabilize the medial longitudinal arch [13]. Subtalar joint inversion locks the midfoot and prevents a pronatory moment through the oblique axis of the midtarsal joint. The PTT has multiple insertions in the plantar midfoot and is a strong stabilizing force to the medial longitudinal arch.

A flatfoot is characterized by abduction and supination of the forefoot with a collapsed or absent medial longitudinal arch and a valgus angulation of the heel. AAFF usually is a result of longstanding posterior tibial tendinopathy. Causes of AAFF include rheumatoid arthritis, seronegative arthritides, tarsal coalition, Charcot neuroarthropathy, paralysis, and acute trauma to the PTT.

Radiographic views should include anteroposterior (AP), lateral, lateral oblique, long-leg axial, and hindfoot alignment. AP radiographs reveal peritalar subluxation with high talo–first metatarsal angles (Fig. 1A). Peritalar subluxation typically occurs because of lateral subluxation of the navicular on the talus. Lateral radiographs typically reveal an increase in the talo–first metatarsal angle (Fig. 1B).

Early stages of AAFF demonstrate a deformity that is reducible and supple. A gastrocnemius–soleus contracture further accentuates and maintains the deformity. The deformity produces persistent stresses on the STJ and midtarsal joints that eventually leads to dorsolateral peritalar subluxation. "Dorsolateral peritalar subluxation" is a term coined by Hansen [14] that describes the AAFF as medial talar head uncovering, with the forefoot abducting, supinating and dorsiflexing around the talus through the midtarsal joint, ultimately leading to a fixed flatfoot deformity.

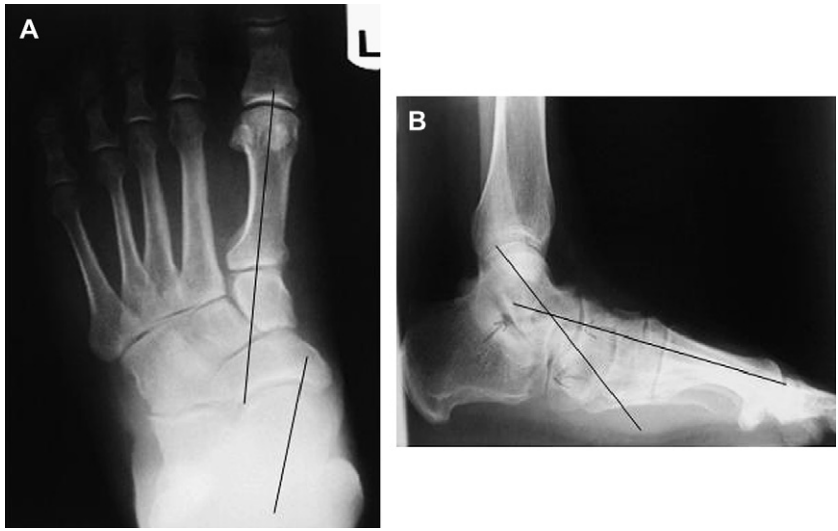

Fig. 1. (*A*) Anteroposterior view of left foot demonstrating talar head uncovering, increased talo–first metatarsal angle (Simmon's angle), and increased cuboid abduction angle. (*B*) Lateral radiograph of the left foot demonstrating decreased calcaneal inclination angle, increased talar declination angle, and increased talo–first metatarsal angle (Meary's angle).

The tibialis posterior muscle functions throughout the entire gait cycle. The PTT acts to decelerate subtalar pronation and internal tibial rotation at heel contact and to accelerate STJ supination and external rotation of the leg during midstance [13]. The PTT has a short excursion of only 2 cm, which maximizes its function. For this reason, a relative lengthening or degeneration of the PTT can result in remarkable loss of biomechanical function and strength [15].

A classification scheme was created by Johnson and Strom [16] in 1989 to aid in the diagnosis and management of AAFF. Stage 1 is characterized by pain and swelling of the foot and ankle along the course of the PTT, with the patient able to perform a single heel-rise test. Stage 2 describes a torn PTT, a weak limb, and the inability to perform a single heel-rise test. The midfoot is pronated, and the forefoot is abducted at the midtarsal tarsal joint. The STJ remains flexible in stage 2 AAFF. Stage 3 AAFF involves degeneration of the PTT and a rigid, nonreducible hindfoot. Stage 4, which was a modification by Myerson and colleagues [17], is characterized by valgus angulation of the talus within the ankle mortise with or without signs of degenerative joint disease (Fig. 2).

