Revision of Subtalar Joint Arthrodesis

Considerations for Bone Grafting, Fixation Constructs, and Three-Dimensional Printing

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KEYWORDS

• Subtalar arthrodesis • Fusion • Nonunion • Revision • 3D printing • Bone grafting

KEY POINTS

- Although relatively high satisfaction and union rates have been reported for isolated subtalar joint arthrodesis, questions still remain as to graft options, fixation techniques, and revisions.
- It is the authors' recommendation that in the setting of failed subtalar joint arthrodesis, to use autograft with intramedullary nailing as a revision construct.
- Isolated subtalar joint arhtrodesis has proven to be a predictable and successful option for treatment of various foot and ankle pathologies.

INTRODUCTION/HISTORY/DEFINITIONS/BACKGROUND

It is well known that foot and ankle surgery in the United States has been increasing for the past couple of decades as shown in the literature. In a period of 17 years, Best and colleagues[1] demonstrated using National Hospital Discharge Survey and National Survey of Ambulatory Surgery that arthrodesis procedures have increased 146% with outpatient arthrodeses increasing by 415%. Subtalar joint arthrodesis is a commonly used procedure in foot and ankle surgery for various pathologic conditions. Grice and colleagues[2] were the first to describe an isolated subtalar arthrodesis in 1952. Generally, subtalar arthrodeses are performed in conjunction with other procedures but they can be done in isolation. The rates of union for subtalar joint arthrodesis have been generally positive, with more recent literature showing cohorts achieving 100% union.[3] The purpose of a subtalar arthrodesis is typically pain relief, realignment

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for deformity correction, and functional improvement of the rearfoot.[4] Although subtalar arthrodesis is typically done in conjunction with other procedures, there seems to be an increase in isolated approaches likely secondary to shorter operation times and preservation of hindfoot motion.[5] According to Astion and colleagues,[5] fusion of the subtalar joint limited motion of the talonavicular joint by 74% and of the calcaneocuboid joint by 44%. Nonunion remains one of the most concerning challenges foot and ankle surgeons face when dealing with subtalar arthrodeses.[6] There have been publications demonstrating increased rate of nonunions in patients with smoking history, diabetes, neuropathy, trauma, infection, obesity, revision surgery, devascularized bone, and previous ankle fusion.[7,8] Surgeons have made various attempts to optimize outcomes despite risk factors, focusing on changes in technique, construct, and augmentation with bone grafts.

PERTINENT ANATOMY

The subtalar joint is defined as the 3 facet joints between the plantar talus and the dorsal calcaneus. These facets are known as the anterior, middle, and posterior facets, with the largest being posterior. Between these 2 bones is the interosseous talocalcaneal ligament as well as the artery of the tarsal canal, which anastomoses with the artery of the sinus tarsi. The medial aspect of this joint is known at the tarsal canal, whereas the lateral-most aspect is known as the sinus tarsi. These facets create the subtalar joint, which moves about a single joint axis for triplane motion of pronation and supination. A normal ratio of pronation to supination is considered to be 2:1. This joint is understandably very important in ambulation, as it controls a majority of shock absorption through pronation and rigidity for push-off through supination.[9] This plays a role in surgical technique, focusing on strong compression across the middle and posterior facets and avoiding exuberant amounts of hardware across the talar neck to lessen chances of vascular compromise.

INDICATIONS

Indications for isolated subtalar joint arthrodesis include primary arthritis, posttraumatic arthritis, inflammatory arthritis, subtalar coalition, posterior tibial tendon dysfunction (PTTD), and other hindfoot deformities. Osteoarthritis and inflammatory arthritis require subtalar arthrodesis when bracing and medication have failed to control symptoms and pain. Subtalar arthrodesis is often performed in conjunction with other procedures, such as tibiotalocalcaneal arthrodesis, double versus triple arthrodesis, as well as a variety of osteotomies and ancillary procedures, including gastrocnemius recession and bone grafting. Posttraumatic arthritis is a very well-documented sequela known to occur following intra-articular calcaneal fractures. Calcaneal fractures in and of themselves can be quite a challenge to reduce and fixate, but certain complications have been documented to happen owing to inadequate fixation and/or other patient factors.[10] Failure modes of reduction can increase the occurrence of posttraumatic arthritis involving the following: loss of calcaneal height, hindfoot varus, lateral wall widening, or impingement. Revision to subtalar arthrodesis can be more challenging owing to these factors as well as existing hardware, leading the surgeon to consider grafting and/or corrective osteotomies. Although a subtalar coalition can technically occur between any of the 3 facets, the middle facet is the most common.[11] Subtalar coalitions are known to have a bimodal distribution affecting ages 12 to 16 years and again later in adulthood.[12] Subtalar coalitions typically require an arthrodesis, as resection alone has poor outcomes owing to secondary arthritic changes, especially in an older population. Progressive deformity associated with

PTTD follows a predictable pattern as described by Johnson and Strom.[13] In later stages of PTTD, the hindfoot has developed arthritic changes and has become a rigid deformity. Arthrodesis of the affected hindfoot joints is indicated in late-stage PPTD. Similarly, arthrodesis is indicated in arthritic varus hindfoot deformities.

