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Analysis of a generic talar prosthetic with a biological talus: A cadaver study

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ABSTRACT

Treatment for talar avascular necrosis is challenging. This study evaluates the feasibility of a generic talar implant by cadaveric assessment. Ten cadaveric ankles were CT-scanned to determine talar implant size. The opposite ankles were CT-scanned with the biological talus and then with the implant. 3D ankle geometry was reconstructed and implant position was compared to the biological talus position. The averages among specimens' positive and negative average-deviations were 0.91 mm and 0.70 mm. Seventy percent of talar dome deviations between the biological talus and implant were within an acceptable range. This study yields promising results to support a generic talus bone prosthetic.

1. Introduction

After calcaneus fractures, talus fractures are the most frequent of all tarsal bone fractures and account for 0.1–0.85% of all fractures.[1–3] They are most common in a young, active patient population and are more likely to occur in men than in women by a ratio of three to one.[1,4] Fractures of the talar neck, which account for approximately 50% of significant injuries to the talus, can result in avascular necrosis (AVN) in 20–100% of patients with displaced fractures.[4] The avascular bone can be unsuitable to hold the required load and collapse can occur resulting in severe incongruity of the ankle joint with subsequent pain, swelling, and restricted range of motion.

The most common surgical treatment option for this injury is ankle arthrodesis (fusion), wherein talus is fused to the tibia or to the tibia and calcaneus. Although arthrodesis often enables the patient to walk with decreased pain, it results in loss of motion and function of the joint.[5,6] Additionally, this procedure can be difficult because of a lack of healthy bone due to AVN.

Ankle arthroplasties have become a more desirable alternative to fusion as they have the potential to offer increased mobility of the ankle joint. More recently, they have been designed and implanted with increasing success[7]; however, ankle arthroplasties are not suitable when the talus fracture results in AVN because the talus is often lacking in healthy bone stock that is required for support of the talar portion of the prosthesis.

One possible solution to the issues associated with arthrodesis and arthroplasties is a talar body implant that replaces the avascular portion of the talus or the entire talus to maintain ankle joint motion and function.[8] At this time, there have been some reports of talar body replacements. These implants have been custom made from various materials – stainless steel,[9] alumina ceramic,[10–12] titanium alloy,[13] and cobalt-chrome.[14] The prostheses developed by Harnroongroj and Vanadurongwan used custom measurements of volume and dimensions (including curvatures) of the contralateral talus; they were implanted in 16 patients.[9] Tanaka et al. developed a prosthesis similar to Harnroongroj and Vanadurongwan and implanted it in three patients initially[10] and then in 52 patients with good results.[12] Both Magnan et al.[13] and Stevens et al.[14] replaced a talus utilizing CT scans to develop a prosthesis based on the real geometry of the bone. All of these implants were custom-made and as such, add a level of complexity and can be expensive compared to a generic, off-the-shelf implant if it was available.

Development of a generic talus bone prosthetic in different sizes could simplify the complexity of design and decrease the costs to

Abbreviations: ANOVA, analysis of variance; AVN, avascular necrosis; CT, computed tomography; DCM, deviation colour map; DICOM, Digital Imaging and Communications in Medicine; MRI, magnetic resonance imaging; TTF, Talus-Tibia and Fibula

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provide this treatment alternative. This requires a generalization of the geometry of the talus. Islam et al.[15] proposed an implant in five sizes; however, that study had limitations including a small sample size (n = 27), lack of a diverse sample selection such that the female population was severely underrepresented, a randomly selected reference implant, and an incremental jump in size of volume (which will be more significant in the smaller sizes as volume is a cubic function). Trovato et al.[8] improved upon this study by increasing the sample size (n = 91) with 45% of the subjects being female, selectively choosing the reference implant, and using incremental jump in the cube root of the volume between sizes. From this analysis, ten unisex implant sizes for the talus bone were created to maintain geometric compatibility of the ankle joint.

This study evaluates the feasibility of using 10 implant sizes by verifying the joint compatibility of the talar implants using cadaveric assessment; and attempts to link the contact area differences between the biological and generic implant to deviations in geometry between the two implants when situated in the cadaveric ankle. To achieve this, we explored how a generic talar implant fits into the ankle joint as compared to the biological talus using cadaveric assessment.

2. Materials and methods

2.1. Ankle joint imaging

After obtaining ethical approval from the University of Alberta research ethics board, 10 embalmed cadavers (4 male, 6 female; age at death 84.5 ± 12.0 years) were obtained from the University of Alberta Anatomy department. The feet were isolated from the cadavers approximately 100 mm above the ankle joint and a CT scan was performed on the left ankle.