Physical examination

The diagnosis of symptomatic AAFF is based on clinical and radiographic assessment [18–20]. An adequate history and physical examination

Fig. 2. Stage 4 posterior tibial tendon dysfunction with deltoid attenuation and valgus tilt of the talus within the ankle mortis.

are essential in determining the stage of AAFF and appropriate treatment for the patient. The examination begins by performing a complete evaluation of the overall alignment of the lower extremities, with the patient standing barefoot and the knees exposed. Tibial varum or valgum can accentuate the heel valgus deformity and may need to be addressed [14,18]. The gait should be evaluated for early heel rise, rigid calcaneal valgus, and apropulsion. Early heel rise can be a sign of gastrocnemius contracture [18,21].

Clinical evaluation of stage 3 AAFF reveals a significant triplanar deformity that is noticed both clinically and radiographically. Symptoms of stage 3 AAFF typically include medial hindfoot pain secondary to soft-tissue attenuation and lateral hindfoot pain caused by calcaneofibular impingement and lateral tarsal arthritis. Motion usually is reduced or absent in the tritarsal complex, and the deformity is rigid. The physical examination reveals an abducted forefoot, a short, concave lateral column, and a long, convex medial column. The medial longitudinal arch is collapsed and does not reconstitute with a hallux-raise maneuver. Johnson and Strom [16] first described the "too many toes" sign, which is a clinical assessment of the severity of forefoot abduction by the number of toes seen lateral on the affected side. As the deformity progresses, the number of toes visible increases. Hindfoot flexibility is evaluated by having the patient perform the double heel-rise test [18,20], which indicates the reducibility of the deformity. With a significant level of rigidity, the valgus deformity will not reduce with a double heel-rise test in later stages of AAFF. A single heel-rise test should be performed on the affected foot to ascertain the strength of the PTT. Patients typically cannot perform a single heel-rise test in the later stages of AAFF.

Surgical technique

Triple arthrodesis can be performed under general or spinal anesthesia. Before the procedure begins, prophylactic antibiotics are given to decrease the risk of postoperative infection. A thigh tourniquet is preferred, and a support is placed beneath the ipsilateral hip for improved visualization of the lateral aspect of the hindfoot. The presence of posterior muscle group contracture should be assessed while the patient is under general anesthesia to eliminate any guarding or resistance to examination and to permit a more accurate assessment of equinus. Equinus then may be addressed by performing a posterior muscle group lengthening, including but not limited to a gastrocnemius recession or an Achilles tendon lengthening (Fig. 3A, B). Correction of chronic AAFF without posterior muscle group lengthening will result in a foot that is not plantigrade after realignment and may place significant stress across the remaining mobile midfoot joints [22]. Gastrocnemius recession or Achilles tendon lengthening then is performed, based on whether the equinus is from the gastrocnemius alone or is gastrosoleal in nature.

The most common surgical approach to the triple arthrodesis for AAFF uses a combined medial and lateral incision to obtain adequate exposure to the CCJ, STJ, and TNJs (Fig. 4A, B). This approach originally was described by Ryerson and Davis [5,7]. The lateral incision provides excellent exposure to the CCJ, the sinus tarsi, and the facets of the STJ. This incision begins at the tip of the lateral malleolus and extends to the fourth metatarsal