SURGICAL TECHNIQUE

Approach and positioning for revision subtalar arthrodesis are often dependent on the presence or absence of deformity, such as loss of calcaneal height and/or previous incisions/scars, retained hardware, and soft tissue quality. Typically, the patient is positioned in a supine position with an ipsilateral hip bump to control external rotation. Incisional approaches to be considered in a supine position include lateral sinus tarsi, posterolateral, and medial. Generally speaking, laterally based approaches allow for better access and visualization of the joint, but a medial approach allows the surgeon to gain direct access to the articulating surfaces (described in detail in Chapter 5). The advent of an arthroscopic approach has also become more popularized in recent years.[14] The authors tend to favor a lateral sinus tarsi incision for revisions unless loss of calcaneal height is a concern, in which case a posterior approach is more likely with prone positioning. If there is a need for removal of hardware as one may expect with revisions, one may need to position and place the incision or incisions accordingly, including anterior/posterior or lateral extensile.

A combination of sharp and blunt dissection should be used to dissect down through superficial and deep fascia until the extensor retinaculum and extensor digitorum brevis are encountered, at which point sharp reflection superiorly should take place. Carefully locate the sinus tarsi and lateral process of the talus through manipulation. In revision cases, this is often difficult to assess because of previous fixation and potential pseudarthrosis. The surgeons recommend the use of fluoroscopic guidance with a Kirschner wire or osteotome to help attain visualization. If there is a partial union, an osteotomy or saw may be useful here. Once the subtalar joint is exposed, a pin distractor, such as a Hintermann, or a lamina spreader can be used to enhance intra-articular visualization and access, thus ensuring adequate joint preparation. In a primary arthrodesis, the goal is to prepare both sides of the joint to bleeding bone that can be well opposed with proper fixation. This can be performed using several manual instruments, such as rongeurs, osteotomes, curettes, and power tools, such as burrs and drills. Joint preparation is the key to success in revision cases as well but can be more demanding owing to the presence of fibrous tissue, nonunion, and pseudoarthrosis. All nonviable tissue needs to be properly resected before preparing the bony surfaces. Following joint preparation, bone grafting should be considered. This consideration should help the surgeon decide between various allografts, autografts, or a combination. As discussed later, autograft seems to be preferred, which is harvested from the proximal or distal tibial metaphysis. If large bone defects are present or significant deformity correction is required, a structural graft may be needed. Structural autograft from the pelvis may be considered but is associated with higher morbidity. Structural allograft is another option however may be cost prohibitive and has higher rates of nonunion if there is a large defect.[15,16] Other options for deformity correction or large osseous defects are the utilization of three-dimensional (3D)-printed titanium cages.[17] The authors prefer to use metallic porous 3D-printed wedges and cages with deformity correction or with large defects. These customizable 3D-printed implants provide long-lasting structural support and inherent stability owing to surface roughness and can be packed with bone graft or biologics. These 3D-printed implants are scaffolds, which are osteoconductive, and in the authors' experience, are more reliable for defects greater than 2 cm. Once the desired position is achieved, guide wires for desired size screws are placed. There are a multitude of different orientations or size configurations of subtalar joint arthrodesis. For primary subtalar fusions, the authors prefer 2 to 3 large partially threaded headless cannulated screws. In revision cases, fixation and stability may be more difficult to achieve owing to bone quality, previously placed hardware, and voids. The authors have found intramedullary nails that provide dynamic compression to be the most reliable.

