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Titanium Scaffolding: An Innovative Modality for Salvage of Failed First Ray Procedures

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ABSTRACT

Shortening of the first ray is a potential complication associated with first metatarsal procedures. Correction of this deformity conventionally has required the use of a tricortical bone graft to lengthen the bone. Graft complications, including donor site morbidity, poor graft stability, and graft resorption, have revealed a need for an alternative procedure. The present report shows that titanium cage scaffolding has lower extremity applications beyond its previous uses in the ankle and spine. Two patients underwent surgical correction for failed first ray procedures using a titanium cage apparatus with a calcaneal autograft and other biologic agents. The scaffolds were appropriately sized to fill the defect. Patients remained non-weightbearing until radiographic evidence of healing appeared. Success was determined by diminished pain, a return to activity, ambulation, and patient satisfaction. Patients exhibited faster-than-anticipated healing, including a return to protected weightbearing activities and increased stability within 6 weeks. Titanium cage implants provide long-term stability and resistance to stress and strain in the forefoot. The implant we have described, newly applied to the first ray, is analogous to a system used in salvage of failed ankle replacements. In addition to reducing reliance on the iliac crest bone graft, the titanium cage apparatus is advantageous because it is customized to fill a defect using computed tomography scanning, thereby reducing graft failure secondary to an improper shape. These cases demonstrate the potential beneficial applications for titanium cages in failed first ray reconstruction.
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Failed arthroplasty and other first metatarsal procedures frequently result in iatrogenic shortening of the first metatarsal. These changes in length alter the natural dynamics of the metatarsal parabola, which, in turn, increases the potential for transfer metatarsalgia, lesser metatarsal stress fracture, hammertoe deformity, and collapse of the medial longitudinal arch (1,2). First metatarsal arthrodesis has historically been used as a surgical response to revise unsuccessful hallux valgus and Silastic implant arthroplasty procedures (3–5). If the metatarsal parabola exhibits shortening of the first metatarsal or inadequate viable bone stock, an arthrodesis procedure will be performed in conjunction with a metatarsophalangeal (MTP) joint distraction and bone graft to restore the first metatarsal length (5–7). Traditional techniques rely on corticocancellous autografts as the grafting material used to lengthen the metatarsal; however, these have associated with donor site morbidity and limited resources (6,8). Titanium cage implants provide an alternative: a stable, noncompressible construct in which grafts and graft adjuncts with little structural support can thrive. The present study demonstrates how the titanium truss system, previously applied to the ankle, has been successfully used in first metatarsal salvage procedures.

The use of iliac crest bone graft (ICBG) autografts with MTP joint distraction is currently accepted as the reference standard for a lengthening arthrodesis procedure, but its use comes with a cost (3,9). Donor site morbidity at the iliac crest, tibia, or calcaneus contributes to additional patient discomfort. Goulet et al (10) found that 38% of 87 patients who had received an ICBG experienced donor site pain at 6 months postoperatively and 19% experienced pain 2 years postoperatively. A comparison of intraoperative morbidities between autografts and allografts showed that patients receiving autografts had a greater than threefold increase in blood loss, lengthened operative time, and chronic pain at the donor site (11). The likeliness of associated chronic pain, nearly 1 in 5 after 2 years, and the perioperative

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disadvantages related to autogenous grafting have necessitated a new avenue for grafting technology that relies less heavily on autogenous grafts. In addition to surgical donor complications, autograft resources are limited (12,13). Calcaneal grafts, for example, can be a maximum of 2.0 × 1.0 cm in dimension, and it has generally been accepted that donor morbidity increases greatly with grafts exceeding these dimensions (13,14). Furthermore, viable bone stock is subject to immense variation in the cellularity of different grafting locations.[8] Tibial and calcaneal grafts, for example, contain a greater ratio of quiescent fat to hematopoietic tissue compared with ICBGs. Therefore, the use of a slightly less invasive harvesting technique, such as in the tibia or calcaneus, will also yield a graft with more feeble osteogenic and osteoinductive qualities (8).

Although autografts embody osteogenic, osteoinductive, and osteoconductive qualities, manufactured and allogeneic-harvested graft materials might ultimately yield a more satisfied patient because of the reduced donor site discomfort. A combination of synthetic scaffolds, growth factors, stem cells, and allografts has the potential to yield the positive outcomes of an autograft but with the reduced graft resorption and donor site drawbacks (12,15). Titanium cage implants supply the necessary structure to support amorphic bio-manufactured graft adjunctive materials or delicate cancellous graft chips, which have all 3 of the obligatory components of bone growth. The inert qualities of titanium make its use ideal in a highly inflamed region and its strength provides long-term stability and appropriate resistance to stress and strain in a highly used region of the foot (16).

