The Journal of Foot & Ankle Surgery 58 (2019) 176–183

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Use of Three-Dimensional Printing Techniques in the Management of a Patient Suffering From Traumatic Loss of the Talus

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ARTICLE INFO

Level of Clinical Evidence: 4

Keywords:
anatomical
cement
dimensional
extrusion
loss
talus
three

ABSTRACT

Traumatic loss of the whole talus is extremely rare, and its possible treatment options are limited. Our experience of treatment of a 30-year-old male suffering from traumatic loss of the whole talus with the insertion of an anatomical antibiotic-loaded talus cement spacer using 3-dimensional printing techniques as an interim measure was reviewed and reported. A young motorcyclist was brought to the emergency department after a road traffic accident. He sustained multiple injuries including traumatic loss of his left talus. Despite repeated surgeries of debridement and insertion of external fixator to his injured ankle, the patient had residual problem of ankle instability, ankle infection, and absence of his involved talus. With the help of computerized 3-dimensional printing techniques, an anatomical talus cement spacer was produced in the operating room and inserted into the patient's ankle 7 weeks after the initial trauma. The external fixator was kept for another 3 weeks before removal. At 14 months after the insertion of cement spacer, the patient could walk independently without any pain for 15 minutes with the help of a crutch occasionally. However, the range of motion of his left ankle was limited to 15° in the flexion-extension arc and minimal subtalar motion. The infection of the left ankle was under control.

Total talus dislocation is rare and serious. It is commonly a result of high-energy trauma. Fall from heights and motor vehicle accidents were the commonest reported injuries leading to this condition (1–16). Most of these injuries were open injuries and were associated with multiple injuries involving other parts of the body. Within the group of total talus dislocations, whole talus traumatic loss was a much rarer condition and was scarcely reported in the literature (8,10,17,18). Tibiocalcaneal arthrodesis (18) had been a reasonable surgical option, but it was associated with ankle stiffness and limb shortening. Talus body prosthesis and total ankle arthroplasty with talus prosthesis were reported in the literature (9,17,19). However, because talus traumatic loss was always an open injury, the presence of ankle infection precluded any metallic prosthesis insertion into the ankle. We report our experience of the treatment of a 30-year-old male suffering from traumatic loss of the whole talus with the insertion of an anatomical antibiotic-loaded talus cement spacer that was produced with the help of 3-dimensional (3D) printing techniques as an interim measure to deal with ankle infection caused by a contaminated ankle wound; tackle instability caused by the absence of the talus; maintain equal bilateral limb length; and provide some, although limited, ankle motion to facilitate walking.

Case Report

A 30-year-old male was admitted to the orthopaedic department after his motorcycle crashed in a road traffic accident. He sustained multiple injuries, including a right distal radius fracture, left olecranon and distal humerus intra-articular fractures with left elbow abrasion, a sacrum fracture with pubic symphysis widening, and a left lateral ankle 12-cm contaminated wound with a lateral ankle ligament tear and talus loss (Figs. 1 and 2). Fluid resuscitation, temporary splintage of fractures, and administration of intravenous antibiotics were implemented immediately. Left ankle wound debridement and application of a cross ankle external fixator was performed 2 hours after admission (Fig. 3). Repeated debridement operations of the left ankle wound were performed within the first 2 weeks after the initial trauma because of persistent wound discharge from the left ankle. Bacterial culture of the left ankle wound specimen showed the presence of *Enterobacter* species. Intravenous gentamicin and Augmentin® (amoxicillin and clavulanate; GlaxoSmithKline, Brentford, UK) were administered. A sacroiliac screw to the sacrum fracture, plating to the right distal radius, and plating to

Financial Disclosure: None reported.
Conflict of Interest: None reported.

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https://doi.org/10.1053/j.jfas.2018.08.008

Fig. 1. Clinical photo of the left ankle on admission showing the presence of a contaminated ankle wound.

Fig. 2. Lateral radiograph of the left ankle on admission showing the absence of a left talus.