In cases with secondary deformity, such as loss of calcaneal height and talar dorsiflexion and/or significant varus leading to impingement, the authors prefer prone positioning with a central-posterior incision placement. This incision allows for access to the posterior subtalar joint, preparation of the joint, and placement of graft for restoration of alignment. A similar fixation construct as above is used unless the goal is to maintain distraction and alignment; then 2 fully threaded screws are used to prevent graft collapse.[18] The posterior approach allows for Achilles tendon lengthening to be easily performed, which is often helpful in restoring sagittal plane alignment of the talus and calcaneus and allows for adequate distraction to be maintained. The authors often approach the subtalar joint directly through the Achilles tendon using a central incision.[19] A Z-lengthening of the Achilles tendon is performed, and the proximal/distal aspects are reflected, which enhance visualization of the posterior facet. The Achilles tendon is repaired in a lengthened position before final closure.

CONSIDERATIONS/CURRENT EVIDENCE

Fixation Options

Fixation options to be considered consist of large solid, cannulated screws, or intramedullary nailing. There is general debate on the number of screws (one, two, three) and orientation of the screws (divergent or parallel vs anterior to posterior or posterior to anterior) in terms of which fixation method is superior. There is even some debate into the size of screws typically ranging between 6.5 and 8.0 mm in screw size. Current evidence supports that the delta configuration as discussed by Hungerer and colleagues[20] has the strongest biomechanical stability. Hungerer and colleagues[20] demonstrated in their study by comparing parallel, counter-parallel, and delta configurations, that the delta configuration had the greatest biomechanical stiffness with the lowest degree of deflection in cadaveric models. This study also demonstrated no difference when comparing 6.5- versus 8.0-mm sized screws as well as no difference using cannulated versus solid screws. Another biomechanical study performed by Chuckpaiwong and colleagues[21] challenged several different screw constructs and compared compression, torsional stiffness, and least amount of joint rotation. The constructs they compared included single screw in the talar dome, single screw in the talar neck, double parallel screws, and double diverging screws. According to this study, double-diverging screws was the best construct in all parameters measured. A single 7.0-mm screw construct directed across the posterior facet as discussed by Haskell and colleagues[22] demonstrated 98% fusion rate (99/101) with an average time to fusion being 12.3 weeks. Interestingly, Haskell and colleagues[22] demonstrated increased time to fusion with a prior ankle fusion, but revision subtalar fusion did not affect time to fusion. Each of the patients in this 101 patient cohort did receive autograft from the sinus tarsi and anterior process of the calcaneus. Davies and colleagues[4] also demonstrated great results using a single-screw construct with a single 7.0-mm partially threaded cancellous screw for fixation in both primary and revisional subtalar arthrodesis. Davies and colleagues[4] were able to demonstrate a union rate of 95% in 95 primary isolated subtalar arthrodeses. Decarbo and colleagues[23] published a study comparing 1- versus 2-screw fixation for their subtalar arthrodesis demonstrating no significant difference. Bofelli and colleagues[24] in a 15-patient study demonstrated the efficacy of using their unique 2-screw construct. This unique screw construct includes a typical compression screw across the posterior facet from posterior to anterior but also includes a second screw from the plantar lateral aspect of the anterior calcaneus into the talar head or neck, which is considered a stability screw. Their study had a 100% union rate.[24]

More recently, Wirth and colleagues[25] in 2020 published their article on comparing a 2- versus 3-screw construct for subtalar joint arthrodesis. Their article demonstrated a statistically significant increased rate of nonunion and increased rate of revision surgeries in the 2-screw construct compared with the 3-screw construct in 113 patients. The investigators also concluded that diabetes, a high body mass index (>30), and having a prior ankle fusion surgery increased the need for revision arthrodesis. Similarly, a study by Jones and colleagues[26] demonstrated a decrease in time to fusion as well as a decreased rate of nonunion in the 3-screw construct (N = 28) compared with the 2-screw construct (N = 26) in a cohort of 54 patients. Specifically, the 3-screw construct group had zero nonunions, whereas the 2-screw construct group had a nonunion rate of 26.9%. There does not seem to be a definitive answer in the literature when it comes to screw constructs, but it is the authors' opinion that 2 partially threaded headless screws spanning the subtalar joint in a divergent pattern are sufficient in most cases with primary arthrodesis.

