Bilateral total ankle and total talus replacement (TATTR): A case report

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The combined custom 3D printed total ankle-total talus replacement, or TATTR, as previously described in the literature, is a procedure for the patient with substantial pathology of the ankle including the tibial plafond and the talus. The goals for a TATTR procedure are to provide pain relief, minimize limb length discrepancy, and maintain or improve motion of the ankle joint and functional mobility of the patient. A contralateral Computed Tomography (CT) has previously been used to recreate a “mirror image” for the talar implant design of the affected limb. To the best of our knowledge, no study has demonstrated the use of TATTR when there is pathology in bilateral tali. The purpose of this article is to discuss the process and utilization of bilateral TATTR procedures for a patient with bilateral talar avascular necrosis (AVN).

Keywords: ankle, talus, arthroplasty, joint, implant, trauma

Fractures to the talus are uncommon and typically occur after high-energy trauma [1]. The incidence is unknown and the infrequency of these injuries in part may contribute to historically poor outcomes and complications [2]. Nondisplaced fractures of the talus may be treated conservatively or percutaneously. In cases of severe comminution or displacement, a surgeon may attempt to reconstruct the talus with a combination of screws, pins, plates or staples. Avascular necrosis (AVN) is a common sequela in trauma to the talus and the risk may be increased with any attempted repair. The talus may be stripped of its blood supply and eventually lead to osteonecrosis, talar dome collapse, and severe pain. Initial conservative treatment for AVN may include nonsteroidal anti-inflammatory drugs (NSAIDs), bracing, activity modification, non-weight bearing, extracorporeal shock wave therapy, and intra-articular injections [3]. The use of autologous stem cells has shown promise in halting the progression of AVN of the femoral head in young patients [4], but there is a paucity of literature regarding the efficacy in the foot and ankle. In severe cases with major deformity, compromised soft tissue envelopes, or complex medical comorbidities where surgery is too risky, an amputation may be the best option [3]. When patients have exhausted conservative measures, they may seek alternative surgical treatments to avoid a below the knee amputation. Surgical treatments for talar AVN have included a tibiotalocalcaneal arthrodesis which can be accomplished by external fixation or several means of internal fixation with plates, screws, staples, or an intramedullary nail with or without structural bone graft [5,6]. However, an arthrodesis would remove ankle joint motion entirely and is not devoid of complications such as tibial stress fracture, infection, and malalignment [5]. When the talus is unreconstructable, a takedown may be indicated. A tibiotalocalcaneal arthrodesis can then be performed but will again remove all ankle joint motion and also create significant limb length shortening unless the tibia is lengthened using an Ilizarov frame [7,8]. Another option to address the loss of height while still allowing motion at the ankle is to implant a custom total talus [9,10,11,12,13]. These implants were previously intended for select patients with a preoperatively stable ankle without deformity [14].

Furthermore, in severe talar AVN, increased pressures and destruction to the adjacent tibial plafond may lead to severe ostearthritis at the talocrural joint. When this occurs, a concomitant total ankle may be
performed. The Total Ankle and Total Talus Replacement (TATTR) procedure, which combines a total ankle and total talus replacement, has been shown to be safe and effective with excellent short-term results [10,15,16,17,18,19]. Akoh et al., reported indications for using a TATTR to include talar avascular necrosis with collapse and tibial-sided arthritis or AVN, or having an irreparable comminuted talus fracture. Absolute contraindications to using a TATTR include active infection, unresectable tumor, diabetic neuropathy, high-demand patient, and poor vascularity. Relative contraindications include history of previous infection, pediatric patient, and deformity of the contralateral talus [15]. These indications and contraindications are similar to that of an ankle arthroplasty alone. The relative contraindication for having deformity of the contralateral talus is due to the inherent limitations to surgical planning without the ability to “mirror” a 3D reconstruction from a CT scan to design a custom talus. The purpose of this case study is to publish the short-term results along with the process and utilization of bilateral TATTR for a patient with avascular necrosis in both tali.