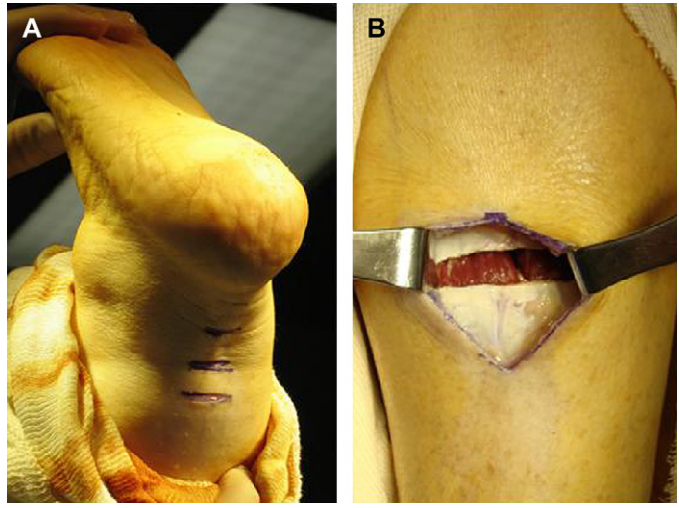

Fig. 3. (*A*) The author's typical three-incision approach to an Achilles tendon lengthening. (*B*) A gastrocnemius recession may be used also. This technique is optimal when equinus is limited to an isolated gastrocnemius contracture.

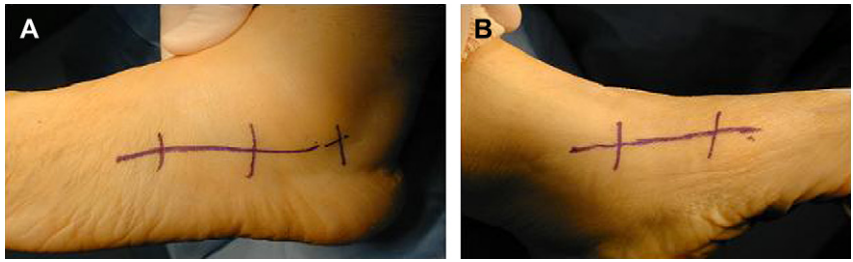

Fig. 4. (*A*) The lateral incision begins at the tip of the lateral malleolus and extends to the fourth metatarsal base. (*B*) The medial incision begins in the area of the medial gutter of the ankle and extends to the first metatarsal base.

base. Care should be taken to avoid injury to the sural nerve or any of its branches. The peroneal tendons then are identified, released from their sheath, and retracted inferiorly (Fig. 5A). The extensor digitorum brevis muscle belly is reflected, and the CCJ is identified. All periarticular

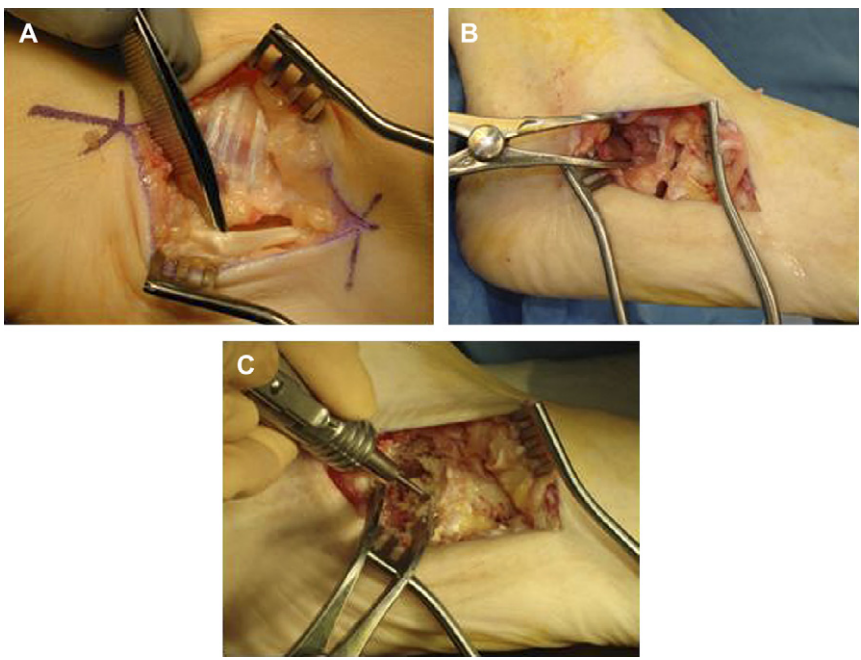

Fig. 5. (*A*) The peroneal tendons are identified and retracted inferiorly, and the extensor digitorum brevis is reflected anteriorly to obtain adequate access to the calcaneocuboid joint and the subtalar joint. (*B*) An Inge retractor is placed between the anterior calcaneus and inferolateral aspect of talar neck and allows joint distraction. (*C*) Adequate joint preparation requires fenestration of the subchondral plate. Various methods used include fish-scaling with a small osteotome and subchondral drilling with a drill bit, Kirschner wire, or small bur.