More recently, subtalar joint-specific implants and intramedullary nails have been introduced to be used for primary or revision arthrodesis. When considering revision options, the authors believe fixation should be more robust by increasing the size or number of fixation points that differ in placement from that used in primary fusion surgery. Intramedullary nailing with cancellous autograft is the authors' method of choice when considering revision options. Intramedullary nailing provides effective stable fixation with minimally invasive placement.[27,28] Furthermore, devices with the ability to provide static and dynamic compression enhance stability and may improve outcomes. Dynamic compression provided by internal NiTiNoL (Nickel Titanium-Navel Ordinance Laboratory) technology provides 2 to 4 mm of active compression in addition to manual static front-loading compression. This is particularly important if aforementioned patient risk factors contribute to potential nonunion.[29]

Bone Graft

The use of bone grafts is to provide osteogenesis, osteoinduction, osteoconduction, and/or structural support. The formation and resorption of bone carried out at the subtalar level are continuous, and interruption or insufficiency of any of the metabolic pathways involved may lead to poor outcomes in patients undergoing osseous surgery, including arthrodesis. There are advantages and disadvantages between different bone grafts, whether autogenous or allograft. Not all bone grafts will have the same properties; therefore, surgeons should consider the patient demographics and comorbidities as well as the specific indication to aid in identifying the ideal graft for that particular situation.[30–32] An overview comparing various bone graft options is provided in **Table 1**.

Successful subtalar joint arthrodesis using autograft and screw fixation has been reported for nearly half a century.[33] Although autograft in many regards remains the gold standard for osseous procedures because it possesses all qualities necessary while maintaining histocompatibility, quantity and quality of autografts are limited and may be dependent on patient demographics and comorbidities.[30,32] Harvesting

Table 1
Properties, advantages, disadvantages, and examples of bone graft options

	Source	Properties	Advantages	Disadvantages	Examples
Autograft	• Obtained from the patient • Corticocancellous vs cancellous • Multiple harvest sites to consider	• Osteoinductive • Osteoconductive • Osteogenetic • Structural support (corticocancellous sources only)	• Traditionally considered gold standard • No risk of disease transmission • Structural & nonstructural options • Cancellous sources provide superior osteoconductive, osteoinductive, & osteogenic properties • Corticocancellous sources provide structural support • Vascularized options enhance osteogenic properties & provide structural support • Various harvesting techniques & instrumentation exist • No direct cost associated	• Donor site morbidity is site dependent • Limited quantity • Quality is dependent on patient demographics & comorbidities • Added surgical time • Increased blood loss	*Corticocancellous* • Iliac crest • Calcaneus *Cancellous* • Tibial metaphysis (proximal vs distal) • Calcaneus • Bone marrow aspirate
Allograft	Cadaveric donors	• Osteoconductive • Variable osteoinduction	• Unlimited quantity • Structural & nonstructural options • Minimal added surgical time • Fresh cadaveric grafts & DBM maintain some osteoinductive properties • Lower cost compared with synthetic substitutes & BMPs	• Integration not as effective as autograft • Possible host-disease transmission	• Fresh structural cadaveric • Frozen structural cadaveric • Freeze-dried cancellous chips • DBM

Synthetic substitutes	Bioengineered/ synthetic ceramics	• Structural • Osteoconductive	• Unlimited quantity • Provides structural support and scaffolding to allow osteointegration • Primarily used to fill bone defects to provide structural support	• Variable integration & resorption rates • Minor osteoconductive properties • Cost typically higher than allografts	• Calcium sulfate • Calcium phosphate • Tricalcium phosphate • Coralline hydroxyapatite • Magnesium phosphate
Bone morphogenetic proteins	Bioengineered/ synthetic	• Osteoinductive • Osteogenetic	• Naturally found in bones & used by multiple organs for maintenance & development • Promotes guided tissue regeneration	• Markedly most expensive option • Nonstructural • Limited FDA approval • Limited indications • Wide spectrum of adverse outcomes reported • Theoretical carcinogenesis	• rhBMP-2 • rhBMP-7 • rhBMP-11 • rhPDGF

autograft also carries a higher risk of morbidity, which is dependent on harvest site location and quantity of graft harvested compared with allografts. Morbidity is often associated with the harvest site location, the type of graft harvested, and quantity of graft harvested. Fundamentally, cortical-cancellous provides structural support while being less metabolically active than purely cancellous sources. Cancellous autograft is nonstructural but much more cellular, and therefore, incorporates into the donor site more readily.[30,34] For example, Attia and colleagues[35] demonstrated a morbidity rate of 6.8% when harvesting from the proximal tibial metaphysis (Gerdy tubercle), distal tibia metaphysis, or calcaneus, which is less than half of the known morbidity rate of harvesting a cortical-cancellous iliac crest graft. Furthermore, the investigators reported, of the 3 lower-extremity sites, calcaneal grafts were associated with significantly more complications, including chronic pain, fractures, and sural neuritis as compared with grafts obtained from the tibia.