Case Report

The patient was a 68-year-old male with chronic bilateral ankle pain after sustaining bilateral talar fractures following a high energy injury two years prior when he slid down a granite slide and abruptly made impact at the bottom. At the time of injury, he was emergently treated with a bilateral talar reconstruction via medial malleolar takedown. Four months following initial ORIF and strict non-weight bearing, he resumed normal activities and suddenly developed significant pain in his ankles following bilateral talar dome collapse. He was treated conservatively by an orthopedic specialist while observing the progression of pathology with serial radiographs. His pain became more excruciating and impacted his activities of daily life without any significant benefit from NSAIDs, ice, or activity modifications. During consultation with the senior author for a second opinion, he reported having an ~80% decrease in his function or ability to complete basic activities, and described using a wheelchair 90% of the time. He was unable to enjoy many activities he once was proficient in doing such as biking, running and hiking. At this time he reported having a weight gain of 25 pounds and was seeking surgical treatment options for a better lifestyle.

Figure 1 Radiographs from initial injury on the right: (A) lateral, (B) antero-posterior, and (C) oblique views; and left: (D) lateral, (E) antero-posterior, and (F) oblique views.

The patient was a non-smoker with a BMI of 31 kg/m2 and a past medical history of hyperlipidemia, hypertension, anxiety, vitamin D deficiency, and right knee post-traumatic osteoarthritis following an ORIF for a right tibial plateau fracture. On the physical exam, the patient had palpable pedal pulses, mild circumferential edema around the ankles, well healed medial incisions, and intact sensation to light touch. Musculoskeletal exam revealed right worse than left pain with palpation over the anterior talar neck and ankle joint. The ankle joints showed 0 degrees of dorsiflexion with knee extension and 15-20 degrees with knee flexion. There was limited range-of-motion to the subtalar joints passively, which the patient reported to be pain free. However, loading of the foot and movement of the subtalar joint would cause significant discomfort. The midtarsal joints were without pain or crepitus passively but noted to be somewhat rigid. The deltoid complex and lateral collateral ligaments were grossly stable. Manual motor testing were rated 5/5 bilaterally with dorsiflexion, plantarflexion, inversion, and eversion action. Peroneal tendons were stable to provocative testing. Plain radiographs from the initial injury, index procedure and weight-bearing images following subsequent talar collapse can be seen in Figures 1-3. A computerized tomography (CT) scan was performed and extensive cystic formation across the tibia and talus is shown in Figure 4.
Figure 2 Lateral radiographs initially following index procedure with near anatomic reconstruction of tali.

Figure 3 Radiographs following avascular necrosis and talar collapse on the right: (A) lateral and (B) antero-posterior; and left: (C) lateral and (D) antero-posterior.

Preoperative Planning and Design Considerations

Due to the nature of this patient’s bilateral talar injury, preoperative planning was complicated by the lack of having an anatomically intact contralateral limb. It was the goal of the patient to maintain motion of his foot and ankle and avoid ankle fusion. The bilateral lower extremity CT scan was sent to the design engineers and converted to a Digital Imaging and Communications in Medicine (DICOM) format.

Figure 4 CT images from the right: (A) axial, (B) coronal, (C) and sagittal views; and left (D) axial, (E) coronal, (F) and sagittal views.

The specifications requested for the implants were to include articulation with the chosen total ankle replacement system along with a subtalar-constrained talar component to minimize malalignment and subsidence.

The planning for implant design was initiated by taking the DICOM reconstruction and then digitally repositioning the anatomy to a neutral position. The native talus was earmarked for removal and large osseous overgrowth in the anatomy of the calcaneal facet was planned for excision (Figure 5). Reference anatomy was aligned as a guide for the implant shape and then modified to fit with the mating anatomy. The dorsal surface was mapped to match the talar dome that would articulate with the tibial tray and an ultra high molecular weight polyethylene insert from the chosen total ankle replacement system. Additionally, trajectories for two 6.5mm screws and an open-pore lattice to allow for osseous incorporation across the subtalar joint. Secondary implants with analogous features were created for each side by performing a global reduction of the volume by 1.0mm of all surfaces with the exception of the talar dome, which remained unchanged to maintain compatibility with the total ankle component. The right side implant was mirrored to be used as a guide for the left side implant shape and then modified to fit with the mating anatomy. Final product was printed and reviewed prior to implantation (Figure 6).
Figure 5 Design plans for talar bone resection (red) and implant/hardware placement.
and comminuted with soft bone and multiple loose screws. Additional soft tissue was resected from the base of the surface of the calcaneus. At this time, the total talus size was decided by placing the two custom 3D printed trials within the ankle void (Figure 7).

