The Effect of Prosthetic Radial Head Geometry on the Distribution and Magnitude of Radiocapitellar Joint Contact Pressures

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Purpose To determine if radiocapitellar contact pressures would be elevated with non-anatomical (circular) prostheses over those mimicking native anatomy and if such pressures would be related to the depth and contour of the articular dish and to the pattern of prosthetic articulation against the lateral trochlear ridge.

Methods Three commercially available circular radial head designs were compared with an anatomical radial head and 2 modified anatomical prototype radial head designs in 10 cadaveric specimens. Each prosthesis and specimen combination was loaded in neutral rotation and maximal extension with a custom testing apparatus while measuring contact areas and pressures using thin-film pressure sensors.

Results Anatomical radial head prototype 2 had similar radiocapitellar contact areas and mean pressures as the native radial head; all other designs showed significant decreases in contact area and increased mean pressures. Peak contact pressures were also measured and were significantly elevated with all prostheses tested. Anatomical designs are statistically more likely to mimic normal contact with the lateral trochlear ridge and its adjacent sulcus than circular prostheses. They are also significantly less likely to have contact pressures above the 5 MPa threshold that is thought to be harmful to cartilage. The depth of the articular dish had a significant effect on contact area and pressure.

Conclusions Commercially available radial head prostheses demonstrated reduced radiocapitellar contact areas and elevated contact pressures during compressive loading. These were significantly greater with symmetrical circular prostheses than with asymmetrical elliptical designs. The prosthesis that best mimicked native contact behavior was the anatomical radial head prototype 2 owing to its design for articulating with the capitellum, the lateral trochlear ridge, and the sulcus between.

Clinical relevance Because radial head prostheses have the potential to cause capitellar erosion or arthritic change, those with lower contact pressures may lead to fewer such complications.
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Key words Radial head replacement, arthroplasty, contact area, contact pressure, biomechanics.

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Prosthetic replacement may be used for a severely fractured radial head. Owing to the nature of the injury, many of the patients are young and have many years during which the prosthesis must articulate with the opposing articular cartilage. Mid- to long-term results are reported for radial head prostheses.[1–4] Although good clinical outcomes thus far are shown in each of these studies, several long-term concerns have arisen. Periprosthetic radial neck resorption,[2,4] humeral osteopenia,[3,5] and capitellar degenerative changes have been noted.[1–4] Four studies have reported capitellar erosions or arthritic changes in 33% to 70% of patients.[1–4] Various etiologies are being considered, including initial trauma to the articular surface, joint overstuffing, material properties of the implant, and prosthesis capitellar shape mismatch. Sahu et al[6] explored the effects of prosthesis shape and elbow flexion angle on isolated radiocapitellar contact profiles. In that study, significant differences in contact area and pressure between a circular and an elliptical design were documented. Our aims were to use a more intact cadaveric model for evaluation and to test a greater variety of radial head designs. We hypothesized that radiocapitellar contact pressures would be elevated with nonanatomical (circular) prostheses compared with those mimicking native anatomy and such pressures would be related to the depth of contour of the articular dish and to the pattern of prosthetic articulation against the lateral trochlear ridge (LTR) and its adjacent sulcus.

MATERIALS AND METHODS

Specimen preparation

Ten fresh-frozen cadaveric limbs from fingertip to midhumerus were used in this study. There were 4 males and 6 females. The average age was 72 ± 3 years. The specimens were thawed at room temperature overnight prior to the experiment. They were examined under fluoroscopy for radiographic pathology at the elbow joint. None of the specimens showed any evidence of arthritis or other pathology during physical or radiographic examination. The skin and subcutaneous fat were removed from the midhumerus to 5 cm distal to the elbow joint. The biceps and brachialis muscles were removed, leaving the anterior capsule intact. The humerus was potted in polyurethane resin. Neutral position of the forearm was visually verified. A dorsal skin incision was made 5 to 10 cm distal to the lateral epicondyle. Within this space, the radius was predrilled parallel to the joint line. A centrally threaded 4-mm traction pin was placed. Another pin was placed similarly 2 cm distal to the first. The articular surfaces were frequently wetted during testing with normal saline.

Pressure transducer

A thin-film pressure sensor (Tekscan, South Boston, MA) was inserted between the radius and the capitellum to record contact pressures and area, as in prior studies.[6,7] For each specimen and prosthesis combination, a 33 × 28 mm Tekscan 4000 was used to visualize the complete area of contact. A 4000 sensor was not used itself for recording because preliminary testing revealed that it was too large to fit the joint space with intact collateral ligaments without wrinkling. Such wrinkling introduced the risks of spurious data from damage to the sensor. For our testing, a single 6900 sensor was used alone unless the contact area was wider than 14 mm, as was the case when multiple areas of contact were noted. Then 2 side-by-side sensors were used to collect each point of contact, and pressure maps were inserted and adjusted to ensure no overlapping prior to recording. The output from these sensors was collected for analysis and displayed in the rounded edges viewing mode of the color-coded map by the I-Scan analysis software (Tekscan). The thin-film Tekscan sensor has been validated for rounded contact areas[8] and used in earlier reports of joint contact pressures for multiple areas of contact.[9,10] Each 6900 sensor has 4 14 × 14−mm matrices (4 × 192 mm^2), each comprising 121 sensels (individual detection units of pressure sensor) located on fingertip extensions of conductive ink grids. The 6900 sensors were preconditioned according to the manufacturer's recommendations. Contact areas were recorded as the product of sensels activated and individual sensel size (1.62 mm^2). Pressure values were acquired in raw sum pressure units and calibrated using a cubic polynomial acquired from Excel that best fit the 10-points of calibration to standard pressure units (MPa). This method was used successfully in previous validations.[11]

Specimen mounting and testing

For specimen testing, a custom mechanical test apparatus was used. The setup included a static load plate attached to a 1−degree of freedom vertical slide to which the potted humerus was clamped in an anatomical position. A 2−degrees of freedom transverse plane (x-y) stage and pin clamp was mounted on a 6-axis load cell (JR3, Woodland, CA). On the other side, the pins were fixed with slight rotational and translational freedom (Fig. 1). This construct allowed the radial pins to be reproducibly aligned and