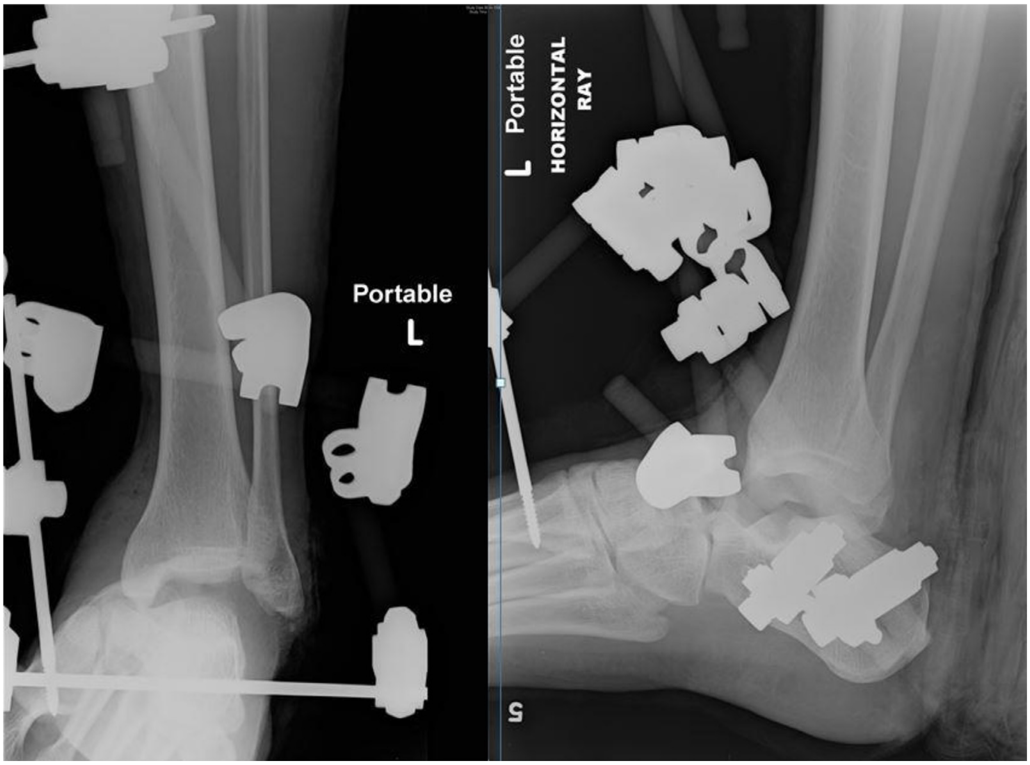

Fig. 3. Anteroposterior and lateral radiographs of the left ankle after application of the external fixator.

the left elbow were performed approximately 2 weeks after the initial trauma.

Owing to the absence of the left talus, left ankle stability was poor despite the application of the external fixator. Furthermore, there was persistent left ankle infection. Therefore, a gentamicin-loaded cement spacer that was molded manually according to the expected shape of the loss left talus was inserted to the left ankle void 2 weeks after the initial trauma (Fig. 4).

The left ankle's stability improved after insertion of the spacer. However, at 4 weeks post injury, there was still slight discharge from the left