The titanium truss system has only recently been applied to the first ray. The system described in the present study is analogous to the titanium cage spacer that has been successfully used in the salvage of failed ankle replacements (17). According to Mulhern et al (17), the titanium cage spacer is advantageous because it can be customized to fill a defect using computed tomography (CT) scanning. The coarse texture of the titanium cage allows for osteointegration and the ability to 3-dimensionally print a custom scaffold addresses the challenges associated with autografts and allografts, including graft failure secondary to an improper shape (18). The present report indicates that the titanium scaffold has beneficial applications in the first metatarsal after a failed first MTP joint Silastic implant and failed first metatarsal lengthening procedure with a calcaneal autograft.

Case Report

Patient 1

An active 55-year-old male nonsmoking patient presented with a history of a right foot first MTP joint arthroplasty and neuroma excision at his third interspace >6 years previously. His initial physical examination revealed an intact neurovascular status and a drooping right hallux with an inability to dorsiflex. The patient had an iatrogenic laceration of the extensor hallucis longus (EHL) at the right first MTP joint from the original surgery. This was confirmed by ultrasound imaging. Passive range of motion at the right first MTP joint was severely limited and revealed notable crepitus. The patient had an antalgic gait with circumduction on the right side. Radiographs and CT imaging (Figs. 1–4) revealed a subluxed Silastic implant with local osteophytes and heterotrophic bone formation. The distal end of the implant abutted the proximal medial cortex of the right proximal hallux with clear signs of cortical erosion in that area. Ultrasound studies showed a 6-cm diastasis between the EHL tendon stumps extending from the first metatarsal cuneiform to the first MTP joint. The combination of the patient's EHL tendon laceration, dysfunction of the first MTP joint, and bony erosion at the first MTP joint, indicated an arthrodesis with an EHL tendon repair.

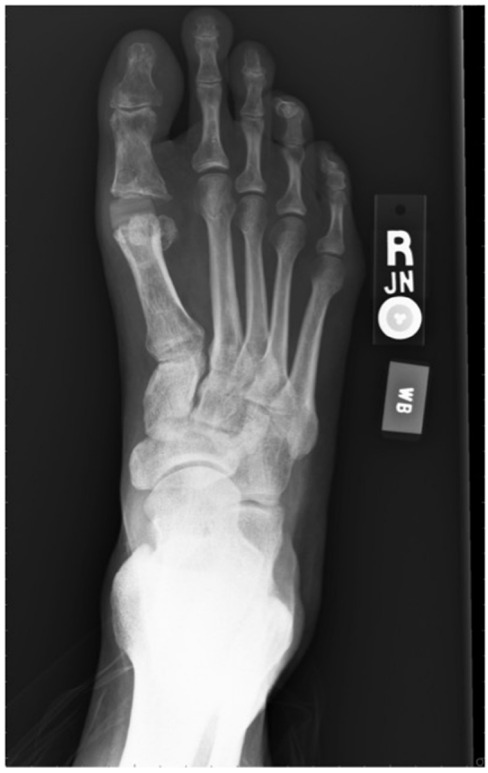

Fig. 1. Preoperative anteroposterior radiograph of right foot showing subluxed Silastic implant with local osteophytes and heterotrophic bone formation.

Before surgical treatment, the patient attempted nonoperative care, including stiff-soled shoes and orthotics, without success. Eight months after his first appointment, he underwent preoperative CT scans, which confirmed subluxation of the Silastic implant and local osteolysis. An

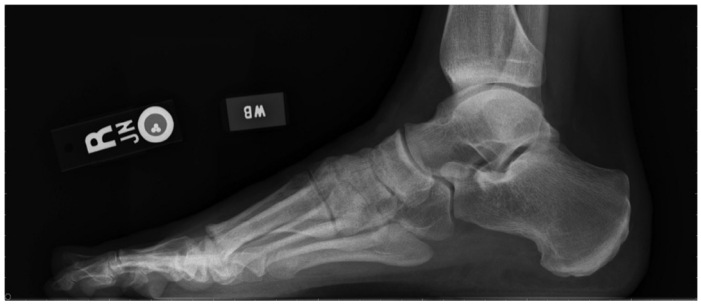

Fig. 2. Preoperative lateral radiograph of right foot showing subluxed Silastic implant with local osteophytes and heterotrophic bone formation.

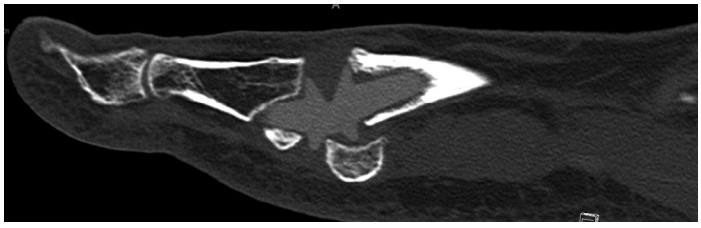

Fig. 3. Preoperative sagittal computed tomography of right foot showing subluxed Silastic implant with local osteophytes and heterotrophic bone formation.