There may be situations when allograft should be used in place of autograft. There is no perceived limit of allograft available and there is no association with increased operative time or harvest site morbidity. Cadaveric allografts are available in cancellous and cortical forms, or as demineralized bone matrix (DBM). Allografts possess osteoconductive properties, and DBM-processing methods allow retention of osteoinductive properties; however, allografts have no osteogenic properties therefore do not incorporate as readily. Allografts also carry the potential for disease transmission.[35,36]

Clinical comparison of autograft and allografts used for subtalar joint arthrodesis has been retrospectively reported. Easley and colleagues[7] reported results of 184 subtalar joint arthrodeses in 174 patients, which included 28 revision cases. All cases were fixated with 1 or 2 screws, whereas 145 of 184 cases received either cancellous autograft (n = 94), structural autograft (n = 29), cancellous allograft (n = 17), or structural allograft (n = 5). The investigators reported an 86% union rate from primary cases and 71% union rate in revision cases. Of note, 3 out of the 5 structural allografts in this study went on to nonunion, but because of limited data, they could not demonstrate a significant relationship between the type of bone graft and the rate of union or the time to union.

In a large retrospective study, Davies and colleagues[4] performed 95 isolated subtalar arthrodeses where autograft was used in 92 of the patients. The investigators reported a 95% union rate, whereas 4 patients required revision for nonunion. The autograft used included structural iliac crest graft for restoration of calcaneal height in posttraumatic arthritis cases, as well as cancellous autograft from the tibia, fibula, or calcaneus.[4] Joveniaux and colleagues[37] reported a series of 28 isolated subtalar arthrodeses with an average of 56-month follow-up. The investigators found a 100% union rate in both 16 cases with iliac crest and 10 cases with allograft. They fixated each subtalar joint using 1 to 2 staples and demonstrated 100% union rate. This study suggests that outcomes of primary subtalar joint fusion may not necessarily be influenced by graft source.

Allogeneic bone grafts are known to be relatively safe; however, reports on union rates have been mixed. In a retrospective review, Scranton[38] compared 12 open, isolated subtalar arthrodeses using iliac crest autogenous bone graft versus 5 arthroscopic arthrodeses using bone morphogenic protein (BMP). In this study, Scranton[38] demonstrated no significant difference when comparing union rates or postoperative complications. This study did demonstrate a longer tourniquet time by 5 minutes on average in the arthroscopic group compared with the open group, but the length of hospital stay on average was higher in the open group. Michelson and Curl,[39] in a prospective study, compared autograft from the iliac crest with

DBM in 55 patients undergoing either isolated subtalar arthrodesis or triple arthrodesis; 18 patients received autograft, whereas 37 received DBM. They demonstrated no difference between cohorts when it came to union rates. Both autograft and allogeneic options can be used when providing structural grafts for deformity correction when performing subtalar joint arthrodesis.

Synthetic bone substitutes have been shown to have a positive patient-safety profile and relatively similar fusion rates to autograft and allograft and are increasingly cost-effective. There is seemingly a plethora of options when it comes to considering synthetic grafts, including calcium sulfate, tricalcium phosphate, biphasic calcium phosphate, hydroxyapatite, bioglass, magnesium, and silicate calcium phosphate. In a published cohort of 17 patients, Fusco and colleagues[40] demonstrated only 70% fusion rate at 12 weeks using biphasic calcium phosphate. This study by Fusco and colleagues[40] used biphasic calcium phosphate for both revisions and primary fusions. In a larger study performed by Shah and colleagues,[41] 135 subtalar arthrodeses were performed, of which 82 received tricalcium phosphate mixed with bone marrow aspirate, 8 received DBM, 2 received iliac crest autograft, one received allograft cancellous chips, and the rest did not receive any graft. They demonstrated a union rate of 88 without graft and 83 with grafting, suggesting these synthetic grafts may not be needed.

BMPs are naturally found growth factors that promote and guide tissue-specific growth. Literature has shown the following BMPs have proven osteogenic properties; BMP2, BMP6, BMP7, and BMP11.[42] Various BMPs are involved in the different stages of bone healing, which can prove beneficial in achieving arthrodesis.[43] Various preclinical reports have shown increased levels of different BMPs during stages of auto-induction, formation of progenitor cells, increasing bone turnover, and promoting remodeling.[43,44] Autograft proves superior in BMP concentrations given its native source; however, this is variable based on the host and may not be currently upregulated by the host. Through the utilization of recombinant DNA technology, there are commercially available BMPs available to add to surgical sites. These are inherently osteogenic and osteoinductive; however, they provide no structural integrity. Cost-effectiveness is of concern but can prove useful in the compromised host. Kanakaris and colleagues[45] achieved a healing rate of 90% in 19 joint fusions (ankle, subtalar, talonavicular, pubic, and sacroiliac) with the use of rhBMP-7 (recombinant bone-morphogenetic proteins). There is further literature using rhBMP-2 in various spinal fusion reports but limited research focusing on lower-extremity arthrodesis procedures and the isolated use of BMPs as adjunctive graft.

