Radiocapitellar Joint Contact Pressures Following Radial Head Arthroplasty

Michael Cohn, MD, Sergio A. Glait, MD, Anthony Sapienza, MD, Young W. Kwon, MD

Purpose To determine the radial head arthroplasty length that best replicates the native radiocapitellar contact pressure.

Methods Eight cadaveric elbows (4 matched pairs) with an average age of 73 years were tested. All specimens were ligamentously stable and without visible cartilage wear. Radiocapitellar contact pressures were digitally analyzed during simulated joint loading at 0°, 45°, and 90° of elbow flexion and neutral rotation in the intact specimens and after ligament-preserving radial head arthroplasty at -2 mm, 0 mm, and +2 mm of the native length. The results were analyzed using 1-way analysis of variance and post hoc Tukey pairwise comparison tests.

Results Paired analysis demonstrated significantly decreased mean contact pressures when comparing the native versus the minus 2 groups. Significantly decreased maximum contact pressures were also noted between the native and the minus 2 groups. Examining the mean contact pressures showed no significant difference between the native and the zero group and the native and the plus 2 groups. As for the maximum contact pressures, there was also no significant difference between the native and the zero group and the native and the plus 2 group.

Conclusions Up to 2 mm of overlengthening may be tolerated under simulated loading conditions without significantly increasing contact pressures of the radiocapitellar joint. Surgeons can use this knowledge along with radiographic parameters and intraoperative examination of elbow stability to gauge the appropriate size of the radial head implant to be used in order to decrease the risk of overstuffing the joint and minimizing radiocapitellar chondral wear. *(J Hand Surg Am. 2014;39(8):1566−1571. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Prognostic IV.

Key words Arthroplasty, biomechanical analysis, contact pressure, radial head, radiocapitellar joint.

Fractures of the radial head account for 33% of all elbow fractures.[1] Surgical options for displaced fractures include open reduction and internal fixation, radial head resection, and radial head arthroplasty. The radial head is important for valgus and longitudinal stability of the elbow.[2] Although internal fixation of these fractures is the preferred treatment, other surgical options must be considered to restore the biomechanical properties of the elbow joint when internal fixation is not possible.[3]

Treatment options for radial head fractures not amenable to internal fixation include radial head resection or radial head arthroplasty, each of which is associated with complications. Radial head resection should only be considered in the absence of injury to the triangular fibrocartilage complex, interosseous membrane, and ulnar collateral ligament of the elbow to minimize the risk of longitudinal radius-ulna instability or valgus elbow instability.[2,4] Radial head arthroplasty is recommended for irreparable radial head

From the Department of Orthopaedic Surgery, NYU Hospital for Joint Diseases, New York, NY.

Received for publication September 15, 2013; accepted in revised form May 14, 2014.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Corresponding author: Sergio A. Glait, MD, Department of Orthopaedic Surgery, NYU Hospital for Joint Diseases, 301 E. 17th St., 14th Floor, New York, NY 10003; e-mail: sergio.glait@nyumc.org.

0363-5023/14/3908-0019$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2014.05.021

fractures with associated ligamentous injury to maintain stability to the forearm and elbow. However, an implanted radial head prosthesis must restore the anatomical characteristics of the original joint to achieve the closest resemblance of the native joint's biomechanics. Overstuffing the radial head causing malalignment of the radiocapitellar joint and lateral gapping of the ulnohumeral joint can create increased pressures or altered kinematics that can ultimately result in hyaline cartilage erosion, synovitis, and osteoarthritis.[5–7]

Several studies have examined the biomechanics of radial head arthroplasty on elbow joint kinematics. They show that ulnar collateral ligament injuries increase the varus-valgus laxity and radiocapitellar contact pressures in a valgus stressed position.[6–8] The goal of this study was to demonstrate whether or not the length of the radial head replacement has to match the native length removed or whether the radiocapitellar joint can tolerate small errors in placement of the radial head replacement. We hypothesized that native radiocapitellar contact pressures would not significantly increase if using a radial head prosthesis that approximated the length of the resected radial head.

MATERIALS AND METHODS

Eight fresh-frozen cadaveric upper extremities (4 matched pairs) were used. All of the cadaveric specimens were males whose average age was 72 years (range, 68–75 y). The specimens were stored at -20°C until thawed at room temperature for 24 hours prior to dissection. There were no macroscopic abnormalities, including any cartilage degeneration, in the specimens at the time of experimentation. All specimens also demonstrated normal passive flexion and extension as well as intact collateral ligaments with stability to varus and valgus stresses.