Attention was then directed to the medial malleolus where a linear incision was made and dissected down to the bone. Two screws from the prior surgery were then removed, leaving a single medial malleolar screw in place. A hook plate was then added prophylactically for added support to prevent potential destabilization of the medial ankle following tibial cuts. The total ankle alignment jig was then applied in the rectus position with the use of fluoroscopy. After the final position was determined, the tibial cuts were made and the bone was resected. Bone cysts were found in the tibial surfaces on both the right and left sides as well as the posterior facet of the right calcaneus. The cysts were debrided and packed with cancellous bone chips soaked in marrow taken from the proximal tibia. The tibial and calcaneal surfaces clinically showed hard, viable and stable bone to proceed with implantation in each case.

The total talus implant was then placed at this time (Figure 8). Alignment was verified before two 6.5mm screws were placed through the implant. The tibial tray and poly insert were then incorporated after trial sizes were tested and determined for sufficient mobility and stability. A large talar component with a size #1 tibial tray and an 11 mm poly insert were used on the right, and the smaller talar component with a size #1 tibial tray and an 8 mm poly insert were used on the left. The full measurements for the talar components can be seen in Table 1.

Final fluoroscopic images were then obtained (Figure 7). The incisions were irrigated and a drain was inserted within the anterior ankle incision. The incision was then closed with absorbable suture in layers and the skin closed with staples. The tourniquet was deflated and there was an immediate hyperemic response of the foot indicating the neurovascular structures had been maintained throughout surgery. Postoperative dressings were applied consisting of soft dressing and a posterior splint.
Figure 7 Intraoperative fluoroscopy images of the right: (A) lateral view with total talus sizer, (B) talar implant with guide wires for subtalar screws, and (C) insertion of the tibial tray; and left: (D) lateral view of the total talus sizer, (E) lateral view of TATTR implant, (F) oblique view of TATTR implant.

Figure 8 Intraoperative images demonstrating resection of talus and implantation of TATTR.

Postoperative Protocol and Course

The patient was admitted overnight following each surgery for post-operative pain management. The drain was pulled and the patient was discharged the next day. Post-operative medication: two weeks anticoagulation, muscle relaxant, PO analgesia, anti-nausea, and stool softener as needed. At one week follow-up, the patient reported 0/10 pain. The staples were removed after two weeks and at this time the patient was allowed to begin gentle range of motion. The patient remained non-weight bearing for the first four weeks with the assistance of a wheelchair or knee scooter and then transitioned to a controlled-ankle motion (CAM) boot with slow progression of weight bearing as tolerated. The patient then began physical therapy and returned to normal shoe gear by eight weeks. Serial radiographs were obtained to evaluate the implant position.

Figure 9 Final weight bearing post-op images of right TATTR: (A) lateral, (B) antero-posterior, and (C) oblique views; and left TATTR: (D) lateral, (E) antero-posterior, and (F) oblique view.

Two months following repair of the second TATTR, the patient began using a stationary bike without difficulty. Radiographs taken at one year status-post right TATTR and six months status-post left TATTR demonstrated hardware alignment was maintained without subsidence or failure (Figure 9). The patient denied any pain and reported mild swelling after weight-bearing throughout the day. He has been able to walk 0.5-1 miles daily and is able to use the gym for non-impact exercise three times a week. He uses a cane for assistance during long-distance walks and he is wearing regular shoes with custom orthotics. The patient was advised to return to the clinic yearly for follow-up as needed.

Discussion

Avascular necrosis of the talus is a common complication following talar neck fractures. In a retrospective review of sixty cases, Vallier et al reported osteonecrosis and dome collapse in 31% of patients treated with ORIF with worse outcomes associated with comminuted and open talar fractures [1]. Talus arthroplasty is a surgical option for unrepairable bone ideally when the patient is without notable arthritic changes of adjacent articular surfaces [3]. When there is radiographic evidence of osteoarthritis in the ankle joint, a combined total ankle-total talus replacement may be indicated. The goals for a TATTR procedure are to decrease pain,
minimize limb length shortening, retain ankle joint motion, and improve functional mobility. To the best of our knowledge, there have been no prior cases on the use of a bilateral combined TATTR for pathology in both tali and tibias. This case presents a successful outcome for bilateral TATTR as a surgical revision for avascular necrosis sequelae following failed bilateral talar ORIF. Our patient went from having severe depression from chronic pain and almost entirely relying on a wheelchair to ambulating pain-free with the assistance of a cane for walks longer than one mile.

