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Radiocapitellar contact characteristics during prosthetic radial head subluxation

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Background: Metallic radial head prostheses are often used in the management of comminuted radial head fractures and elbow instability. We hypothesized that during radiocapitellar subluxation, the contact pressure characteristics of an anatomic radial head prosthesis will more closely mimic those of the native radial head compared with a monopolar circular or a bipolar circular radial head design.

Materials and methods: With use of 6 fresh frozen cadaver elbows, mean radiocapitellar contact pressures, contact areas, and peak pressures of the native radial head were assessed at 0, 2, 4, and 6 mm of posterior subluxation. These assessments were repeated after the native radial head was replaced with anatomic, monopolar circular and bipolar circular prostheses.

Results: The joint contact pressures increased with the native and the prosthetic radial head subluxation. The mean contact pressures for the native radial head and anatomic prosthesis increased progressively and significantly from 0 to 6 mm of subluxation (native, 0.6 ± 0.0 MPa to 1.9 ± 0.2 MPa; anatomic, 0.7 ± 0.0 MPa to 2.1 ± 0.3 MPa; $P < .0001$). The contact pressures with the monopolar and bipolar prostheses were significantly higher at baseline and did not change significantly further with subluxation (monopolar, 2.0 ± 0.1 MPa to 2.2 ± 0.2 MPa [$P = .31$]; bipolar, 1.7 ± 0.1 MPa to 1.9 ± 0.1 MPa [$P = .12$]). The pattern of increase in contact pressures with the anatomic prosthesis mimicked that of the native radial head. Conversely, the circular prostheses started out with higher contact pressures that stayed elevated.

Conclusion: The articular surface design of a radial head prosthesis is an important determinant of joint contact pressures.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Anatomic radial head; subluxation; malpositioning; radiocapitellar contact pressures; radiocapitellar contact area; radiocapitellar stability; biomechanics

Metallic radial head prostheses are often used in the management of comminuted radial head fractures and complications following radial head excision.[4,25] Radial head prostheses restore significant stability in the elbow joint, but they have also been associated with radiocapitellar joint subluxation, capitellar cartilage erosion, and degeneration.[5,12,15] Furthermore, mismatch between the design of a radial head prosthesis and the native radial head anatomy may result in radiocapitellar joint subluxation or malpositioning that may cause cartilage degeneration.[34] However, it is not currently known how the radiocapitellar contact pressures and areas change with radiocapitellar instability and resultant malarticulation of a prosthesis. Anatomic radial head implants have been designed to mimic certain anatomic aspects

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of the native radial head.[30-32] Recent biomechanical studies have demonstrated that an anatomic radial head more closely mimics the contact pressures of the native radial head than do nonanatomic designs.[2,23] Whereas bipolar implants have been designed with the intention of improving contact with the capitellum and compensating for inaccuracies in the design,[16] it is not known how the contact pressures and areas may change with subluxation. The purpose of this study was to compare the changes in radiocapitellar contact pressures with 3 different types of radial head prostheses. We hypothesized that the contact pressure characteristics of an anatomic radial head prosthesis will more closely mimic those of the native radial head compared with a monopolar circular or a bipolar circular radial head design.

Material and methods

Specimen preparation

Six fresh frozen elbows were obtained from our cadaver laboratory and allowed to thaw for 24 hours before use. They were checked and verified to be free of gross pathologic changes, such as osteoarthritis. All surrounding soft tissues, including the capsule and ligaments, were removed. The radius and the humerus bones were disarticulated and dissected free of all soft tissues. These two bones were then potted separately in cylindrical tubes using methyl methacrylate.