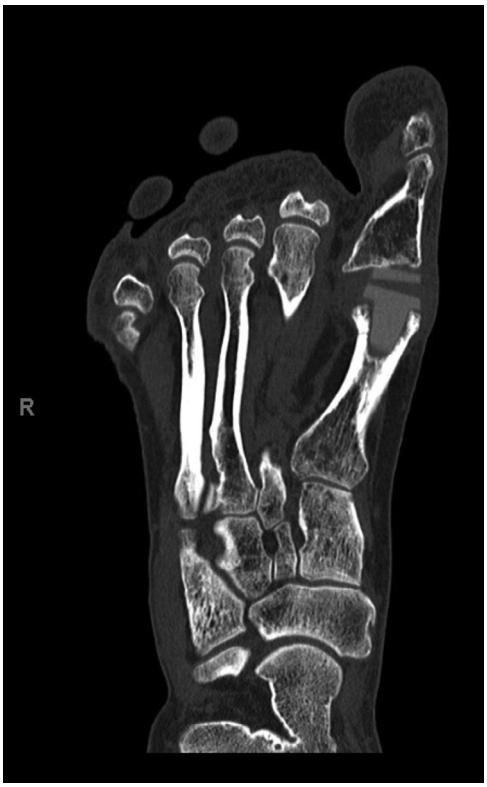

Fig. 4. Preoperative axial computed tomography of right foot showing subluxed Silastic implant with local osteophytes and heterotrophic bone formation.

Fig. 5. Implant packed with autologous cancellous and cortical bone graft and demineralized bone matrix.

autograft, including demineralized bone matrix, was indicated to perform this arthrodesis because of the extensive bone loss incurred by the failed implant. The use of a cage implant was discussed, and the patient ultimately consented to its use, given the potential benefits.

In the operating room, the patient was placed in a supine position under general anesthesia with the use of a thigh tourniquet at 250 mm Hg. A 7-cm incision was made dorsomedially over the first MTP joint to reveal both the implant and the ruptured EHL tendon. The implant appeared to be protruding out of the dorsal aspect of the first metatarsal with associated bone fracturing, reactive tissue, and debris. The debris and implant were removed using a rongeur, curette, and rasp and then flushed with copious plain saline. Additionally, the EHL tendon showed significant fraying and substantial fibrous reconstitution and was freed to return to its proper positioning.

An autologous bone graft was harvested using a punch graft from the lateral wall of the right distal tibia and right lateral calcaneus under the guidance of fluoroscopy. The graft included cortical and cancellous bone, and the defects were filled with demineralized bone matrix bone putty. Next, the ablated joint space was assessed for size and shape using the sizer specific to the titanium implant. Before placing the 6-mm cage into the arthrodesis site, it was packed with the autologous bone graft and the demineralized bone matrix containing growth factors (Fig. 5). After placing the cage, a spanning plate with was fastened over the base of the proximal phalanx to the first metatarsal using 3.0-mm locking and nonlocking screws. A second 6-hole plate was placed medially over the same region using six 2.4-mm nonlocking screws to prevent any motion at the cage–graft site (Fig. 6). Intraoperative fluoroscopy confirmed appropriate placement of the titanium truss and plate construct at the right first MTP joint (Fig. 7). The goal of the additional plate was to increase the stability and prevent frontal plane rotation of the cage construct. After closing, a well-padded splint was placed on the patient for postoperative immobilization.

The patient endured 6 weeks of non-weightbearing in a cast, posterior splint, and, ultimately, a controlled ankle motion walker boot. The patient also began using a low-intensity pulsed ultrasound bone stimulator at 2 weeks postoperatively. By 6 weeks postoperatively, the patient had noted a drastic decrease in pain, and he was ready to bear weight protected in a controlled ankle motion walker boot.

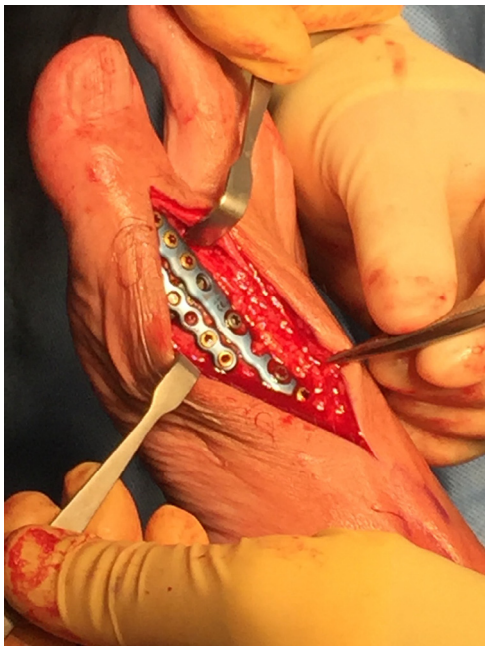

Fig. 6. Dual locking and nonlocking plate fixation was used to enhance the stability of the grafting construct at the first metatarsophalangeal joint.