attachments are transected to allow exposure and manipulation of the joint surfaces. The sinus tarsi is identified, and the soft-tissue contents are evacuated thoroughly to reveal the posterior facet of the STJ. All periarticular structures of the STJ, including the calcaneofibular ligament, are released, so that the calcaneus can be reduced from its valgus position. The cartilage of the STJ and CCJs then are removed through a limited débridement technique using osteotomes and curettes (Fig. 5B). Kissel and colleagues [23] reported that curettage techniques preserved length of the foot and increased the surface area of bony contact. The cartilage debris then is carved away, and the subchondral bone is broken methodically using a fish-scaling or fenestration technique (Fig. 5C). Attention then is directed to the medial aspect of the foot where the incision begins in the area of the medial gutter of the ankle and extends to the first metatarsal base. The incision is deepened to expose the joint capsule of the TNJ. All soft-tissue attachments then are released to allow manipulation and exposure of the cartilaginous surfaces (Fig. 6). The soft-tissue release should be sufficient to allow realignment of the hindfoot. Joint preparation is accomplished through the techniques previously described.

Jeng and colleagues [24,25] have described another optional approach using a single medial incision. The authors surmise that with a long-standing fixed valgus deformity, the lateral incisional approach can cause potential incisional complications and make subsequent wound healing and closure difficult, although this has not been the present authors' experience. Jeng and colleagues' study included 17 patients who underwent a medial-approach triple arthrodesis. All 17 patients achieved radiographic union of the STJ and TNJ, and 15 of the 17 demonstrated definitive radiographic evidence of CCJ union. According to the cadaveric study by Jeng and

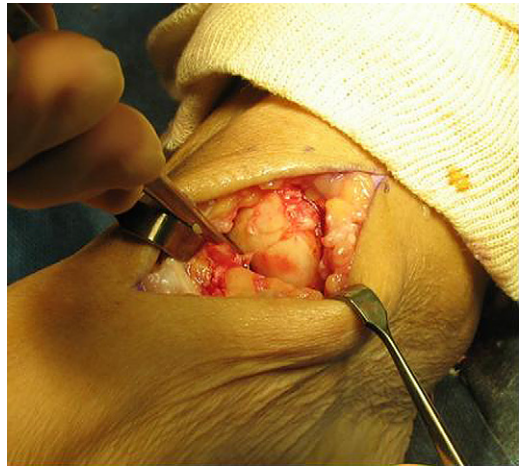

Fig. 6. Adequate exposure of the talonavicular joint is required for joint preparation.

colleagues [24], an average of 91% of all the articular surfaces for a triple arthrodesis could be prepared through the isolated medial approach. They concluded that the CCJ can be prepared adequately with no diminution in the quality of joint preparation.

After the articular cartilage has been completely denuded of all cartilage, the foot is manipulated into proper alignment. Optimal positioning of the hindfoot can be achieved with slight valgus to vertical. This position is obtained by placing the heel vertical to the lower leg, the forefoot parallel to the hindfoot (straight lateral border), and the first ray at the same level as the lesser metatarsals. Clinical realignment can be confirmed with image intensification. Axial, lateral, and AP views of the foot should be checked for adequate reduction of the deformity.

After realignment, provisional fixation can be obtained with Kirschner wires, Steinman pins, or guide wires from a cannulated screw system. This fixation is performed under image intensification. The authors routinely use intraoperative AP (foot and ankle), lateral, and calcaneal axial views to confirm realignment of the tritarsal complex. The authors use one or two large-diameter cannulated screws delivered through the plantar aspect of the heel to fixate the STJ. Care must be taken to ensure that the ankle joint is not violated. This placement should be checked in two planes under fluoroscopy. The TNJ and CCJ then are fixated, either with one large-diameter screw or with two smaller-diameter cannulated screws directed distal to proximal. If inadequate bone stock is encountered intraoperatively, the surgeon may consider the use of washers with screws.