In cases of posttraumatic deformity, such as decreased calcaneal height, traditionally structural cadaveric allografts or tricortical iliac crest graft have been used. With the advent of 3D-printing technology, customized, patient-specific porous metallic wedges and cages are available and are particularly useful for severe osseous deficits and/or significant deformity. The macroscopic porous quality allows for nonstructural graft or bone substitute to be packed into the implant. The microscopic porous structure mimics that of cancellous bone, which historically plays the primary role of osteoinduction. However, traditional methods of harvesting cancellous bone yield graft with poor handling characteristics, creating poor graft retention, and therefore, allograft and substitutes are used. The senior author has developed a method for efficient graft harvest that then allows for the solid and liquid portions of the graft to be separated using the Hensler Bone Press (Hensler Surgical Technologies, Wilmington, NC, USA). The patented methodology improves handling characteristics of the cancellous autograft, allowing it to be easily packed into porous 3D-printed implants while enhancing graft retention. The use of specialized bone graft harvesters do add direct cost but decreases operative time. The direct cost of using the Hensler Bone Press is $550 to $700, which is far less than competing devices that do not improve handling characteristics. The authors prefer to harvest cancellous graft from the proximal or distal tibia owing to lower morbidity compared with the calcaneus.[35] In addition, it is the authors' experience that a larger quantity of graft can be obtained from the tibia. It should be emphasized that the authors' preferences are currently anecdotal, as there are no published comparative reports at the time of writing this article. In an ovine cortical and cancellous model, Kelly and colleagues[46] demonstrated a linear relationship between porosity of 3D implants and mechanical properties but a parabolic relationship between porosity and pushout strength. This study demonstrated the highest pushout strength of the porous titanium gyroid implants at a 4-week and 12-week time point was 60% porosity implants. However, there has been a significant increase in the foot and ankle literature to the efficacy and ability of patient-specific 3D-printed porous cages for osseous deficits.[47–49]

Case Reports

Patient 1 is a 52-year-old man who presented with hindfoot pain. The patient underwent a previous subtalar joint arthrodesis with a two-screw construct that ultimately failed, including broken hardware (**Fig. 1**). Upon revision, most of the hardware was removed; the nonunion was resected, and both sides of the joint were reprepared. Tibial autograft was harvested and placed within the fusion site. The area was fixated and compressed with an intramedullary nail. After a period of non-weight-bearing, the patient demonstrated union at 8 weeks on radiographs and confirmed union at 10 weeks on computed tomographic (CT) scan. The patient went on to heal successfully and returned to ambulation without pain and use of an ASO brace (**Fig. 2**). Approach and intraoperative approach of a similar case requiring a custom-printed metallic wedge are depicted in **Fig. 3**.

Patient 2 is a 37-year-old man who presented with hindfoot pain. The patient underwent a previous subtalar joint arthrodesis with a 2-screw construct that ultimately failed with a frank hypertrophic nonunion (**Fig. 4**). Upon revision, the hardware was removed; the nonunion was resected, and both sides of the joint were reprepared. Tibial autograft was harvested and placed within the fusion site. The area was fixated and compressed with an intramedullary nail (Envois Lewisville, TX). Serial radiographs demonstrated union at 6 weeks, confirmed on CT scan at 10 weeks. The patient went on to heal successfully and returned to ambulation without pain and in regular shoes (**Fig. 5**). Approach and intraoperative approach of a similar case requiring a custom-printed metallic wedge are depicted in **Fig. 6**.

Fig. 1. Patient 1: preoperative radiograph at time of presentation.

Fig. 2. Patient 1: postoperative radiograph at time of union.