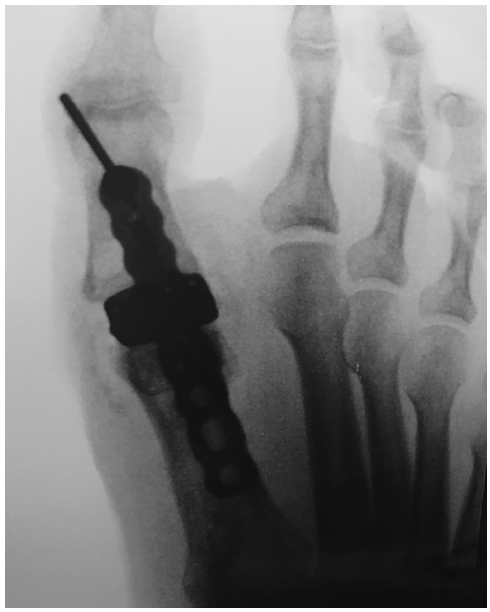

Fig. 7. Immediate postoperative anteroposterior radiograph of the right foot depicting plate fixation and use of the titanium cage implant.

Radiographs (Figs. 8 and 9) and a CT scan (Figs. 10 and 11) at 2 months postoperatively showed bony fusion between the distal aspect of the right first MTP joint and the titanium cage implant without signs of bony resorption. At 9 months postoperatively, the patient exhibited

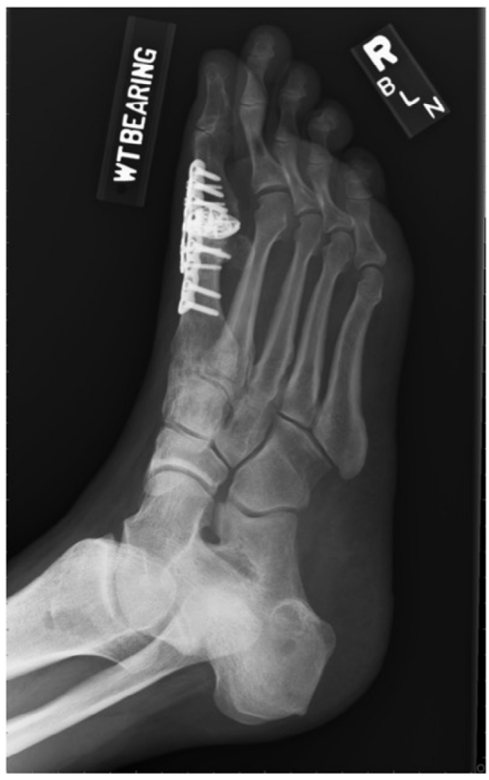

Fig. 8. Medial oblique radiograph of the right foot at 2 months postoperatively showing bony fusion between the distal aspect of the right first metatarsophalangeal joint and the titanium cage implant.

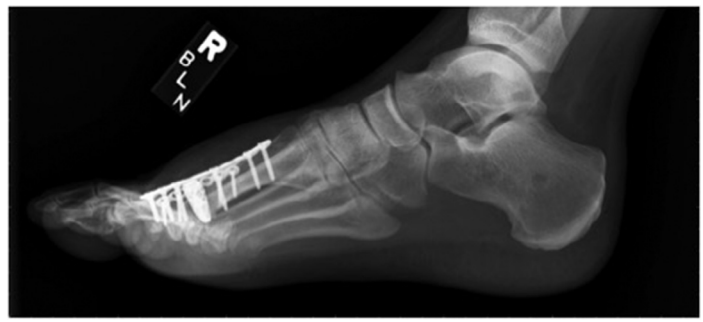

Fig. 9. Lateral radiograph of the right foot at 2 months postoperatively showing bony fusion between the distal aspect of the right first metatarsophalangeal joint and the titanium cage implant.

bony fusion and had returned to work wearing regular shoe gear. The treatment dates included surgery in August 2016 and 10 months of follow-up examinations through May 2017.