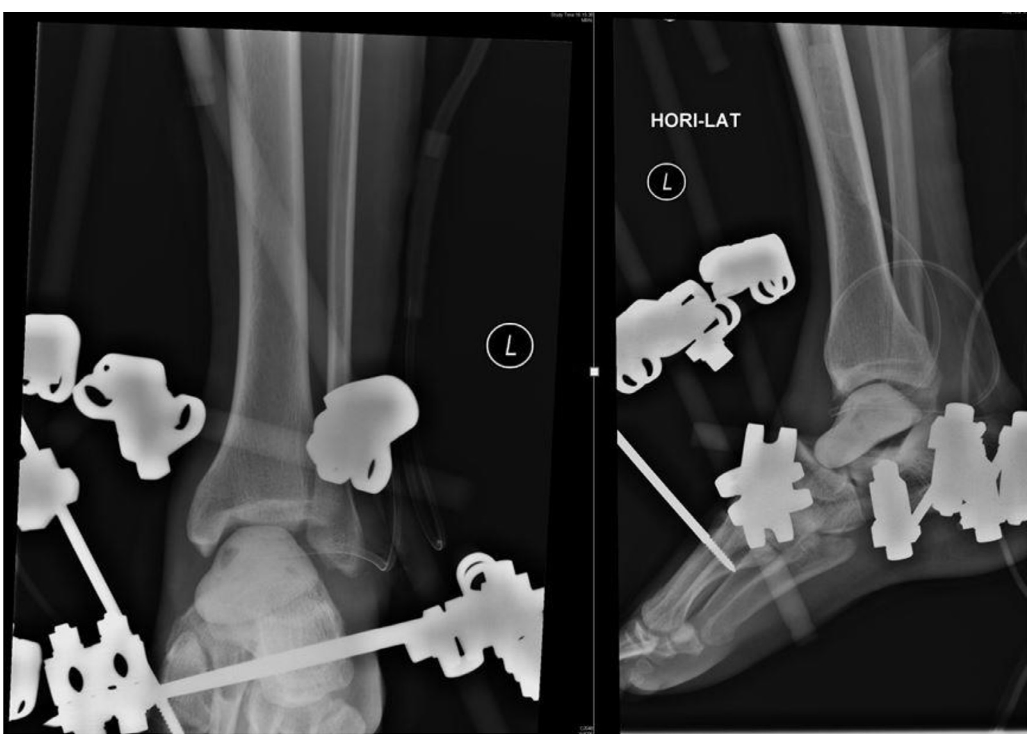

Fig. 4. Anteroposterior and lateral radiographs of the left ankle after insertion of the antibiotic-loaded nonanatomical talus cement spacer.

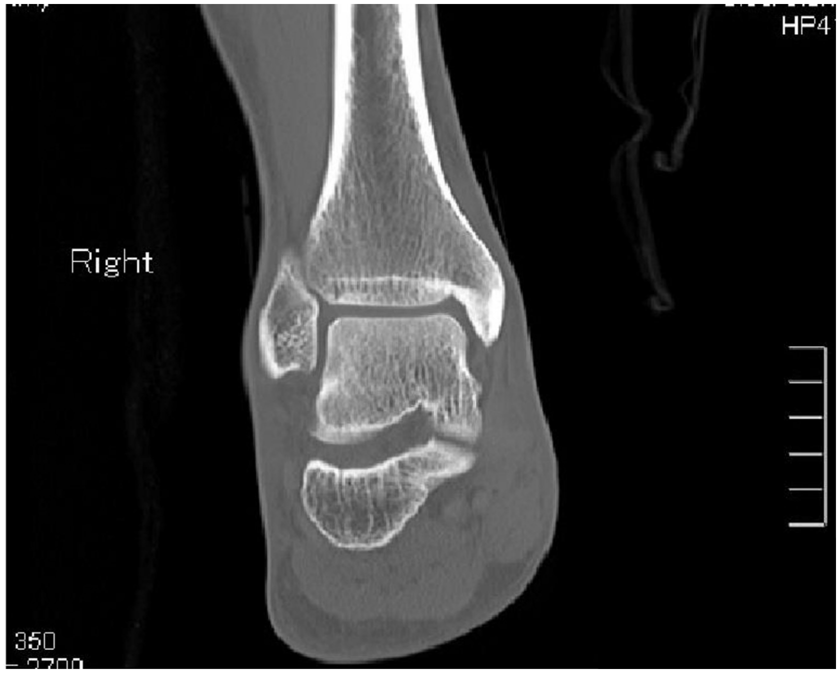

Fig. 5. Computed tomography of the right ankle.

