COMPUTATIONAL SIMULATION OF ANKLE CONTACT MECHANICS FOLLOWING FOCAL DEFECT RESURFACING WITH A METALLIC IMPLANT

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INTRODUCTION

Focal resurfacing of persistent osteochondral defects (OCDs) with a metal implant is a promising new treatment option for certain patients. The superior dome of the talus is a common site for this pathology, but the geometric complexity of the talar articular surface presents challenges to successful implant design, selection, and surgical placement.

The purpose of this study was to document the effect of small perturbations of implantation parameters upon ankle contact mechanics after focal resurfacing of the talar dome with a metal implant.

METHODS

Finite element (FE) simulations of loading of the intact ankle, the ankle after the introduction of a 15 mm cylindrical defect to the medial edge of the talar dome, and the ankle with a focal resurfacing implant (Figure 1) were performed. The effects of various implantation parameters (implant height, rotation about its post axis, and valgus/varus tilt) were studied over a simulated motion cycle.

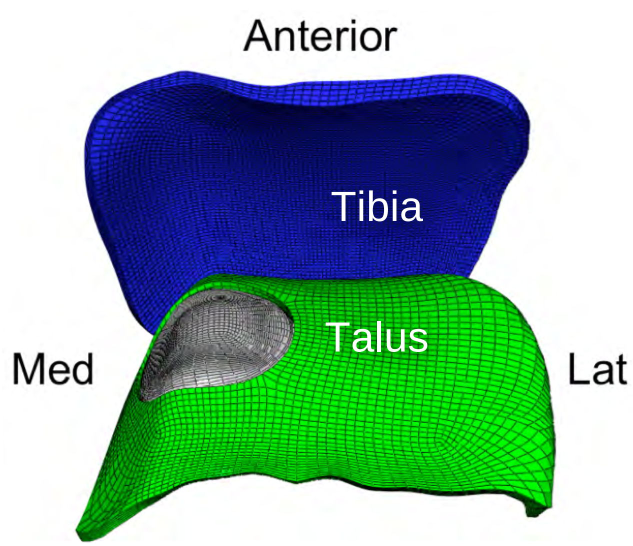

Figure 1. This antero-superior view of the ankle (joint is opened for visualization) shows the FE contact model, with a focal resurfacing metal implant placed medially upon the superior surface of the talus.

The ankle contact FE modeling approach was based on previous work [1], with bone being treated as rigid, and cartilage as a linear elastic material (E=12MPa; ν=0.42). The resurfacing implant was included as an additional rigid surface. Contact was modeled between cartilage surfaces, as well as between the superior cap surface and the opposing tibial surface, and between the cap sides and the adjacent talar cartilage surface.

A 300 N axial load was applied across the ankle joint. Then the tibia was rotated (under load) about the talus through a functional arc of flexion/extension (±10°), with the talus free to rotate in response to tibio-talar articulation.

Complementary static loading experiments [2] were performed in seven fresh-frozen cadaver ankles, before and after creation of a 15 mm cylindrical OCD on the medial edge of the talar dome, in part to validate the FE model. Ankle contact stresses were measured using a high-resolution sensor (TekScan) [3]. The defect was then resurfaced with a metallic implant (HemiCAP; Arthrosurface Inc.), supplemented with a custom implant-bone interface fixture that allowed very fine control (0.25 mm increments) of implantation height. Contact stress measurements were repeated at implant heights from -0.5 to +0.5 mm with respect to an as-implanted reference.

RESULTS AND DISCUSSION

With the untreated defect, experimentally there was a 20% reduction in the ankle contact area and a 40% increase in peak contact stress, plus a pronounced shift in the highest-loaded region. Following flush resurfacing with the implant, contact area recovered to 90% of intact, but peak contact stresses remained

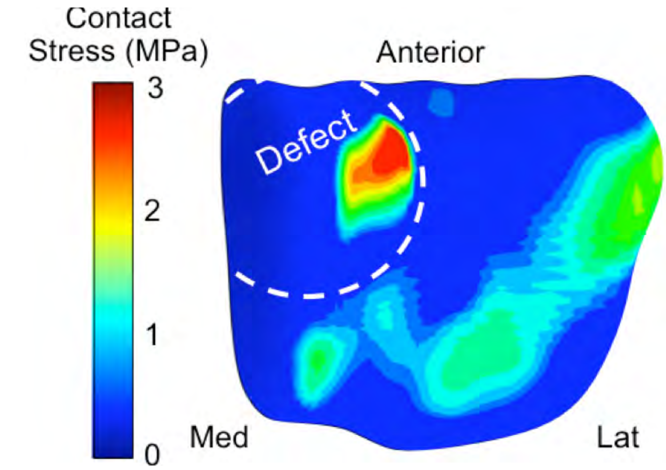

Figure 2. This view of the inferior aspect of the tibia shows the elevated contact stress over a resurfacing metal implant placed 0.25 mm proud with respect to the surrounding cartilage, as computed by the FE model.

elevated. When the implant was 0.25 mm proud, there was a 120% elevation in peak contact stress atop the metal cap (Figure 2). FE-computed contact stresses and trends agreed closely with experiments.

Whereas simulations in the intact state showed smooth and regular motion across the duty cycle, in the presence of an unfilled defect, there was dramatically increased external rotation with ankle plantarflexion (3.4° of external rotation as plantarflexed from neutral to 10° in the defect state, versus 1.0° of internal rotation in the intact state – Figure 3). There was also a striking elevation in

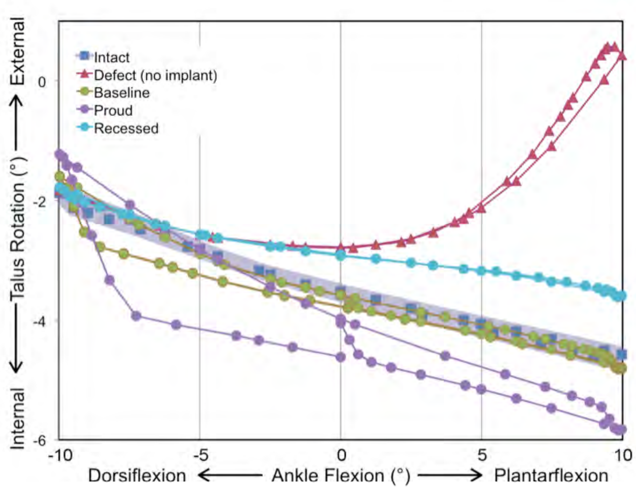

Figure 3. Coupled talar internal rotation associated with plantarflexion of the ankle was greatly disrupted when an unfilled talar OCD was modeled. A focal resurfacing implant restored the normal talar kinematics.

cartilage stress on the talar dome directly adjacent to the defect at the higher angles of plantarflexion, reflecting an absence of buttressing of cartilage at the defect lip. The implantation of a resurfacing device substantially restored the natural kinematics, but did not uniformly restore stresses to levels in the intact ankle.

CONCLUSIONS

Focal resurfacing with a metal implant appears to be a viable strategy to restore normal joint mechanics in ankles with a large talar OCD. However, given that implant-on-cartilage contact stresses were highly sensitive to proudness and malpositioning, very precise implantation is necessary. Over time, active tissue remodeling may compensate for small incongruities in the implant-to-cartilage interface. The FE approach holds substantial attraction for studying other resurfacing options, such as osteochondral plugs or other implant designs.

REFERENCES

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