Guide wires are removed after delivery of the screws and confirmation of realignment by means of fluoroscopy. Closure begins by reattaching the extensor digitorum brevis into its anatomic position followed by subcutaneous and skin closure. The TNJ capsule is reapproximated, followed by subcutaneous and skin closure. A closed-suction drain may be used to prevent formation of a hematoma. A common peroneal and popliteal block is used to enhance postoperative pain control and is performed in the operating room upon completion of the procedure.

Realignment considerations

Achieving adequate position results in a stable, plantigrade foot and ultimately leads to minimal gait disturbances and protection of the ankle. The end result of intraoperative positioning should be a perpendicular relationship of the hindfoot to the forefoot in the frontal plane and a parallel relationship in the transverse plane. Clinically, the hindfoot should be aligned with the lower leg in the frontal plane.

Fluoroscopy is used to confirm intraoperative alignment and to adjust the realignment of the hindfoot to the tibia and of the forefoot to the hindfoot. An intraoperative calcaneal axial view is used to ensure that the long axis of the calcaneus is parallel to the mid-diaphyseal line of the distal tibia

(Fig. 7A). Provisional fixation then is used to maintain correction until screws are delivered across the arthrodesis sites. The forefoot is positioned parallel to the hindfoot in both the frontal and transverse planes. The goal is a parallel rearfoot-to-leg relationship (Fig. 7B). The talar–first metatarsal angle is measured on both the AP and lateral views to assess the forefoot-to-hindfoot relationship. The anteroposterior talar–first metatarsal angle is used to assess the transverse plane, and the lateral talar–first metatarsal angle is used to assess the sagittal plane. Hindfoot alignment radiographs are used to assess frontal-plane relationships between the leg and the ground, hindfoot to leg, and hindfoot to ground. It is important to evaluate all three relationships to obtain optimal alignment.

Adjunct procedures

Based on the severity of the AAFF, various procedures may be needed in addition to triple arthrodesis. Adjunct procedures include lateral column lengthening, first tarso–metatarsal arthrodesis, bone grafting, posterior muscle group lengthening, and posterior calcaneal osteotomies.

Triple arthrodesis has required the removal of bony wedges to obtain acceptable alignment [6]. The authors' goal is to perform minimal bone resection while derotating the supinated and abducted forefoot to provide a stable, plantigrade position. Distraction through the lateral column with use of a bone graft has been successful in the treatment of severe AAFF [26]. This technique may be necessary after realignment of a severe deformity with significant adaptation of the CCJ. The authors use a bone block to fill the deficit that remains after realignment. This technique can be combined with the triple arthrodesis to restore length and eliminate forefoot abduction.

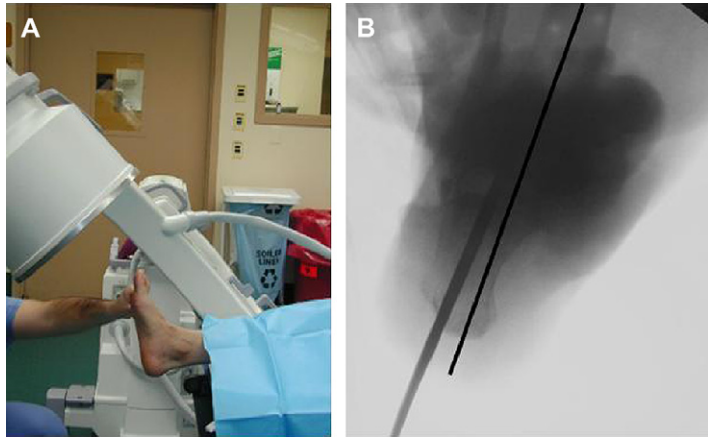

Fig. 7. (*A*) The method used to obtain an intraoperative calcaneal axial view. (*B*) Intraoperative calcaneal axial view demonstrating the calcaneus in good alignment to the long axis of the tibia.