ankle wound. The serum C-reactive protein remained high at 47mg/L. In view of the persistent left ankle infection, a longer period of use of the antibiotic-loaded cement was expected before proceeding to any definitive surgery. A decision to produce and insert an anatomical antibiotic-loaded cement spacer was made. Computed tomography (CT) of the opposite ankle was performed (Fig. 5). The CT images of the right talus were extracted and transformed into the 3D images of the left talus with the help of a 3D-printing software program—Materialise Mimics Innovation Suite™ (Materialise, Leuven, Belgium). The negative 3D left talus mold was designed and printed using the material ABS-M30i™ (Stratasys, Eden Prairie, Minnesota) (Figs. 6 and 7). Using the negative mold, a gentamicin-loaded anatomical left talus cement spacer using Palacos® R+G (Heraeus, Wehrheim, Germany) was made in the operating room 7 weeks after the initial trauma. The negative mold of the cement spacer was removed after cement setting (Fig. 8). Using the previous anterolateral ankle wound, the previously inserted nonanatomical cement spacer was removed. The anatomical cement spacer was inserted after wound debridement (Fig. 9). The ankle wound was closed. The external fixator was retained for another 3 weeks before removal. However, a deep left elbow infection developed at the same time. Left elbow implants were removed. The systemic antibiotics were continued for another 6 weeks. The patient was allowed to walk with weightbearing of the involved limb (Figs. 10 and 11). He was discharged from the hospital 13 weeks after the initial trauma. Fourteen months

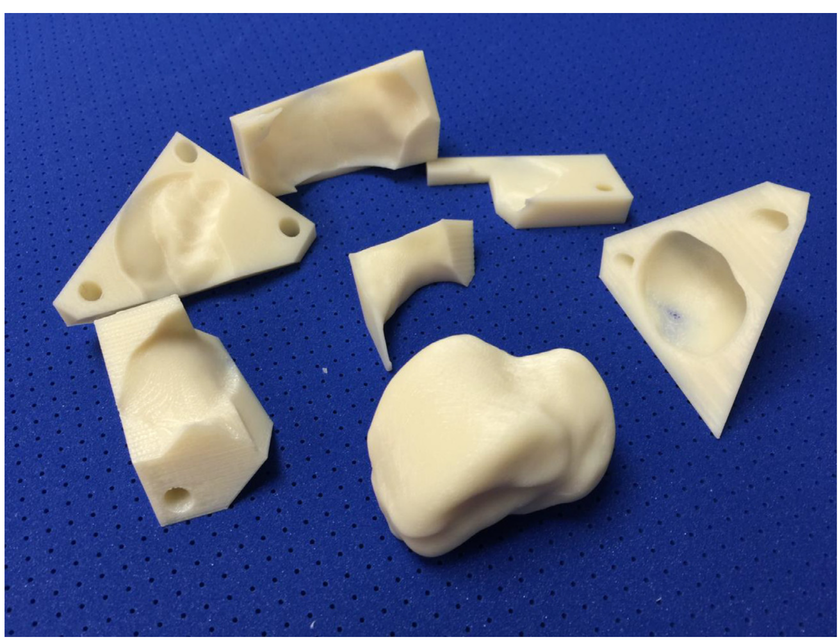

Fig. 6. The positive left talus model and the negative mold for the production of the left talus cement spacer.

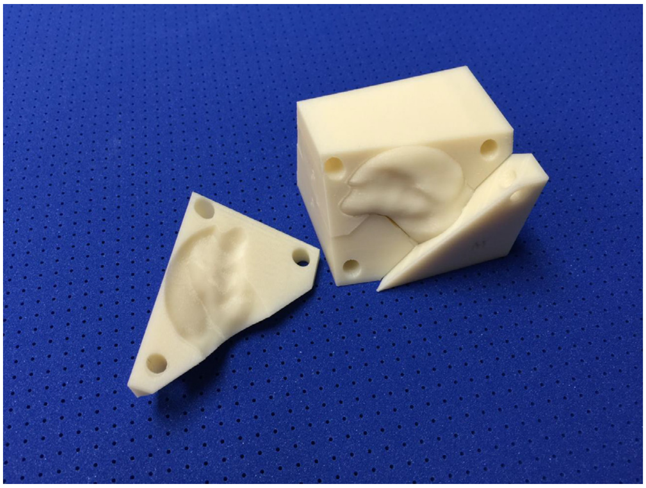

Fig. 7. Partial assembling of the positive left talus model and the negative mold for the production of the left talus cement spacer.

