Finite Element Contact Analysis of the Native Radiocapitellar Joint Compared to Axisymmetric and Non-Axisymmetric Radial Head Hemiarthroplasty

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Disclosures:

Introduction: Radial head (RH) fractures are commonly treated with a prosthesis that articulates with the native surface of the capitellum. Since current RH hemiarthroplasty prostheses are manufactured from stiff metallic materials, the joint contact area between the implant and the capitellum is significantly reduced and may lead to capitellum cartilage degradation [1,2]. King et al [3] have reported that the native RH is not circular, with radial differences of up to 3.1 mm. The concave radiocapitellar contacting surface has also been shown to be non-axisymmetric [4], with contact radii differing up to 4.5 mm from the smallest to largest curvature. Recent RH hemiarthroplasty implants have included non-axisymmetric geometries in an effort to more closely replicate the shape of the native RH. Previous work has shown that non-axisymmetric RH implants can increase contact area but can, in some forearm rotations, also increase contact stress that may accelerate cartilage degeneration [5]. The purpose of this finite element study was to compare the joint contact area and stress of axisymmetric and non-axisymmetric RH implants to the native radiocapitellar joint. The hypothesis was that the non-axisymmetric RH implants would have improved articular contact mechanics relative to axisymmetric RH implants.

Methods: A series of finite element models were developed in ABAQUS using CT data from eight native elbows (age: 78±7.8 yrs), which were scanned intact and then denuded and rescanned in air to acquire accurate cartilage geometry. The modeling process gave contact areas within 10% of those obtained experimentally [6]. The models were then aligned to the intact and neutral positions and bone material properties were assigned based on CT attenuation [6]. The cartilage was modelled as a nonlinear elastic material. For the native case, the capitellum was articulated against the radial head, which was allowed to translate to find its 'optimal' position. For the hemiarthroplasty cases, the capitellum was articulated against a RH prosthesis sized based on each specimens minor RH diameter (size: 18, 20, or 22 mm) having either an axisymmetric (spherical) or non-axisymmetric (elliptical) contact geometry. The non-axisymmetric prosthesis was produced by reducing the diameter along one axis (and as a result the radius of curvature) to that of a RH implant one size smaller (i.e. 20 mm vs. 20 x 18 mm). This was done to best replicate the natural radial head articular geometry [4]. A constant load of 100 N was applied to the native radial head or RH implant. Contact stresses, and contact areas were computed. All study parameters were investigated for both supination and pronation (±90° range) with the elbows at 0°, 45°, 90°, and 135° of flexion.

Results: When compared to the native articulation, all hemiarthroplasty models produced significantly lower contact areas and higher contact stresses (Figure 1, p=0.012). The native radiocapitellar contact areas were not circular in shape, and neither were the areas generated in both axisymmetric and the non-axisymmetric RH cases (Figure 2). The non-axisymmetric implants produced a sinusoidal profile when the contact area and contact stresses were plotted versus forearm rotation. As a result of the interaction of these two non-axisymmetric surfaces, there was a 'best' case where the long axes of both the capitellum and non-axisymmetric RH were aligned, and a 'worst' case where the long axes were 90° apart causing impingement (Figure 2); the latter resulting in significantly reduced contact areas at some angles of flexion, and significantly elevated contact stresses at all angles of flexion (Figure 1). On average, the non-axisymmetric RH had a 1.9% increase in contact area and a 50% reduction in contact stress compared with the axisymmetric RH in their 'best' rotations, however in their 'worst' rotations a 4.6% reduction in contact area and a 110% increase in contact stress was calculated. The contact area and stress performance of the axisymmetric RH consistently fell in between the 'best' and 'worst' results of the non-axisymmetric RH results (Figure 1). The 'best' forearm rotation angle varied between specimens and flexion angles (standard deviation = ±65.6° and ±43.3° respectively).

Discussion: The results show that, in comparison to the axisymmetric design, a non-axisymmetric RH hemiarthroplasty in the 'best' rotational position can significantly reduce peak contact stress, and for some flexion angles increase contact area, however there is also a corresponding 'worst' rotational position, typically occurring perpendicularly, which significantly increases peak contact stresses and reduces contact area. This is because the natural capitellum is not uniformly spherical and is also elliptical to some extent, which was exhibited in the non-circular contact area generated during articulation with the axisymmetric RH as previously described [5]. The rotational angle between the 'best' and 'worst' positions was fairly consistent (89° ± 8.7°) which supports the aforementioned impingement phenomena observed between the non-axisymmetric capitellum and RH. Therefore, although the non-axisymmetric RH models were able to achieve improved contact mechanics in one 'best' orientation, there...
always existed a ‘worst’ orientation that was significantly worse than the axisymmetric design. The efficacy of the non-axisymmetric articulation in improving joint contact mechanics is dependent on the position of forearm rotation and elbow flexion; hence it seems unlikely that the prosthesis is optimally articulating throughout motion. The contact mechanics of the axisymmetric RH prosthesis are not sensitive to forearm rotation or elbow flexion, perhaps making them more forgiving than a non-axisymmetric design.

**Significance:** The current study shows that while non-axisymmetric radiocapitellar hemiarthroplasty can provide significantly larger contact areas and thus lower average contact stresses compared with the axisymmetric designs in certain positions of forearm rotation and elbow flexion, they may also be subject to impingement phenomena where contact area is reduced and contact stress is increased. Axisymmetric designs provide more consistent articular contact mechanics throughout motion. Further studies are needed to optimize RH implant design to improve long-term cartilage health after radiocapitellar hemiarthroplasty.

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Figure 1. Change in contact area (blue) and stress (red) compared to native for axisymmetric (middle), NON-AX symmetric BEST (left) and NON-AX/symmetric WORST (right) positions.
Figure 2. Representative contact area and contact stress maps for (A) Native, (B) Non-Axisymmetric Best, (C) Axisymmetric, and (D) Non-Axisymmetric Worst with the white arrow showing region of impingement and resultant high contact stress.

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