Patient 2

A nonsmoking 57-year-old female presented with a complicated right foot deformity, including a history of 2 previous distal bunion procedures and second and third interspace neurectomies. The previous bunionectomies had resulted in a short first ray with an abnormal parabola and an elongated second ray. Additionally, the patient experienced pain in her second metatarsal, which was later shown radiographically to have a significant stress fracture. The physical examination revealed an intact neurovascular status. The patient underwent a right foot revision bunion procedure with lapidus and interpositional calcaneal bicortical graft, along with a second metatarsal shortening osteotomy. The patient's graft resorbed, which resulted in nonunion of the right first tarsometatarsal joint. It was later

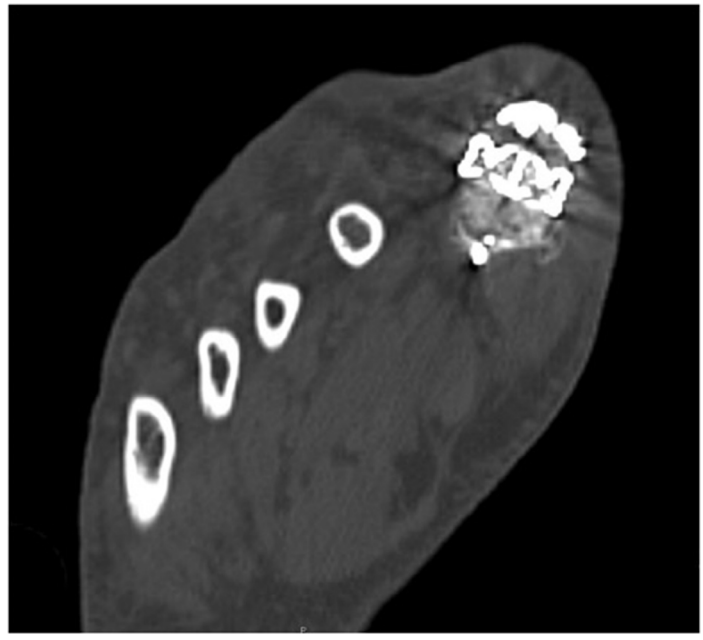

Fig. 10. Coronal computed tomography scan at 2 months postoperatively showing the dorsal plate with multiple transfixing screws and cage interfacing the osteotomy of the distal first metatarsal base and base of the proximal phalanx with good bony fusion of the distal first metatarsal and cage.

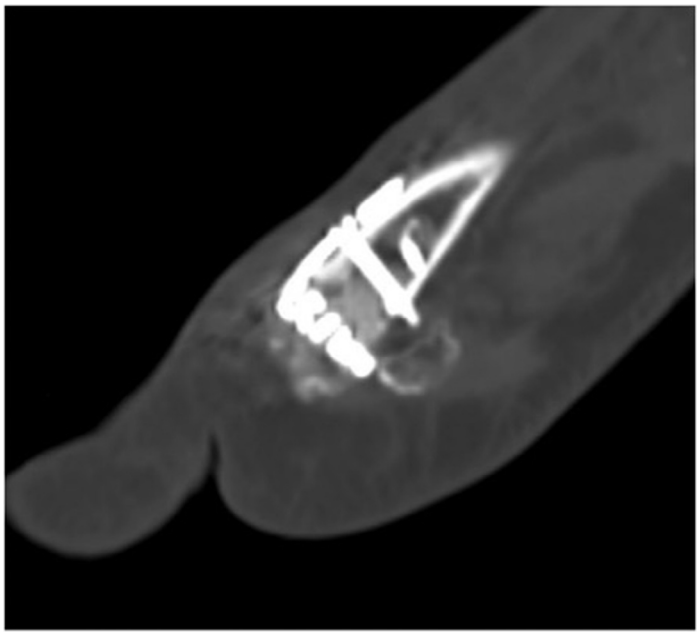

Fig. 11. Lateral computed tomography scan at 2 months postoperatively showing the dorsal plate with multiple transfixing screws and cage interfacing the osteotomy of the distal first metatarsal base and the base of the proximal phalanx with good bony fusion of the distal first metatarsal and cage.

determined that the patient had a vitamin D deficiency, which likely contributed to the nonunion. Preoperative radiographs and CT imaging confirmed nonunion with bony resorption at autograft implantation site (Figs. 12–14). At 7 months after her diagnosed nonunion lapidus procedure and correction of her vitamin D deficiency, a titanium cage implant with stem cell allograft and a medial column fusion plate was determined to be the most effective option for surgical revision.