There are many total talus options available to surgeons. Some of the talar implants that have been created have been made from aluminum ceramic, stainless steel, titanium, cobalt-chromium, or other combinations of alloys. Using 3D printed alloy implants are beneficial in areas of high load such as the talus [20]. Furthermore, there are many ways of altering the implant design, allowing for infinite customization to meet the specific needs of the patient. TATTR implants can be made to include eyelets for fixation of artificial medial and lateral ankle ligaments for patients with stretched out ligaments from significant coronal plane deformity [21]. The implants may be constrained with fixation to adjacent joints, unconstrained with articulation to the native adjacent joints, or combined with a total ankle implant [22]. Magnan et al., illustrated a TATTR that included a constrained subtalar and talonavicular portion. They concluded that the combination of a total ankle arthroplasty and a custom-built talar prosthesis secured to both the calcaneus and the navicular can provide good medium-term functional results and enable the surgeon to avoid, or at least to delay, the performance of a conventional arthrodesis [17]. In our patient, a cobalt-chromium subtalar-constrained talar implant was used to eliminate future osteoarthritis pain to the subtalar joint, however talonavicular arthritis may certainly result in the future. Liu et al., suggests adding a polycarbonate-urethane layer over the stiff alloy talar implant which may reduce the risk of cartilage wear and bone fracturing in future implants [23]. For our patient, the tibial component was chosen based on the senior surgeon’s experience and familiarity with the system, as well as the excellent five-year survivorship of up to 97.6% in traditional total ankle arthroplasty [24]. Other tibial trays are available and should be chosen based on compatibility with the total talus implant and surgeon ability. Comparative studies on the different variations of tibial and talar components would help guide implant choice.

When bilateral tali are pathologically deformed, a CT scan may not provide the manufacturer enough detail for talar design. Thus, approximating the size and shape needed for the talar component can be challenging. In an anthropological study looking at osteometric data, 110 cadaveric male and female tali (n = 220) were measured in millimeters and the means were calculated for: talar length, width of the talus, talar height, length of the trochlea, width of the trochlea, head–neck length, height of the head, length of the posterior articular surface for the calcaneus, and the breadth of the posterior articular surface for the calcaneus. The greatest differences between male and female tali were talar length and head height which were 55.6 and 33.4, and 51.6 and 31.0 respectively.[25] In another cadaveric study with 126 male and female tali (n = 252), similar metrics were recorded with the addition of minimum interarticular distance across the neck medially and maximum height for the lateral malleolar facet of the talus [26]. In comparison to the average measurements in these cadaveric studies, the talar implants used in our study were slightly larger with respect to length, talar height, posterior facet width, maximum height for the lateral malleolar facet, and minimum interarticular distance across the neck, and slightly smaller with respect to talar width, head-neck length, and posterior facet length. Each measurement used in our patient was within the ranges seen in these studies, except for the posterior facet length and width (Table 1). However, because the inferior talar implant was constrained, we believe these two measurements did not need to be exact. The complex morphology of the talus is different amongst race, age, and gender, which makes it more difficult to create standard sizes for total talus replacement like we have for total joint replacements. However, the averages from these cadaveric studies may help future surgeons and engineers design a more anatomic custom talar component.
Combined TATTRs have not been widely used and therefore studies depicting their outcomes are limited. Nonetheless, the evolution of joint replacement therapy in the ankle to include total talon component have shown some favorable short-term results. Fletcher et al., reported outcomes on 67 ankles receiving a TATTR with a 3D printed talon made from a cobalt-chromium alloy demonstrating significant postoperative improvements compared to preoperative included: VAS (2.8 vs. 8.2; \( p < 0.0001 \)), ankle dorsiflexion (11.0° vs. 4.7°; \( p = 0.0007 \)), ankle plantarflexion (31.9° vs. 23.7°; \( p < 0.0001 \)), and talocalcaneal height (79.6mm vs. 74.2mm; \( p < 0.0001 \)). There were a total of 10 (14.9%) complications, 7 (10.4%) of which required repeat surgery. There were 3 (4.5%) failures requiring explant, revision, or amputation [10]. A Japanese study of 22 patients demonstrated successful combined TATTR's with a mean of 34.9 month follow-up for treating osteoarthritis, rheumatoid arthritis, or talon osteonecrosis with ankle osteoarthritis. Following TATTR implantation, these patients had improved ankle mean range of motion from 4.0 to 14.4 degrees in dorsiflexion and from 23.8 to 32.0 degrees in plantarflexion, and the Japanese Society of Surgery of the Foot scale improved from 50.5 to 91.5 points [18].