The radiocapitellar joint was approached anteriorly between the brachioradialis and the pronator teres to preserve the integrity of the collateral ligaments. A transverse anterior capsulotomy was established to allow insertion of the pressure sensor into the radiocapitellar joint, and pressure measurements were made prior to radial head osteotomy and implant insertion. We exposed the radial neck distal to the radiocapitellar joint and transected the radial neck beginning with a fine osteotome and finishing with a narrow oscillating saw. The location of the osteotomy relative to the proximal aspect of the radial head corresponded to the length of the trial component using the zero offset radial head and standard-sized

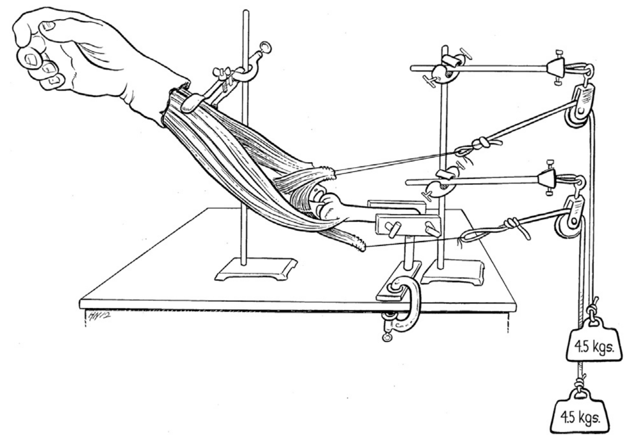

FIGURE 1: Representation of the experimental setup. Joint forces are simulated by hanging weights from sutures placed into the elbow flexors (biceps and brachialis) and extensor (triceps).

stem up to the collar that abuts the cortex of the radius. This value was measured using a vernier caliper. This allowed the native length of the proximal radius to be reproduced with the implant; we denoted this the zero group. The diameter of the radial head implant chosen was based on the size that best matched the resected native head. A modular, monopolar radial head (Wright Medical Inc., Arlington, TN) was inserted using the manufacturer's recommended technique. Stainless steel trial implants were inserted, and a set screw was placed at the head-neck junction to prevent toggle. The same implant-loading protocol was repeated using the offset radial head components of -2 mm (minus 2 group) and +2 mm (plus 2 group). After sensor insertion into the radiocapitellar joint, the anterior capsulotomy was sutured.

The biceps, brachialis, and triceps tendons were identified, and a heavy Krakow stitch was placed into each of these tendons. The humerus was then stripped of soft tissue and mounted onto a custom jig with the wrist in neutral rotation (Fig. 1). The biceps and brachialis tendons were loaded with a single 4.5-kg weight, and the triceps was loaded with another 4.5-kg weight representing approximately 10% of maximal physiological load of these muscles based on similar validated elbow joint-loading protocols.[2,9,10]

Radiocapitellar joint pressure measurements were obtained using the Tekscan I-Scan pressure measurement system 6900 model sensor (Tekscan Inc., South Boston, MA). The sensors were calibrated prior to each measurement, and measurements were obtained using the TekScan software. All specimens were tested in neutral rotation at 0°, 45°, and 90° of elbow flexion. Measurements were taken during a 5-second loading period and were repeated 3 times to

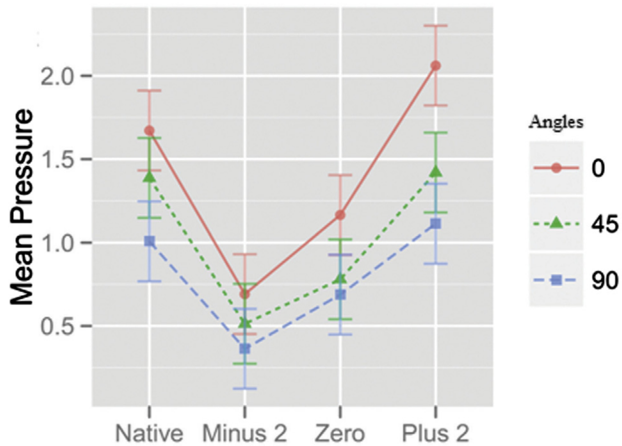

FIGURE 2: Main pressures measured in megapascals with corresponding 95% confidence intervals based on the pairwise Tukey test.

