Effect of Implantation Height Upon Contact Stresses in the Human Ankle with a Focal Resurfacing Implant

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PURPOSE: Focal resurfacing of persistent osteochondral defects with a metal implant is a promising treatment option for patients who are poor candidates for biological resurfacing. 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 height on the cartilage contact mechanics after focal resurfacing with a metal implant.

METHODS: Five human cadaver ankles were subjected to a series of loading experiments. Each specimen was first tested in an intact condition; while the specimen was axially loaded to 300 N (simulating bipedal standing), contact stresses in the talocural joint were measured using a high-resolution piezoresistive (Tekscan) transducer. Next, a simulated osteochondral defect (15 mm diameter) was created on the medial edge of the talar dome, and the defect was then resurfaced with a metal implant (HemiCAP®, Arthrosurface Inc.) using a custom implant-to-bone interface that allowed fine (0.25 mm step) control of implant height (Figure 1). An experienced surgeon made all decisions in this surgery, including selection of a “best fit” surface component and the zero-reference height of implantation. Contact stress measurements were obtained at a variety of implant heights (5 conditions: -0.5 mm, -0.25 mm, 0 mm, +0.25 and +0.5 mm, with respect to the reference height), as well as without attaching the metal surface component (i.e., a non-resurfaced defect control). The full series of tests were then repeated at least three times for each ankle, with the order of testing randomized. Complementary finite element (FE) contact modeling was performed to study various implantation parameters independently in a single ankle for which bone and cartilage geometries had been previously obtained using stereophotographic methods [1]. The FE modeling approach was based on previous work [2], with bone being modeled as rigid, and cartilage as a linear elastic material. An osteochondral defect and subsequent placement of the implant were implemented using Geomagic software. FE models of the intact ankle, the ankle with defect, and the ankle with defect filled by the implant were generated and run. The implantation height was parametrically varied to match the experimental study, and the loads applied corresponded to those used experimentally.

RESULTS: In intact ankles, contact stresses were distributed relatively uniformly across the articular surface (Figure 2). Local contact stress values were typically below 2.0 MPa, while contact area was 511 ± 18 sq-mm (mean ± SD). Following the introduction of a surface defect, contact area decreased to 85 ± 9 % of the original contact area, and locally elevated contact stresses were observed at the anterior-central region near the border of the defect. The “flush” implant height, i.e. the height at which the original contact stress distribution was best restored, was within ± 0.25 mm of the zero-reference height. With flush implantation, contact area was recovered to 95 ± 7 %. However, peak local contact stress values remained elevated, due to residual mismatch between the native and implanted surface geometries and stiffnesses (Figures 2 & 3). When the implant was 0.25 mm proud, the peak contact stress values were significantly increased, mostly because of elevated contact stresses between the implant and apposing cartilage (p < 0.05). Contact stress changes computed in the FE simulation were consistent with those seen experimentally, although the absolute values of the FE results tended to be moderately lower (Figure 4).

DISCUSSION: Restoration of contact area after implantation suggests capability of this metal resurfacing implant to improve biomechanical abnormality resulting from a talar osteochondral defect in clinical situations. However, cartilage contact stresses after focal resurfacing, especially opposite the implant itself, appear to be sensitive to relatively small perturbations of implantation height. In clinical situations, the poroelastic characteristics of articular cartilage, along with active tissue remodeling, may offset small incongruities in the implant-to-cartilage interface. Bone remodeling capability also may allow longer-term accommodation. However, to minimize the risk of excessive cartilage contact stresses acutely after focal resurfacing, even a very small degree of proud implantation seemingly should be carefully avoided.

Going forward, the FE model leads itself to several considerations not practical for investigations experimentally. For example, pre-operative simulation using this model could help selection of the “best fit” implant. Parametric analysis, such as to identity the surface contour that allows small perturbations in implant positioning (including the height, rotation, and angles of implantation), would also be helpful for optimizing the implant surface designs.

Figure 1. Control of implantation height in the talar defect.

Figure 2. Representative contact stress distribution in the experimental model.

Figure 3. Changes in local contact stresses (mean ± SD, n = 5).

Figure 4. Height dependence of changes in contact stresses in the FE simulation.


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