<table>
<thead>
<tr>
<th>Metric</th>
<th>Right implant</th>
<th>Left implant</th>
<th>Bidmos et al.</th>
<th>Mahakanukrauh et al.</th>
<th>Range</th>
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<td>Talar length</td>
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<td>33.4</td>
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<td>27.5</td>
<td>35.5</td>
<td>34.65</td>
<td>34.70</td>
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<tr>
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<td>28.7</td>
<td>32.5</td>
<td>29.53</td>
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<td>21.8</td>
<td>24.12</td>
<td>–</td>
<td>–</td>
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<tr>
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<td>27.7</td>
<td>28.32</td>
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<td>–</td>
<td>8.32</td>
<td>8.61</td>
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</table>

Table 1 Comparison of measurements for the right and left 3D printed talon components used in the current study with the measurements from other male cadaveric studies (mm).
Additional case studies have also shown great success with using a TATTR. Akoh et al., presented a 59 year old female who underwent a unilateral TATTR utilizing a cobalt-chromium-molybdenum tibial component, mobile-bearing polyethylene liner, and 3D cobalt-chromium custom total talus implant. At one year follow-up, standing radiographs showed maintained ankle alignment of TATTR position without complications. The patient showed 1/10 pain, walking ½ mile daily, 15 degrees of passive ankle DF and 40 PF, with an overall satisfaction with the procedure [15].

In some patients, the combined TATTR may provide a better solution than a TAR alone. Kurokawa et al., performed a comparative retrospective study on 10 patients treated with combined alumina ceramic artificial TATTR and 10 patients treated with standard ceramic TAR. The mean follow-up was 58 months and 64 months for each group, respectively. The mean postoperative Japanese Society for Surgery of the Foot (JSSF) ankle-hindfoot scores were significantly higher in the combined group compared to TAR alone with a p-value of 0.0034. The authors concluded that the combined TATTR resulted in better short-term clinical results than the standard TAR [16].

In preparation for creating the talar implant, a contralateral CT of the unaffected limb has been used to recreate a “mirrored” chiral image for implant design [10,12,13,15,16,19,27,28]. Unfortunately for the patient in our case, both tali had significant pathology and the 3D reconstruction of the CT had limitations in its use for the implant design. Therefore, multiple discussions and alterations of product designs were necessary in preparation for these surgeries. After review from the final follow-up imaging, the senior author would recommend greater attention to the talar neck length which appeared shortened compared to a lateral radiograph from a normal foot without pathology. However, caution should be advised for implanting a longer or larger size which can increase the strain on neurovasculature and lead to complications such as: painful neuritis, subsidence or malincorporation of a constrained talar implant into the calcaneus, hindfoot driven forefoot imbalance leading to plantar skin ulcers, or an ischemic foot. For this reason, multiple sizes of the implant along with trial implants are created to help guide the surgeon for using the optimal implant. More studies to develop an intraoperative fluoroscopic evaluation of trial implants may elucidate a standard protocol for determining optimal implant size. Nevertheless, the risks in having a TATTR procedure should be clearly informed to the patient including the possible need for additional surgery, revision or even a below the knee amputation. It is not the purpose of this paper to discuss revision for a TATTR procedure, but it should be noted that surgical options exist for large bone defects following implant extraction as described in trauma and limb salvage including structural bone grafting procedures of many varieties, implantable trabecular metal grafts, and distraction osteogenesis [27,29,30,31]. In addition, revision options for talar trays are available, although limited.

If performing bilateral TATTR procedures, it is important to stage the surgeries and to allow enough time between the cases for adequate healing and incorporation of the first implant. This is important while knowing that the postoperative protocol for the second surgery to follow will likely necessitate weight bearing on the first surgically corrected limb. Furthermore, if ancillary procedures need to be performed on the lower extremity to create a rectus foot and ankle, a surgeon may decide to perform those procedures prior to implanting a TATTR to limit alterations in biomechanics and potential complications after the implant is placed.

**Conclusion**

This case study shows that significant improvement to functional mobility can be achieved with bilateral TATTR even if the contralateral talus is deformed. Utilization of CT imaging with pathology in bilateral tali can still be utilized for custom talar designs by subtracting the talus and using the void to approximate sizing. Proper planning and coordination between patient, surgeon and implant manufacturer may help prevent sizing issues. More studies are needed to determine optimal measurements surrounding the complex morphology of the talus. Finally, long term follow-up is needed to elucidate the survivorship of these new and evolving implants and their effect on adjacent joints.
Conflict of Interest

The authors have no conflicts of interest to declare as related to the content of this paper.

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