Finite Element Analysis of Radial Head Hemiarthroplasty: Implications of Dish Depth on Contact Mechanics

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Disclosures:

Introduction: Radial head hemiarthroplasty is the recommended treatment for selected unreconstructable comminuted radial head fractures [1]. Its long-term viability is largely dependent on the ability of the prosthesis to replicate natural cartilage contact mechanics. Radial head prosthesis design is thus focused on maximizing radiocapitellar contact area and minimizing contact stress, to potentially circumvent cartilage erosion. Chanlalit et al previously identified radial head dish depth as an important variable in radiocapitellar joint stability, since a shallow dish reduces the magnitude of forces required for subluxation [2]. The average native radial head dish depth has been reported to be in the range of 1.9-2.4 mm [3,4] but selecting an appropriate prosthesis dish depth is complicated by the implant’s material properties, which result in increased contact stiffness and decreased articular surface congruence thereby altering contact mechanics [5]. The purpose of this study was to investigate the effect of radial head hemiarthroplasty implant dish depth on radiocapitellar contact mechanics with the hypothesis that a deeper dish would exhibit increased contact area due to increased conformity. Contact mechanics were quantified in terms of both contact area, which has been previously explored using different techniques in cadaveric studies [5,6], and peak contact stress to yield further insight regarding load transfer across the articulation.

Methods: Finite Element Analysis (FEA, ABAQUS (v6.11),) models were constructed using CT images of eight intact cadaveric humerus and radius pairs (age: 78±8.4 yrs) which were then rescanned in air after disarticulating the joint to quantify accurate cartilage thicknesses [7]. Axisymmetric radial head prosthesis models were constructed with shallow (1 mm), moderate (2 mm), and deep (3 mm) articulation concavities. The 2 mm depth model best replicates several commercially available radial head hemiarthroplasty prostheses, and on average most closely coincides with the depth of the native radial head. The 2 mm model has a constant radius of curvature, however the 1 and 3 mm models were designed with variable radii of curvature that increases toward the dish periphery in order to alter dish depth while maintaining the other geometric properties of the dish. The optimal implant size was selected based on the minor diameter of the native radial head. Radiocapitellar contact was simulated at four different flexion angles (0°, 45°, 90°, and 135°) with 100 N of load applied to the radial head, which while constrained rotationally, could freely translate to its 'optimal' position to articulate with the native capitellum to represent the best possible implant positioning. Cartilage was modeled with neo-Hookean hyperelastic material properties [8]. Contact area and stress were computed and compared to the native case.

Results: In comparison to the native radiocapitellar joint, all radial head hemiarthroplasty prostheses resulted in significantly reduced joint contact area and increased peak contact stresses (p<0.05) (Figs. 1,2). Radiocapitellar contact area increased with dish depth for all flexion angles except full extension. The effects of dish depth on contact stress however were more complex, with both the shallow and deep hemiarthroplasty models resulting in significantly elevated peak contact stress relative to the moderate depth case at 0°, 45° and 90° flexion angles (p<0.05). The 2 mm depth RH consistently produced the lowest peak contact stress levels compared to the 1 and 3 mm depths at all flexion angles. Analysis of contact morphology showed the shallow model produced a smaller contact patch and an area of concentrated stress at the centre of the articulation, while the deeper model generated a stress concentration at the transitional trough between the capitellum and trochlea (Fig. 2).

Discussion: The results show that contact area and peak contact stress are both dependent on radial head dish depth. In the shallow model, contact stress increased because the articular surface was too flat resulting in high contact stresses at the centre of the dish. The deep articular dish model appeared to have too large a concavity and this resulted in an edge-loading effect where the peak contact stresses were observed at the outer rim, most commonly due to contact with the prominent cartilage surface at the transition between the trochlea and the capitellum (Fig. 1). Contact area increased with increasing dish depth, while contact stress was minimized with a moderate, near-native dish depth of 2 mm. There appears to be a tradeoff between increased conformity and rim impingement as dish depth is increased. The present study seems to show that a 2 mm dish depth is optimal in terms of contact stress while still providing relatively high contact areas, however a finer resolution of depths may suggest that the true optimal number could lie slightly above or below 2 mm. The contact areas observed in this FEA study were slightly larger than those previously documented in cadaveric studies [5,6], however the relative discrepancies can be attributed to differences in measurement/modelling techniques, most markedly in terms of what constitutes contact in the silicone casting
method, compared with the optimal positioning and ideal contact modeled in the FEA technique. Further studies investigating a wider range of dish depth options at smaller intervals would prove useful in order to determine the optimal dish depth which best reproduces native elbow function and promotes cartilage preservation in radial head hemiarthroplasty.

**Significance:** The effects of dish depth on peak contact stress, and therefore its potential continuing implications on cartilage wear, have remained unexplored. The current results provide insight into an under-examined component of radial head prosthesis design and selection, the results of which may lend themselves to the optimization of radial head hemiarthroplasty dish depth with the objective of further improving clinical outcomes of this procedure.

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Figure 1: Representative results illustrating radiocapitellar stress and contact pressure for one hernioplasty specimen's articulation with prostheses of various depths.
Figure 2. Mean ± 1 SD radiographic contact area and peak contact stress of radial head osteotomy proximally coronal compared with different depths relative to the intact radial head contact relative to various flexion angles. (WT: Left axis = Contact Area; Right axis = Contact Stress).