Comparative Analysis of Fixed and Mobile Bearing Total Ankle Prostheses: Effect on Tibial Bone Strain and Tibial Component Fixation

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Introduction: Total ankle replacement (TAR) is an alternative to arthrodesis for surgical treatment of end-stage arthritis. However, results are not as good as those being achieved for total hip or knee arthroplasty [1, 2]. Two major types of ankle prosthesis exist: those with a fixed-bearing and those with a mobile-bearing insert. At the moment, there are no clear reported advantages of one over the other. The mobile-bearing is thought to provide greater mobility, reduce polyethylene wear, and reduce bone and bone-implant stress, but this has not yet been verified. In fact, in the USA, the FDA has not approved any mobile-bearing implants, while in Europe there is a trend towards the re-introduction of fixed-bearing implants. Thus, the goal of this paper is to compare these two prostheses through a validated finite element model.

Methods: We used seven finite element models of seven tibia that were built and validated with cadaveric data [3]. The geometry and non-homogeneous linear elastic properties of the tibias were obtained from computed tomography of the cadaveric tibias. The cortical and trabecular bones were segmented and meshed separately.

Three cases were compared on each tibia: a fixed prosthesis (FC), a mobile prosthesis with the mobile component in a centered position (MC), and a mobile prosthesis with the mobile component in an eccentric position (ME). We used the Salto Talaris (fixed) and Salto (mobile) prostheses (Tornier, Inc. Edina, MN, USA). The CAD models of the prostheses were obtained from the manufacturer and positioned into the numerical tibial model according to manufacturer recommendations with the supervision of an experienced foot surgeon. For the ME case, we considered an extreme anterior displacement of 3.7 mm of the mobile bearing, which was estimated from in vivo measurements [4].

The contact between the tibial bone and tibial implant was assumed fully bonded, as was the contact between the metallic tibial implant and the polyethylene component. The contact between the polyethylene component and the talus implant was assumed frictionless. The metallic (CrCo) and polyethylene (UHMWPE) components of the prosthesis were assumed linear elastic.

The loading conditions were derived from the ASTM F2665 protocol. The proximal part of the tibia was fully constrained. A point corresponding to the center of the ankle joint was rigidly linked to the talus component. An axial compressive force of 5560 kN (5 times body weight of an overweight patient) was applied on this point. The three rotations of this point were constrained to zero, corresponding to maximum loading during stance phase of walking (no flexion). The translations were free.

The bone and prostheses were meshed with quadratic tetrahedral elements. The model was implemented in Abaqus v6.13 (www.simulia.com) and the analysis was performed with the implicit solver.
We evaluated octahedral shear strain within the tibia and bone-implant interfacial shear stress. We considered the amount of total bone volume with a strain above a critical value of 1%. We also considered the total surface of bone-implant interface with a shear stress above 3 MPa. A paired 2-tailed Student’s t-test was used to verify that the fixed and mobile prostheses are related to different levels of volume of stain above 1% and area with an interfacial stress higher than 3 MPa.

**Results:** For the seven tibias and the three cases, bone strain was maximal around the implant keel (Fig. 2). Compared to the centered cases (FC and MC), strain distribution was slightly shifted anteriorly for the (anterior) eccentric mobile case (ME). Among all simulated cases, the volume of bone strain above 1% varied from 0.11 to 7.07 cm³. There were no significant (p > 0.67) differences between the three cases. The peak of interfacial stress was located above the keel and at the plate rim. The area with an interfacial stress higher than 3 MPa varied from 0.96 to 3.76 cm². There were no significant (p > 0.45) differences between the three cases.

**Discussion:** There is a trend to prefer a fixed-bearing over a mobile-bearing component for total ankle arthroplasty, but there is no rationale to indicate that one is better than the other. With a validated finite element model, we compared the two prostheses. Based on seven cadaveric tibia, our results showed that there are no significant differences in critical bone strain and bone-implant interface stress between the two prostheses.

The predicted strain was consistent with the reported value of 0.3% for typical activities. We used a critical strain value of 1% as an estimate of bone damaging strain [5]. The critical value of interfacial stress of 3 MPa was also reported as initiation of bone-implant bonding failure [6]. The eccentric positioning of the mobile-bearing tested here corresponded to extreme eccentric positions [4]. We thus assume that we have simulated the worst case of eccentric loading of the mobile-bearing prostheses. By using a validated finite element model of the tibial component, we were able to statistically quantify the difference between a fixed and a mobile prosthesis on seven specific tibias. Although we were able to test our hypothesis on seven tibias, we were still limited here by a single and simplified loading. We might indeed observe other stress and strain patterns for more complex loading. However, the loading conditions used here correspond to an extreme worst case loading, and should therefore be representative of the potential mechanical effects that might lead to failure in theses two types of prostheses.

**Significance:** The eccentric position of the mobile-bearing slightly increased the anterior peak strain, but not significantly. We concluded that, even if slight differences are observed between fixed and mobile-bearing inserts, it is not enough to put forward the superiority of one of these implants regarding their reaction to axial compression.
Figure 1. Talaris fixed-bearing (left) and Salto mobile-bearing (right).

Figure 2. Middle sagittal cut view of the tibia. Bone strain was maximal around the implant keel. Compared to the fixed implant (left), the strain was shifted anteriorly with the anterior eccentric mobile component (right).