DISCUSSION

Subtalar joint arthrodesis is a commonly used procedure for numerous pathologic conditions. Although rarely performed in isolation, they generally have a high rate of union with limited complications. However, patient factors, including cause of pathologic

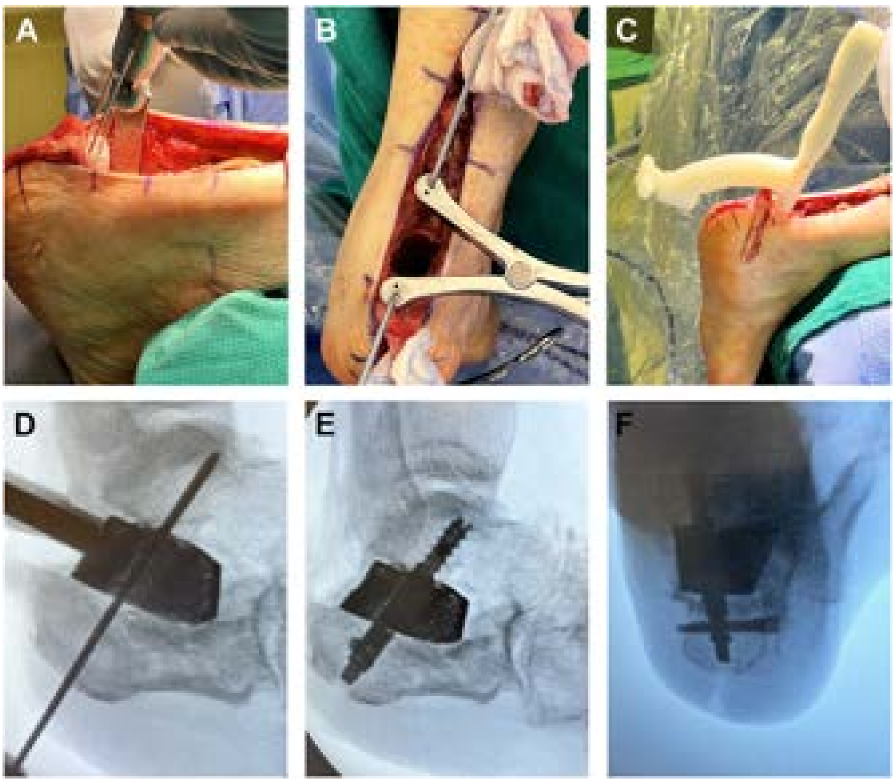

Fig. 3. (*A*–*F*) Patient initially presented as a 65-year-old woman with past medical history of diabetic neuropathy and rheumatoid arthritis with a malunion of her intra-articular calcaneal fracture. Because of the loss of height, the senior author elected to restore alignment using a custom 3D-printed titanium cage(Retor3d, Durham NC). (*A*) A custom 3D-printed cut guide with temporary wire fixation. (*B*) The resection of calcaneus. (*C*, *D*) One of the trials/insertion of a 3D-printed custom cage implant with precision pin placement using this guide. (*E*, *F*) Placement of calcaneal intramedullary nail(Envois Lewisville, TX) across the 3D implant for isolated revision subtalar joint arthrodesis.

Fig. 4. Patient 2: preoperative radiograph at time of presentation.

condition, can contribute to an increased rate of nonunion. When nonunion or malunion is to be addressed, the authors recommend the following considerations.

It is imperative to identify patient factors that may have contributed to nonunion, which then should be corrected or optimized before considering revision surgery. Surgical technique, fixation selection and augmentation, and use of bone graft to the revision are imperative to increase chances of union. Multiple approaches exist, and selection is dependent on prior incision and hardware placement, as well as presence of deformity and/or osseous deficit. Joint preparation is paramount for obtaining fusion and often can be more time consuming as compared with primary cases. With numerous fixation options discussed in literature, having a robust and rigid fixation construction is critical to revision arthrodesis. Fixation for revision cases should be more robust than that used in the previous failed procedure, which can be challenging depending on previously placed hardware that requires removal, which yields additional osseous compromise. The authors recommend a similar approach to the "superconstruct" methodology as described by Sammarco[50] when considering fixation. The surgeon should consider using more points of fixation (ie, increasing the number of screws), larger fixation options as well as altering the orientation of the fixation construct. The authors have found intramedullary fixation that has the ability to provide postoperative dynamic compression in addition to traditional manual static compression achieved intraoperatively.

Although the literature has no stout consensus on type or use of bone graft, autograft remains superior with uncompromised success particularly with revision arthrodesis. The authors use a specialized technique to harvest a significant amount of nonstructural bone from the tibial metaphysis (proximal or distal). With the use of the Hensler Bone Press, this can be performed with minimal increase in operative times, increased graft handling characteristics with improved quality of autograft. The authors strongly recommend harvesting tibial bone graft with revision arthrodesis.

Fig. 5. Patient 2: postoperative radiograph at time of union.