First tarsometatarsal arthrodesis for AAFF can be used adjunctively with the triple arthrodesis procedure after hindfoot correction and fixation. The only correction of forefoot supination that can be obtained through a triple arthrodesis is by means of the TNJ. If residual supinatus or instability is remaining in the forefoot, a plantarflexory first tarsometatarsal arthrodesis can be performed if the forefoot supinatus is overlooked. Lateral column overload can result and lead to poor patient satisfaction [22]. Adding this procedure provides stability to the medial column.

Equinus may be a soft-tissue contracture of the gastrosoleal complex that is a common finding with longstanding AAFF. The Silfverskiold test should be performed preoperatively and intraoperatively to choose the appropriate procedure for lengthening the posterior muscle group [27]. Based on the results of the Silfverskiold test, the posterior muscle group can be lengthened with either an isolated gastrocnemius recession or a percutaneous tendo Achilles lengthening.

The ankle joint is affected in stage 4 AAFF. Attenuation of the deltoid ligament and other medial soft tissues will result in a valgus talar tilt and accelerated degenerative disease in the ankle joint. A posterior calcaneal displacement osteotomy has been shown to decrease the valgus forces to the ankle (Fig. 8) [2,19,28,29].

Bone grafting may be necessary if a void is present at any of the arthrodesis sites after realignment. This situation is likely to be encountered after realignment of a severe deformity. Large voids typically are filled with structural bone grafts, although this requirement is rather uncommon with AAFF (Fig. 9A). Smaller voids, which are more common, may be filled with autogenous or allogenic bone, a bone-graft substitute, or orthobiologic materials. These materials may be used alone or in combination to enhance fusion. The authors prefer a combination of demineralized bone matrix and allogenic bone chips (Fig. 9B).

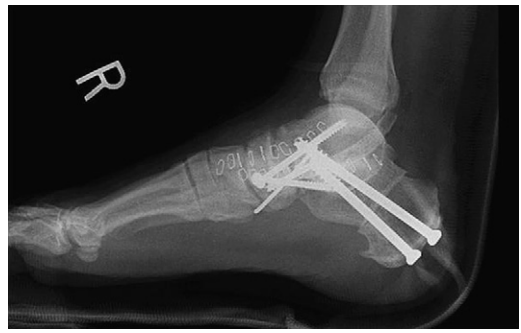

Fig. 8. Postoperative lateral radiograph demonstrating restored alignment. A posterior calcaneal displacement osteotomy was used in conjunction with the triple arthrodesis for this stage 4 AAFF deformity.

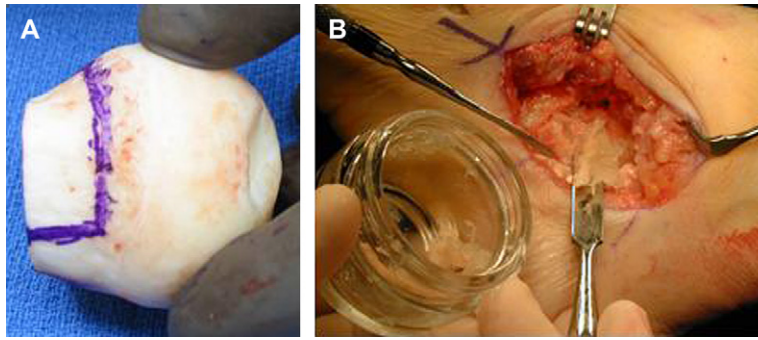

Fig. 9. (*A*) A fresh-frozen femoral head can be used as a structural allograft to fill large deficits and restore alignment of severe deformities. (*B*) The authors frequently use other orthobiologic materials, such as demineralized bone matrix and allogenic bone chips, to fill smaller defects and assist in the formation of extra-articular arthrodesis.

Rosenfeld and colleagues [30] stated that bone grafting was not necessary when performing a triple arthrodesis. They used only local bone graft obtained at the site of the operation to fill voids across the arthrodesis sites, and only 4 of 100 cases developed non-union in their study. They believed that comparable rates of union can be achieved without supplementary bone graft.