Each ankle was placed in the CT scanner approximating the clinical position. The CT scan was performed using a high-resolution Somatom definition flash scanner with the following specifications: pitch 0.8 mm, gantry tilt 0 °, effective mAs 300, voltage 80 kV, rotation time 1.0 s, and a constant slice thickness of 0.6 mm and increment of 0.1 mm. The Digital Imaging and Communications in Medicine (DICOM) images were provided with a resolution of 512 × 512 pixels/slide.

2.2. Geometric analysis

From these scans, the DICOM images were imported into the 3D image processing software, MIMICS (Materialize NV, Belgium), and a 3D model was created (Fig. 1). Following this, the computer software Geomagic (Geomagic®, Morrisville, North Carolina; USA) was used to obtain the volume of the talus and from this volume, the implant size for the right talus was selected by comparing the volume of the talus to the implant sizes defined in a previous study.[8] The talus was then scaled up by 0.5 mm over the entire surface area to account for articular cartilage on the talar dome that is approximately 1 mm thick,[16] and then 3D printed.

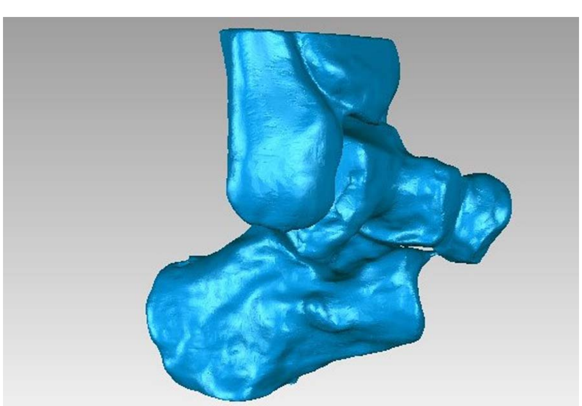

Fig. 1. 3D model of the right biological talus and surrounding bones.

Fig. 2. Cadaveric foot with elastics.

The right ankle of each cadaveric specimen was dissected in a consistent fashion (Fig. 2). Skin, subcutaneous tissue, muscle and tendons were excised from the anterior and posterior aspect of the talus, ankle joint and subtalar joint. To maintain connectivity of the leg (tibia and fibula) to the foot, the tibiocalcaneal ligament and surrounding soft tissues were left intact on the medial side, and the calcaneofibular and surrounding soft tissues were left intact on the lateral side. All ligamentous attachments to the talus were then excised and the biologic talus was removed from each specimen. Elastic bands were placed around the ankle to improve connectivity and apply a small load when the biologic talus was reinserted for imaging (Fig. 2).

The biologic talus was inserted back into the right ankle and was scanned perpendicular to the length of the tibia from just above the talus to the bottom of the foot three times with only the elastic band load: (1) in a neutral position, (2) 20° dorsiflexion, and (3) 20° plantarflexion. A custom holder, (Fig. 3), held foot in the pre-determined position. Subsequently, the biologic talus was removed from the ankle and replaced by the prosthetic implant and scanned in the same manner. Three-dimensional models of the scans were reconstructed in the same manner as stated above.

2.3. Implant vs. biological talus: geometric comparison

For each angle and each specimen, the position of the talus-tibia and fibula (TTF) articulating surfaces was compared between the biologic and the implant tali. The articulating surface was isolated and the change of position of the implant was appraised by comparing the talar

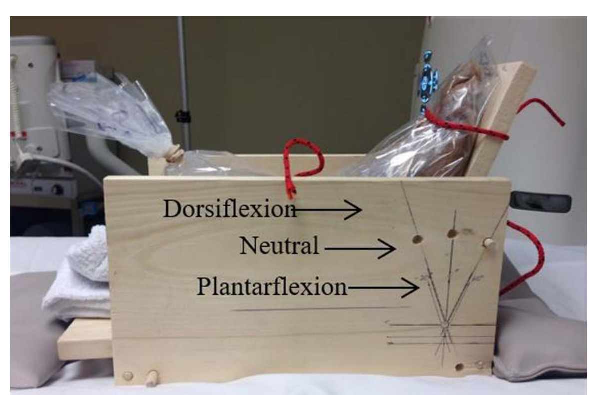

Fig. 3. Cadaver foot holder.

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