The Effect of Radial Head Hemiarthroplasty Shape on Proximal Radioulnar Joint Contact Mechanics: A Finite Element Contact Analysis

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Introduction: Radial head (RH) fractures are often repaired using an implanted prosthesis, which is typically manufactured from a stiff metallic material, that articulates with the native surfaces of the capitellum and ulna. As a result, the proximal radioulnar joint (PRUJ) contact area may well be significantly reduced, as has been reported for the radiocapitellar joint [1]. These abnormal contact mechanics may cause degeneration and erosion of the ulnar cartilage with which the prosthesis articulates. The native RH has been shown to have a varying profile at the location of radioulnar articulation that is dependent upon forearm rotation [2,3], and King et al [4] have reported that the RH is also not circular, with radial differences of up to 1.7 mm. There is no clear consensus on which RH profile is optimal for use with RH prostheses and as a result there are several designs currently used clinically. The PRUJ articular profile can be defined simplistically using two parameters; (i) the side radius of the implant, and (ii) the angle of the side profile with respect to the radiocapitellar articular surface. Both parameters vary for the native radial head, and the effect of changing these parameters on PRUJ contact mechanics is currently not described in literature. The purpose of this finite element study was to compare the joint contact area and stress of different RH hemiarthroplasty PRUJ articular profiles to the native radial head with the hypothesis that increasing the side radius and the side profile angle would provide contact mechanics closer to those of the native joint.

Methods: Using CT data from six native elbows (age: 80±6.5 yrs), finite element models were developed in ABAQUS. The elbows were initially scanned intact, after which they were denuded and rescanned in air to acquire cartilage surface geometry, and then aligned to the intact state and using CT attenuation bone material properties were assigned as described in [5]. The modelling process has been shown to give computational contact areas within 10% of areas obtained experimentally [5]. The radial head was articulated with the ulna for the natural case. For the hemiarthroplasty case, a RH prosthesis sized based on specimen minor RH diameter (size: 18, 20 or 22 mm) and positioned to best match the location of the native radial head, was articulated with the ulna. Six different RH side profiles were investigated having varying radii (4.5, 8.1, 16.3 and ∞ mm) or side angles (0°, 5° and 10°). A constant load of 20N was applied to the radius in the medial direction. Contact stresses and areas were computed and compared with the native joint.

Results: Overall, all RH implants significantly reduced contact areas (-55.1% ± 12.8%, p<0.007) compared with the native RH (Figure 1). All implants significantly increased peak contact stresses compared with the native RH (p<0.02). As the radius of the RH side profile was decreased, the contact area increased but the lowest radius (r=4.5mm) produced contact only at the outer edge of the implant resulting in reduced contact area and elevated peak contact stresses (Figure 2). As the side profile angle was increased, the contact area increased and the peak contact stress significantly decreased at both 5° and 10° angles (p<0.03, p<0.02 respectively). The contact profiles (Figure 2) showed that for the flat model (r=∞ mm) the contact occurred at the most distal location of the prosthesis. As the radius decreased, the contact moved proximally. A similar pattern was observed with the angled models where as the angle increased, the contact patch grew as the angle of the prosthesis approached the angle of the native ulnar cartilage (Figure 2).

Discussion: The results show that the shape of the side profile of RH prostheses can affect contact mechanics including contact area and contact stress. Decreasing the RH side radius can increase PRUJ contact area and decrease peak contact stress but at the smallest radius (r=4.5mm), these effects were diminished as the contact migrated to the outermost radial edge of the prosthesis resulting in a stress concentration. As the RH side profile angle is increased, the PRUJ contact area increases and the peak contact stress decreases, as the geometry more closely approaches that of the natural ulnar cartilage (Figure 2). A flat profile (r=∞ mm) was the worst in terms of both contact area and stress. Further investigation of the interaction between RH hemiarthroplasty prostheses and the ulna at the PRUJ is needed to determine the optimal implant design.

Significance: The longevity of hemiarthroplasty depends on maintaining the viability of the native cartilage. The current study shows that the shape of the PRUJ articular surface of RH hemiarthroplasty prostheses can have a marked effect on the contact area and contact stresses at the PRUJ, both of which are likely to affect the long-term cartilage health after RH hemiarthroplasty.
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Figure 1. Percent change compared to native observed for Contact Area (blue) and Peak Contact Stress (red) for all models (top).
Figure 2. Representative Contact Area and Contact Stress Maps for the native PRUJ (left), different radius modes (top), and different slice angles (bottom).