Postoperative management

The authors follow a strict postoperative regimen that begins with the patient's admission to the hospital for 1 to 3 days for management of postoperative pain and edema. The patient is placed in a compressive dressing with a posterior splint, with care taken to place the ankle in neutral position immediately after surgery. The patient receives deep venous thrombosis prophylaxis and proper pain management. The patient undergoes gait training preoperatively and/or postoperatively to ensure the patient's ability to remain non–weight-bearing (NWB). If unable to be NWB, the patient must be placed in a skilled nursing facility. The patient is placed in a well-padded below-the-knee fiberglass cast before discharge. The patient remains NWB for approximately 2 to 3 months. Serial radiographs are obtained to monitor consolidation of the arthrodesis sites. If there is minimal edema and warmth after cast removal, the patient transitions to a partial-weight-bearing fracture brace. The patient resumes standard footgear thereafter. Physical therapy can be useful for strengthening atrophied muscles, controlling edema, and gait training.

Complications

The triple arthrodesis has been described as a technically very demanding procedure [2,3,8,12,22,31]. The average time to maximum improvement

after triple arthrodesis is 10 months [3], and some residual pain may remain from problems that were not addressed by the procedure.

Pseudoarthrosis and non-union rates have been reported as frequent causes of persistent pain and subsequent patient dissatisfaction [3,8,12]. Non-union has become less common with the advent of more contemporary methods of fixation. Historically, non-union rates were as high as 33%, but with more advanced techniques and rigid internal fixation, non-union rates have dropped significantly [22] and are reported to range from 6% to 33% [8,32,33]. The most common site for non-union of the triple arthrodesis is the TNJ [11], especially if a single lateral incision is used [31], but non-unions can occur at any of the three articulations. Fortunately, non-unions often are asymptomatic. Risk factors leading to non-union include cigarette smoking [34–36], the performance of simultaneous bilateral triple arthrodeses [37], and the lack of rigid fixation in the early history of the procedure [7]. The use of bone graft as an adjunct to triple arthrodesis has shown excellent results, most likely because of the formation of an extra-articular arthrodesis in the sinus tarsi [38]. Fortin and Walling [22] reported a 3% non-union rate with the use of bone graft, a two-incisional approach, minimal bony resection, and rigid internal fixation. Likewise, Pell and colleagues [2] found a 2% non-union rate in 132 triple arthrodeses.

Positioning of the hindfoot to obtain optimal alignment and a stable, plantigrade foot is the most crucial part of the procedure. The literature supports the positioning of the heel into slight valgus of 5° [23,39,40], although the authors prefer the heel to be as close to vertical as possible. According to Fortin and Walling [22], positioning the heel in varus may lead to accelerated degeneration of the tibiotalar joint and an overloaded lateral column. In their study, four patients had a varus malunion, and two of them required revisional surgery for relief of pain. Conversely, excessive valgus malunion also is not well tolerated. Graves and colleagues [3] noted that placing the hindfoot into excessive valgus provided adequate pain relief but poor patient satisfaction. Maenpaa and colleagues [41] reviewed 307 triple arthrodeses and concluded that the primary cause for revision was malunion of the hindfoot, whether the malalignment was varus or valgus.

Secondary arthritis of the ankle is another major concern for most investigators. Fortin and Walling [22] state that in situ fusion without correction of deformity typically results in a painful, stiff foot with progressive degenerative changes to the ankle. Some studies have discovered that fusion of one joint increases the mechanical stress on all adjacent joints, and the reported prevalence of adjacent ankle arthritis after a triple arthrodesis has ranged from 2% to 77% [2]. Pell and colleagues [2] reported that 79 of 132 ankles had clear signs of progressive degenerative joint disease in the ankle at the time of follow-up. Twenty-eight percent had grade I arthritis, 19% had grade II arthritis, and 11% had grade III arthritis of the ankle joint. Five ankles had developed severe degenerative arthrosis and already had had an ankle arthrodesis performed before the presentation of their study.

Most importantly, Pell and colleagues [2] concluded that there was a strong correlation between patient satisfaction and hindfoot alignment.

Other complications such as nerve injury, wound dehiscence, infection, and fixation failure can occur as well. Meticulous sterile technique, gentle handling of soft tissues during dissection, and proper placement of the incision are essential in limiting these complications.

Summary

Triple arthrodesis is an effective procedure to relieve pain and correct structural deformities associated with AAFF. Appropriate realignment is the most critical factor for achieving a functional outcome.

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