Specimen mounting

The specimens were tested in a previously published,[6,20,26,27] custom built device consisting of a pneumatic-controlled actuator, a 6-axis load cell (JR3 Inc, Woodland, CA, USA), and a 2-degree of freedom motorized x-y stage—permitting precision translation of the base of the construct (Fig. 1). Based on pretapped bolt holes in the apparatus, this machine allowed the bones to be aligned reproducibly at an angle of 30° as previously reported[7,8,23,27] with this testing system to simulate a position that would facilitate subluxation. The bicipital tuberosity was consistently oriented medially to mimic the position of supination thought to be at risk for posterolateral subluxation.[6]

Pressure sensor

A Tekscan Sensor 4000 (Tekscan Inc, South Boston, MA, USA) was placed in the radiocapitellar articulation to record contact pressures and areas as previously reported.[23] These sensors are resistance-based transducers that measure contact pressures through a change in impedance in a matrix of pressure-sensitive and pressure-conductive ink.[10] This particular sensor (Model 4000) has a sensel (sensing unit of sensor) density of 62/cm^2. It has a 28 × 33-mm matrix, made of 572 sensels, each with an area of 1.6 mm^2. The saturation pressure of the chosen sensor was 10.3 MPa. Based on the sensor's size, it was considered appropriate for a radial head and has been validated in earlier reports.[10,23] The manufacturer's recommendations were used to precondition, to adjust the sensitivity, and to calibrate the sensor. The in-line load cell and pneumatic cylinder measuring and applying the 100 N load, respectively, in the testing apparatus allowed the Tekscan sensor to be calibrated in situ under the exact conditions as those in which our data were collected.[24] The software provided by the manufacturer (I-Scan, Tekscan Inc), displayed a color-coded pressure map on the computer and collected the data for analysis.

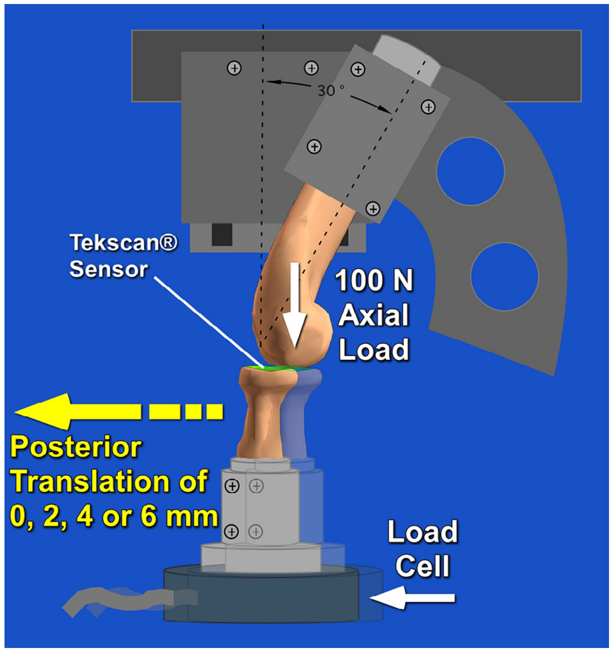

Figure 1 Testing machine schematic. The specimens were reproducibly aligned to articulate in 30° of flexion, and contact parameters (pressures and areas) were recorded at the 0 (nonsubluxated) position. The radius was then subluxated in 2-mm increments posteriorly up to 6 mm relative to the starting 0 position. At each position (0, 2, 4, 6 mm), the joint was loaded with 100 N of compression force, and contact pressures and areas were recorded. This testing sequence was first performed with the intact native radial head and then with prosthetic radial heads in random order. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Specimen testing

The specimens were reproducibly aligned to articulate in 30° of flexion, and contact parameters (pressures and areas) were recorded at the 0 (nonsubluxated) position. Using the Labview controlled motorized X-Y stage built into the testing apparatus, the radius was then subluxated in 2-mm increments posteriorly to a maximum of 6 mm relative to the starting 0 position. At each position (0, 2, 4, and 6 mm), the contact pressures and areas were recorded after the joint was loaded (to simulate the force of light-duty activities of daily living[17,23]) with 100 N of axial compression. The load of 100 N was then removed, the joint was incrementally subluxated, and the load was reapplied at each subsequent subluxated position. This testing sequence was first performed with the intact native radial head and then with the prosthetic radial heads in random order.

Radial head designs

The manufacturer's recommended procedures were followed for replacing the native radial head with prosthetic radial heads and