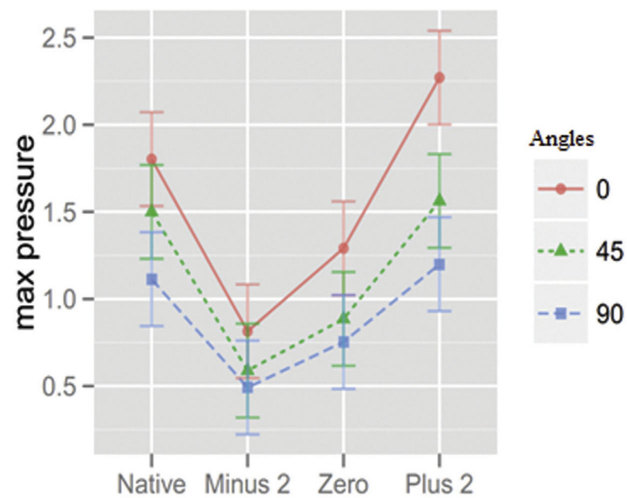

FIGURE 3: Maximum (Max) pressures measured in megapascals with corresponding 95% confidence intervals based on the pairwise Tukey test.

TABLE 1. Pairwise Comparison Between Groups

	Mean Pressure	Maximum Pressure
	P Value	*P* Value
Native vs minus 2	**.001**	**.004**
Native vs zero	.23	.29
Native vs plus 2	.46	37
Zero vs minus 2	.28	.37
Plus 2 vs minus 2	**< .001**	**< .001**
Zero vs plus 2	**.004**	**.004**

Bold *P* values are significant at $P < .05$.

ensure accurate measurements. The final measurement used was an average of the 3 data points taken. Outcomes recorded included mean and maximum pressures recorded in megapascals for each measurement taken.

Statistical analysis was performed by comparing mean differences between groups with a 1-way analysis of variance test. Post hoc testing was conducted using Tukey-Kramer pairwise comparison to compare the various groups. Significance level was set at *P* less than .05.

RESULTS

Mean contact pressures

The mean contact pressure data are noted in Figure 2. Pairwise statistical comparison between groups is shown in Table 1. In comparison with the native radiocapitellar joint, the contact pressures for the minus 2 group was statistically lower ($P = .001$). No statistical difference was found between the native and the zero group ($P = .23$) or the plus 2 group ($P = .46$).

Maximum contact pressures

The maximum pressures and statistical comparisons among the various groups at different angles are shown in Figure 3. Similar to the mean contact pressure measurements, the maximal contact pressures for the minus 2 group was statistically lower than the native group ($P = .004$). In comparison with the native group, no statistical difference was found against the zero group ($P = .29$) or the plus 2 group ($P = .37$).

DISCUSSION

Our data demonstrate that up to 2 mm of overlengthening may be tolerated in a radial head replacement without causing significant increases in the radiocapitellar joint contact pressures. In addition, placing a smaller implant (minus 2) compared with the native radiocapitellar joint results in a significant decrease in both mean and maximum contact pressures.

A well-performed radial head arthroplasty allows for restoration of both valgus elbow and longitudinal forearm stability. A poorly sized radial head implant may lead to premature cartilage degeneration of the capitellum, instability, loss of motion, or altered joint biomechanics.[11–14] Sixty percent of the load at the elbow is transferred through the radiocapitellar joint.[9,15] In our study, there were no significant contact pressure differences between the native elbow and the zero and plus 2 groups, and there was a significant decrease in contact pressures in comparing the native and minus 2 groups. Our findings suggest that a radial head can be placed between -2 and +2 mm of the native radial length without causing significant increases in radiocapitellar pressure. Based on our study, there is some variability with the size of implants that can be placed without causing significant increases in radiocapitellar pressures. Minimizing contact pressures is only one variable surgeons need to consider when implanting a radial head prosthesis. It is important to ensure that the elbow is stable within a functional range of motion after implantation as well.

Several studies discuss the failure of radial head implants due to overstuffing. van Riet et al[16] reported on 47 radial head replacements that underwent excision of the radial head component owing to failure. The most common reason for reoperation was reduced elbow motion, which the authors attributed to either stiffness or secondary to pain and/or component overstuffing. Prior to the revision operation, radial head arthroplasty was the primary procedure in 11 patients owing to acute trauma, and the remaining radial head implants were placed in subacute/chronic settings secondary to failure of internal fixation, radial head resection, or arthroplasty. Among the 47 failures in van Riet et al's study, 11 showed evidence of overstuffing based on preoperative radiographs of the implant position relative to the lesser sigmoid notch of the ulna. Severe erosion of the articular capitellum was noted in 43% (20/47) of the elbows. The authors showed that the timing of the original implantation of the radial head component was the best predictor of capitellar erosion, with most of the erosion occurring in patients who received a radial head arthroplasty beyond 6 weeks after the initial trauma. However, 36% (4 of 11) of the patients who received an overlengthened radial head had severe capitellar erosion at the time of revision surgery, which was a mean of 13 months after the index procedure. This suggests that overstuffing the radial capitellar joint still plays an important factor in the development of radiocapitellar arthritis.