after the operation, the patient could walk independently with mild pain for 15 minutes with a crutch occasionally. Only 5° of dorsiflexion, 10° of plantarflexion, and minimal subtalar motion could be achieved. The serum C-reactive protein level returned to normal at <5 mg/L. Radiologically, there was no visible erosion of the left tibia, navicular, and calcaneum, and there was no fracture of the talus cement spacer (Fig. 12). The duration of follow-up of the patient after the implantation of the talus cement spacer was 14 months.

Fig. 9. Operative photo of the left ankle after insertion of the anatomical left talus cement spacer.

Discussion

Total talus extrusion is a rare and serious injury. In the literature, only case reports and case series were found (1–7,9,11–13,15–17, 19,20). The choice of definitive treatment remains controversial and may include talectomy (21), tibiocalcaneal arthrodesis (1–3), reimplantation of the extruded talus (4–7,11–13,15,16,20), talar body or total talar prosthesis (17,19), and total ankle replacement (9). If the extruded talus was available, literature suggested that reimplantation of the extruded talus be performed (4–7,11–13,15,16,20). The potential advantages of reimplantation are maintenance of limb length; preservation of bone stock; and preservation of the tibiotalar, talocalcaneal, and talonavicular joints and their range. However, there are risks of infection, avascular necrosis of the reimplanted talus, and peritalar joint osteoarthritis.

Fig. 8. Comparison of the antibiotic-loaded talus cement spacer to the positive left talus model.

In our reported case, the option of reimplantation was impossible because the talus was lost. Traumatic loss of the talus is rarer than total talus extrusion with a found talus. Only a few reports of whole talus traumatic loss were available in the literature (8,10,17,18). Tibiocalcaneal arthrodesis (10), insertion of a total talar prosthesis (17), and total ankle replacement (9) were also reported. A case of talar body, neck, and medial malleolus loss following an open injury was reported (9). After the initial debridement, external fixator application, and deltoid ligament reconstruction, a titanium total ankle replacement with the total talar prosthesis component fixed to the calcaneum and navicular was performed at 5 months. At 28 months, the patient had an American Orthopaedic Foot and Ankle Society score of 92 and there were no signs of loosening radiologically. Angthong (17) reported a 25-year-old patient who suffered from talus traumatic loss. A custom-made stainless steel total talus prosthesis was inserted into the talar void 3 months after the initial trauma. The patient could walk unaided with an acceptable range of motion of the ankle 5 months postoperatively.

In addition to repeated debridement of the wound and systemic use of antibiotics, insertion of a nonanatomical antibiotic-loaded cement spacer into the talar void as an interim has been scarcely reported in the literature (3,11). Those nonanatomical talar cement spacers were replaced with either reimplantation of a "sterilized" extruded talus or definitive tibiocalcaneal arthrodesis after eradication of ankle infection. Our patient had a nonanatomical antibiotic-loaded talar cement spacer inserted into the talar void 2 weeks after the initial trauma because of ankle infection and ankle instability owing to the absence of the talus and a lateral ankle ligament tear. The talar cement spacer served to provide additional ankle stability and control infection.

Persistent left ankle and left elbow infections rendered definitive treatment such as insertion of a talus prosthesis to the left ankle

Fig. 10. Clinical photo of the left ankle in maximum dorsiflexion 2 weeks after removal of the external fixator.

dangerous; a longer period of use of a cement spacer was expected before proceeding with the definitive treatment. The exchange of the nonanatomical talar cement spacer with an anatomical antibiotic-loaded cement spacer had a theoretical advantage of less damage to the surrounding cartilage. During rehabilitation, we were in a dilemma of whether the patient was allowed to walk and bear weight on the involved limb. Although the final cement spacer produced with the help of 3D-printing techniques was more anatomical in shape, the surface of the spacer was definitely not as smooth as a normal talus. Walking with weightbearing on the injured leg carried additional risks of cartilage damage of the adjacent tibial plafond, navicular, and calcaneum; cement spacer breakage; and generation of cement particles following cement mantle wear. However, because of the injuries of both upper limbs and the pelvis, he had difficulty walking without weightbearing on the injured leg.

