The Effect of Hemiarthroplasty Implant Shape on Early Cartilage Wear in Linear Reciprocal Sliding

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Introduction: Hemiarthroplasty (HA) procedures restore joint functionality, stability, and kinematics while preserving more native anatomy than total joint replacement. However, it is important that these implants optimize load transfer so as to minimize stresses at the articular surface to prevent wear in the adjacent articular cartilage. There is evidence that implant geometry may be optimized to reduce contact pressure by increasing contact area and congruency with the adjacent articular cartilage (Lalone et al., 2013; Langohr, et al., 2013). However, experimental data which supports the concept that implant articular conformity influences cartilage wear are lacking. While some studies have quantified the wear of articular cartilage in the context of hemiarthroplasty (Chan, et al., 2011; McGann, et al., 2012) and the effects of material properties on wear have been investigated (Chan et al., 2011; Luo et al., 2010; McCann, et al., 2009), the effect of implant geometry has yet to be examined. The purpose of this study was to investigate the effect of HA implant shape on the wear of cartilage specimens in linear reciprocal sliding.

Methods: Volumetric wear was examined in bovine articular cartilage specimens using an inter-surface distance algorithm which compares pre- and post-wear three dimensional scans of the cartilage surface (n=8 for each implant model). Cylindrical specimens of cartilage and underlying subchondral bone were harvested from bovine tibial plateaus. Specimens were frozen within 12 hours of death, thawed, and submerged in phosphate-buffered saline (PBS) to equilibrate. The specimens were then potted into custom holders and scanned using a NextEngine 3D scanner to generate a digital surface that represents the unworn cartilage. The specimens were then worn on a pin-on-plate wear simulator in reciprocal sliding mode at a rate of 1.2 Hz and linear range of 5 mm, for 140 minutes. Five implant models were custom-made from stainless steel, with radii of curvature ranging from hemispherical (r=4.7mm) to nearly flat (r=11.7mm). A constant load of 27.5 N was applied to the specimens for the duration of testing. After being worn, the specimens were scanned again to generate a post-wear surface. The pre- and post-wear scans were aligned using landmarks on the cartilage surfaces and overlaid so that the distance between the surfaces would represent the volume of cartilage lost. Distances were displayed using colour contour maps (see Figure 1). Volumes were measured by calculating the normal distance from the centroid of each triangular element on the unworn surface to the closest point on the worn surface. The area of each triangle was then multiplied by that distance and summed over entire surface to compute the total wear volume. This volume was normalized by the
surface contact area between the implant model and the cartilage plug to generate an average wear depth, which is the metric of evaluation used to quantify the damage to the articular surface.

**Results:** All contact geometries investigated produced visible evidence of cartilage wear. Figure 1 shows the pre- and post- wear 3D scans along with a colour-contour map which visualizes the distance between the registered surfaces for a characteristic cartilage sample worn with the 4.7mm radius pin. Figure 2 shows the average volume lost. The implant model with the greatest radius of curvature (r=11.7mm) wore away significantly less cartilage than all implant models except the 9.35mm radius of curvature model (p<0.05). The flattest models (r=11.7mm and r=9.35mm) also produced significantly shallower (p<0.05) wear tracks in the cartilage than the other three implant models, as shown by Figure 3, in which the average wear depth for each geometry is presented.

**Discussion:** The data suggest that when the HA contact surface is more conforming and load is distributed over a greater area, less acute cartilage damage occurs. This may be attributed to an improvement in contact mechanics resulting from reduced contact stress concentrations between the pin and the cartilage that result from the increased contact radius. Fewer differences were observed in net volumetric wear among implant geometries, and the level of significance was much greater among tip geometries for wear depth than it was for average volumetric wear. This may indicate that the severity of wear is more closely tied to wear depth than it is to the net volume of material lost. This indicates that incorporating gradual curves into the design of hemiarthroplasty implants may increase their longevity and performance.

**Significance:** Increasing the implant conformity in hemiarthroplasty applications may reduce the severity of cartilage wear.

![Fig. 1- a) Pre-wear scanned surface. b) Post-wear scanned surface. c) Colour-contour map showing wear depth in millimeters.](image)

![Fig. 2- Volumetric wear for each HA implant model. *p<0.05; **p<0.01](image)
**Fig. 3** - Average wear depth for each HA implant model. *p<0.05; **p<0.005; ***p<0.001