In the operating room, the patient was placed in the supine position under general anesthesia with the use of an ankle tourniquet. A linear incision was made over the preexisting scar in the right foot. Internal fixation was removed at the first tarsometatarsal joint. The nonunion was identified and debrided to healthy bleeding cancellous surfaces, resulting in an 8-mm defect, determined using a sizer specific to the implant. An 8-mm titanium mesh cage implant was then loaded with stem cell allograft and placed and then tamped into position, with the foot held in the neutral position. A medial column fusion plate was placed over the titanium cage with screws purchasing viable bone on both sides. The naviculocuneiform joint was fixated for additional stability, which was necessary to achieve the fixation construct. The naviculocuneiform joint was added to achieve a superconstruct. Stabilizing 1 joint proximally offered more stability in her previously compromised fusion. The proximal locking screws could be removed later for additional motion. After closing, a well-padded splint was placed on the patient for postoperative immobilization. Fig. 15 shows the immediate postoperative cage implant placement with medial column plate fixation.

The patient remained non-weightbearing with crutches for 2 months. After 2 months non-weightbearing, the radiographs and CT scans (Figs. 16–18) confirmed bony union, and the patient was transitioned to weightbearing in normal shoe gear. At 3 months postoperatively, the patient sustained a right calcaneal avulsion secondary to trauma at a previous calcaneal graft site requiring open reduction and internal fixation. At 11 months postoperatively, the patient returned to work ambulating in regular shoe gear, having recovered from the calcaneal graft complications related to the original failed first ray

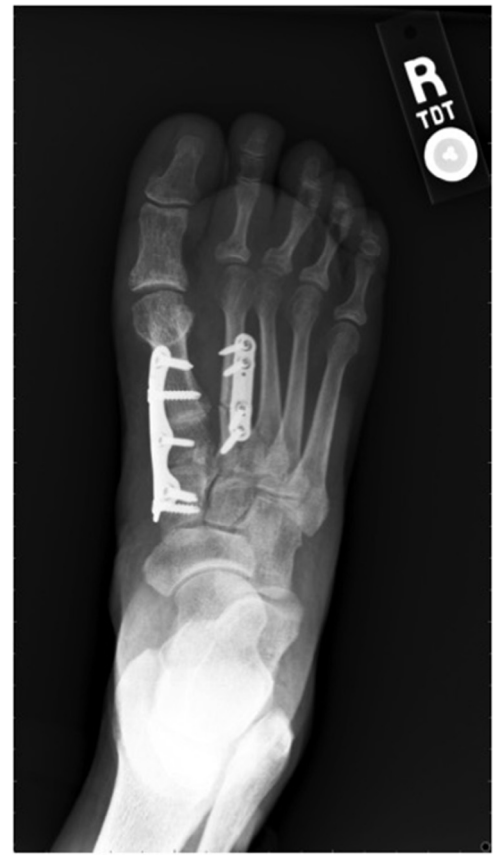

Fig. 12. Preoperative anteroposterior radiograph of the right foot confirming nonunion with bony resorption at the autograft implantation site.

procedure. The treatment dates included surgery in May 2016 and 1 year of follow-up through May 2017.

Discussion

Although first ray procedures are common, the resulting nonunions or excessive shortening have made these procedures difficult to correct. Bone grafting with fusion is the current standard of care to repair a

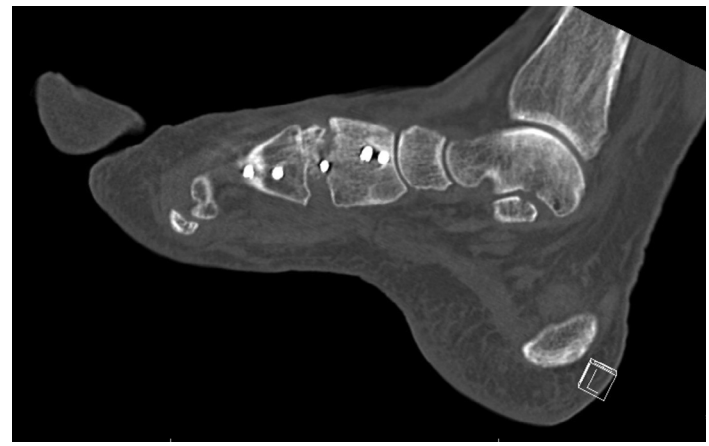

Fig. 13. Preoperative sagittal computed tomography scan of the right foot confirming nonunion with bony resorption at the autograft implantation site.