In the literature, the effect of bone cement articulating with hyaline cartilage, particularly the possible wear of articular cartilage and cement, was reported sparingly. The most similar case found in the literature was reported by Haddad et al (22). The management of a patient suffering from infection following arthroscopic shoulder rotator cuff repair with insertion of a humeral cement spacer articulating with the glenoid with intact cartilage was studied. At the 1-year follow-up visit, the patient was pain free with satisfactory range of motion. However, the cartilage and polymethylmethacrylate status was not mentioned. Leclair and Gangi (23) reported a case of rapid chondrolysis after an intra-articular leak of bone cement in the treatment of a benign acetabular subchondral cyst. In contrast to our patient, the extruded part of the cement in the case of Leclair and Gangi (23) was irregular.

Possible wear of the cement spacer and the subsequent polymethylmethacrylate particles might trigger an inflammatory cascade resulting in synovitis, granulomatous or nongranulomatous bony destruction, or lymphadenopathy (24,25). In vitro study confirmed that after ingestion of the polymethylmethacrylate particles, particularly those 5.6 to 9.6 μm, macrophages increased production of proinflammatory cytokines, which led to subsequent inflammation (26). Although there were no radiological visible bone cement and cartilage debris found in our patient, wear particles and further cartilage erosion were expected.

Fig. 11. Clinical photo of the left ankle in maximum plantar flexion 2 weeks after removal of the external fixator.