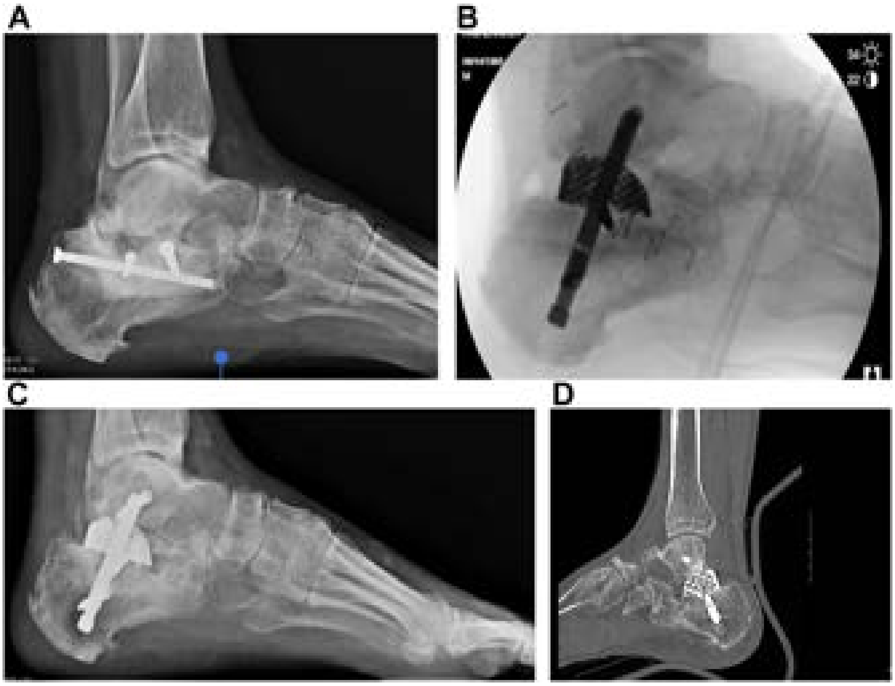

Fig. 6. (*A–D*) Patient was a 54-year-old man who initially presented 4 years following an open reduction and internal fixation of an intra-articular calcaneal fracture from an outside hospital. (*A*) In-office preoperative consult lateral projection showing depressed posterior facet with arthritic changes in the subtalar joint. (*B*) Intraoperative positioning and placement of 3D custom cage and intramedullary nail. (*C, D*) At his 3-month postoperative office visit demonstrating satisfactory alignment, no hardware failure, and osseous ingrowth within the cage.

As discussed above, the authors present 2 cases with frank nonunion of the subtalar joint. In both cases, intramedullary nailing and harvesting of tibial autograft were performed yielding success results.

SUMMARY

Although subtalar joint arthrodesis is rare, care should be taken to optimize the patient and approach when performing revisional subtalar joint arthrodesis. Given that isolated arthrodesis is not known to commonly fail, this signifies the importance of identifying factors that may be contributory to failure and addressing them upon revisional surgery.

CLINICS CARE POINTS

- Subtalar joint arthrodesis may be performed in isolation or in conjunction with adjacent joint arthrodesis, osteotomies, and other ancillary procedures.
- Revision subtalar joint arthrodesis is associated with lower union rates and increased time to union as compared with primary subtalar joint arthrodesis.
- Infection must be ruled out or treated if subtalar joint nonunion is encountered.

- Preoperative computed tomographic scans, in addition to weight-bearing radiographs, are highly recommended to assess deformity, bone quality, and presence of osseous defects
- As with primary subtalar joint arthrodesis, joint preparation is paramount but can be more time consuming.
- Multiple approaches can be used and are determined by the presence of deformity, previously placed hardware, and soft tissue quality.
- Fixation during revision should be more robust than primary cases, which can be achieved by increasing point of fixation, increasing the size of fixation, and altering the orientation of fixation.
- Intramedullary nails should be strongly considered for revision subtalar joint arthrodesis.
- Using autograft is preferable but can be supplemented with allografts, synthetic substitutes, and bone morphogenic proteins.
- Harvesting autograft from the tibial metaphysis is associated with less morbidity,
- Utilization of specialized autograft harvesting instrumentation may decrease operative time while enhancing handling characteristics,
- Patient-specific 3-dimensional-printed titanium alloy implants should be considered when deformity and/or substantial osseous defects are encountered.

DISCLOSURE

R.J. Lerch, DPM and Amar Gulati, DPM have no disclosures or conflicts. Peter Highlander, DPM is a consultant for Restor3d, Inc (Durham, NC) and Hensler Surgical Technologies, LC (Wilmington, NC).

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