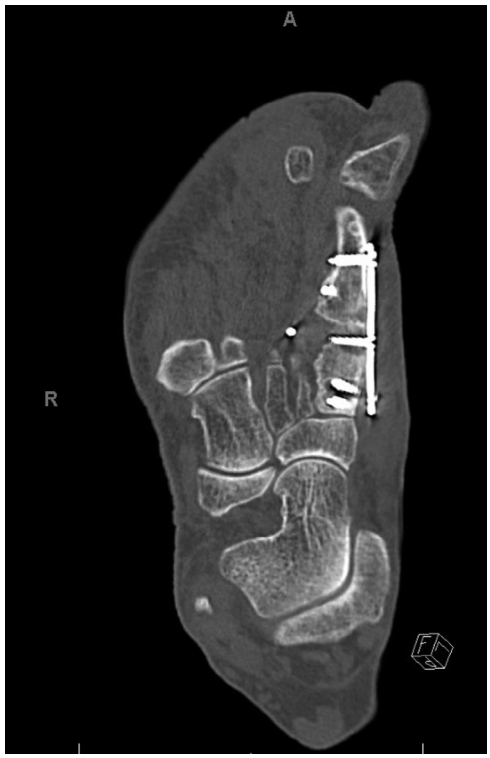

Fig. 14. Preoperative axial computed tomography scan of the right foot confirming nonunion with bony resorption at the autograft implantation site.

nonunion with excessive shortening (15). To have optimal functionality, a graft must have mechanical stability. Graft stability is difficult to achieve, especially with trephine autogenous grafts and osteobiologic agents, because they lack strong cortical surfaces (19). Access to tricortical autogenous grafts is limited and postoperative morbidity is not uncommon; therefore, alternative methods to create stability in a weightbearing region are necessary (19). The cage implant's strength and high coefficient of friction create a stable construct even before both sides of the grafting system have fused, unlike a traditional cortical graft (19,20). Its design allows for great strength that is minimally heavy or bulky and also creates an ideal lattice for bony ingrowth (20). Moreover, the titanium cage spacer is able to absorb and distribute the weight forces as soon as the bone has healed. In

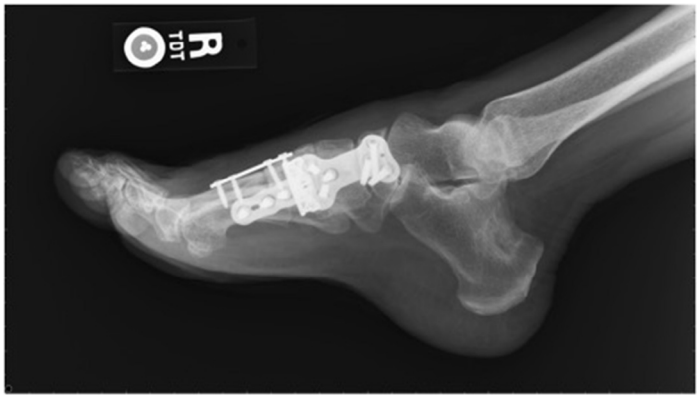

Fig. 15. Immediate postoperative lateral radiograph of the right foot showing the cage implant with medial column plate fixation.

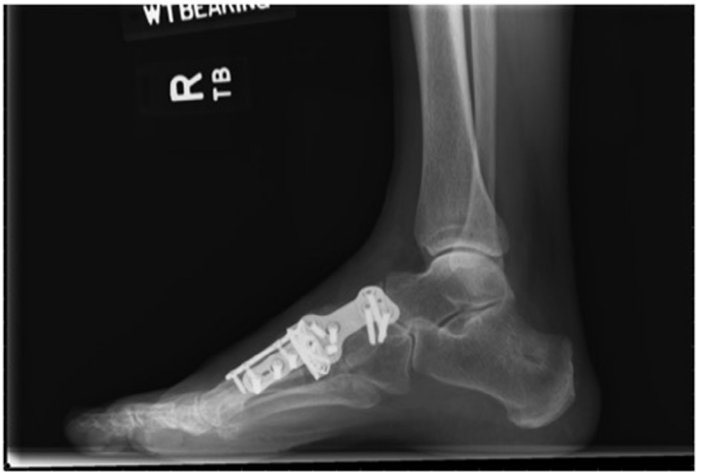

Fig. 16. Lateral radiograph of the right foot at 2 months postoperatively showing bony union at the cage implantation site.

contrast, autogenous grafts can resorb and disintegrate before fusion has occurred at the site of arthrodesis (19). The titanium cage maintains the structure as osteoclastic activity slowly dissolves the graft components. Our cases explored a unique application of the titanium cage at weightbearing joints of the first ray as a mechanical stabilizer and as a housing system for structureless grafts.