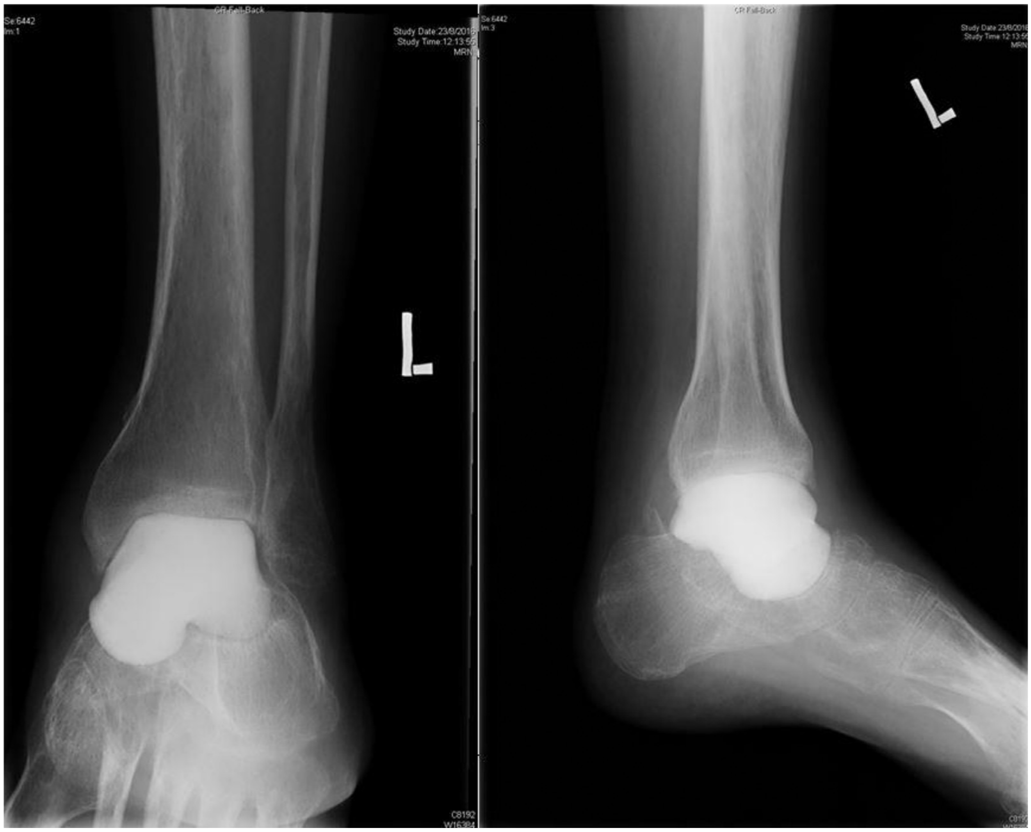

Fig. 12. Anteroposterior and lateral radiographs of the left ankle with no radiological breakage of cement at 14 months after the insertion of the cement spacer.

Further studies about the quantities and sizes of the particles generated from a weightbearing cartilage-cement articulation and the subsequent local and systemic effects will be helpful.

A cement spacer fracture rate of 10% in patients using Prostalac (Heraeus, Hanau, Germany) in treating infected total hip replacement was reported (27). In contrast to the proximal femoral cement spacer, the talus cement spacer in our patient mainly withstood an axial compressive load with little tensile force. During level ground walking, the ground reaction pressure across the ankle is usually <800 KPa for an average adult, whereas the ultimate tensile strength and ultimate compression strength of Palacos G were about 70 and 100 MPa, respectively (28). Therefore, the possibility of major breakage of the talar cement spacer was low, and no cement fracture was seen in our patient.

The insertion of polymethylmethacrylate bone cement with the addition of antibiotics is a common measure to treat infected total joint replacement. Gentamicin is the most common additive because of its good spectrum of concentration-dependent bactericidal activity, thermal stability, and high water solubility (29). Studies have confirmed that the addition of 5% antibiotics did not significantly affect the porosity and mechanical strength of the cement (30). Furthermore, systemic antibiotic toxicity, particularly renal impairment in association with a local antibiotic cement spacer, is a rare complication (31). This complication was absent in our patient. Moreover, the anatomical cement spacer provided extra stability to the ankle joint. Clinically, there was no coronal or sagittal laxity after the removal of the external fixator in our patient.

Furthermore, the presence of an anatomical talus cement spacer provides the possibility for ankle flexion-extension and subtalar eversion-inversion motions. However, in our patient, the arc of motion in the sagittal plane was only 15°, and there was a very limited eversion and inversion demonstrated. Possible reasons include the following. First, the talus cement spacer is rougher than a natural talus. Second, following infection and repeated surgeries, scar around the ankle joint might limit range of motion.

Before the era of 3D printing, it was difficult to produce a custom-made anatomical talus cement spacer manually to replace a lost talus. We assumed that the anatomies of both tali of a healthy adult were similar. With the help of 3D printing software, the CT images of the opposite talus were extracted and transformed to a 3D image that subsequently was transformed to the 3D image of the involved missing talus. To facilitate the retrieval of the “positive” talus cement spacer from its negative mold during the surgery, the negative 3D talus mold was designed to be in several pieces.

In conclusion, we believe that the insertion of an anatomical talus cement spacer is an interim to definitive treatment of traumatic loss of the talus such as tibiocalcaneal arthrodesis or total talar prosthesis. Our experience had demonstrated that the short-term clinical and radiological results following the insertion of an anatomical cement spacer using 3D printing techniques for the treatment of traumatic loss of the talus were satisfactory. Our study is limited by its short follow-up period; therefore, the long-term effect of the talus cement spacer in relation to surrounding cartilage and bone remains uncertain. Although the talus cement spacer is not as smooth as a metallic implant or the native talus, it carries the property of withstanding the compressive load from body weight, allowing dispersion of antibiotics to treat infection, working as a spacer to stabilize the ankle joint without a talus, and providing some ankle range of motion. The patient provided written consent for our management of his condition and the publishing of his case study in the literature.

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