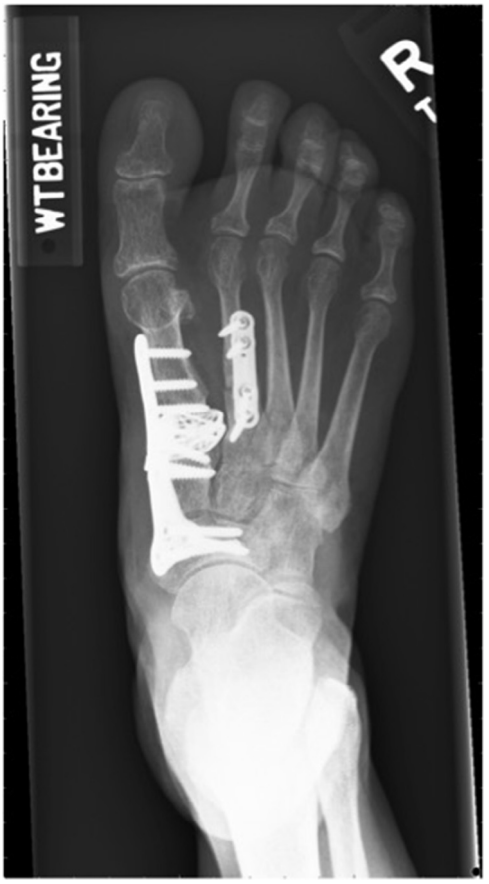

Fig. 17. Anteroposterior radiograph of the right foot at 2 months postoperatively showing bony union at the cage implantation site.

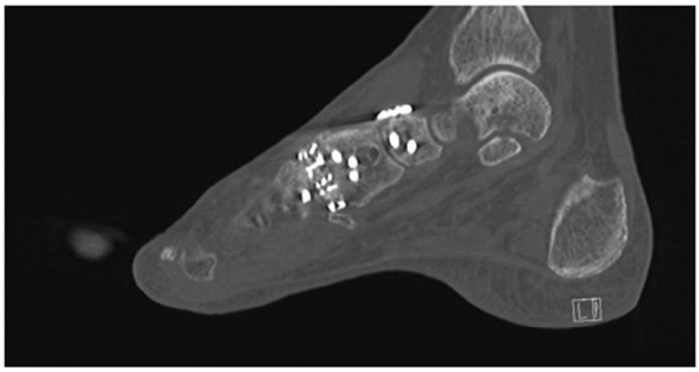

Fig. 18. Lateral computed tomography of the right foot at 2 months postoperatively showing bony union at the cage implantation site.

The future of osseous grafting is in 3-dimensional (3D) printing. Although the present study used sizers with prefabricated titanium cages, the technology to create fully customizable implants has many applications. The indications for 3D printing include segmental defect replacement, joint arthrodesis, void filling, and, eventually, total bone replacement (20). Tetsworth et al detailed the uses of 3D-printed custom titanium cages with extensive femoral shaft defect substitution. They recommended the addition of plates for metaphyseal and juxtaarticular applications, intramedullary nails for diaphyseal applications, and screws or cerclage wires to further stabilize the construct (20). Additionally, they reported that cages create a secure environment through which bony growth can occur. Moreover, the rutted surface promotes the cage's osteointegration (20). In the context of arthrodesis, Mulhern et al (17) reported success using custom trusses in their conversion of a failed total ankle reconstruction to an ankle arthrodesis. At a 30-week follow-up examination, their patient maintained anatomic alignment, demonstrated joint stability, and was fully weightbearing and pain free in a regular shoe (17). Their case report indicates that customizable cage implants could play an important role in complex revisional arthrodesis (17). The cases described in the present report drew from both titanium cage applications as a segmental defect filler and as a tool for stable arthrodesis, as well as a novel lengthening device.

Although the titanium cage spacer has the capacity to lengthen the first ray quite drastically, it is limited in use with contracted and scarred local soft tissue. Caution must be taken when lengthening a ray drastically in a single-step procedure because of the danger of neurovascular embarrassment and digital deformities secondary to a restricted tendon length (21,22). The present study found that in both cases, suboptimal lengthening was achieved because of soft tissue limitations. Regardless, a functionally acceptable metatarsal parabola was accomplished in both patients, who had previously experienced severe first ray length deficits. During the follow-up period, neither patient experienced second metatarsal transfer pain and both had normal mechanical ambulation.

The present study had a few procedural flaws. It lacked substantial patient volume, long-term patient follow-up (>1 year), and used poorly substantiated guidelines for determining procedural success. The present study was retrospective, and we were responsible for interpretation of the clinical outcomes; therefore, bias was possible.

Failed first ray procedures present a plethora of revisional challenges. The joints of repair are orthogonal to the weightbearing forces, which compounds the difficulty of achieving bony union. Titanium cages are mechanically strong, stable, and allow for osseous integration. Furthermore, they are lightweight and highly customizable, which make them ideal for grafting in the smaller joints of the foot. This technology could permit surgeons to rely less heavily on the ICBG and avoid unnecessary donor site morbidities, especially in patients with poor bone stock. It is not a first-line treatment and does not replace standard fusion; however, it does demonstrate an innovative approach to complex revisional surgery.

In conclusion, although the present study had a limited patient volume, the success in the form of first ray mechanical stability, radiographic union, and patient satisfaction should be considered. Larger scale studies with long-term follow-up are needed to confirm our results.

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