Burkhart et al[17] looked at outcomes in 19 patients with bipolar radial head arthroplasty at a mean of 8.8 years later. Among these patients, there were 3 cases of capitellar erosion. One case involved a patient with implant subluxation who refused treatment and developed marked arthritis; the other 2 cases involved capitellar erosions that the authors attributed to overstuffing of the joint with large components. Another 5 cases in this cohort showed degenerative changes of the capitellum with increased subchondral density on radiographs; however, most of these patients remained asymptomatic.

The literature on radial head arthroplasty revision is limited, and the conversion rate of a radial head arthroplasty to a capitellar resurfacing procedure based on oversized radial head implants is not known. Most complications from radial head arthroplasty result in a loss of motion, and the revision rate in the literature ranges between 4% and 27% with the main causes in 5 studies being pain and loss of motion attributed to overstuffing the radiocapitellar joint.[18] It is uncertain how much overstuffing contributes to degenerative changes or whether these changes relate to the initial injury and the changes that occur between the time of injury and radial head arthroplasty.[16]

Studies have shown statistically insignificant increases in contact pressures when comparing a normal elbow with a medial collateral ligament–deficient elbow with a radial head arthroplasty under valgus stress loads.[19–21] In addition, van Glabbeek et al[6] demonstrated in medial collateral ligament–deficient elbows that increasing the radial head length by 2.5 mm showed significant increases in radiocapitellar pressures and that these pressures decreased with increasing flexion angles. Both of these conclusions were confirmed in our study.[6]

This biomechanical study did show a nonsignificant but increasing trend toward higher pressures when comparing the native elbow with the zero and plus 2 implant groups. The clinical importance of this in terms of degenerative changes or symptoms is not fully understood. However, edge loading can occur with these implants, and asymmetrical wear may be expected given the unique anatomy of each individual's radiocapitellar joint. For example, in this study, an 11% increase in contact pressures was shown when comparing the average pressure of the plus 2 implant group at 0° (2.06 MPa) to the maximal pressure with the plus 2 implant (2.28 MPa). This maximal pressure was concentrated in a specific location likely owing to edge loading, even though the average pressure was overall lower and no statistically significant increase was measured. The clinical importance of edge loading over time is unclear, and although our study did not show any significant increases in pressures, larger implants may cause harm on the chondral surface. Surgeons should take into account the radiographic analysis as well as intraoperative examination prior to choosing an implant.

Study limitations need to be considered. Joint forces across the radiocapitellar joint were approximated to physiological loads. Forces across the joint were not consistent between elbow positions owing to the loading jig and angle of muscle forces acting across the joint. However, comparisons between groups at each elbow position still provided meaningful clinical information. The *in vivo* muscle balance is much more complex than that which can be simulated in the laboratory. In addition, 8 elbows were tested, and although the number seems low, it is similar to other studies that have considered radiocapitellar pressures.[16] These studies do not mention power analyses, and it would be interesting to see the data in a larger sample size.

Lastly, although we tested ligamentously intact elbows, other injuries occur in conjunction with radial head fractures without any dislocation. A magnetic resonance imaging (MRI) study looked at 46 radial head fractures and found that 35 of 46 elbows showed concomitant injuries, most commonly lateral collateral ligament and capitellar osteochondral injuries.[22] The lateral collateral ligament injuries were subclassified as contusions or partial or complete lesions on MRI. Imaging demonstrated 27 of 46 elbows (57%) with associated lateral collateral ligament injuries, and 8 of 27 (30%) were complete injuries on MRI, which can be subject to interpretation. There was no mention of the clinical examination of the elbow in that study. On a follow-up study, Kaas et al[23] described the clinical relevance of their MRI findings and noted that most injuries found on MRI were not symptomatic or clinically important in follow-up averaging 13 months. Radial head fractures can be associated with ligamentous disruption, and although these MRI findings may be clinically insignificant, the ligamentous injury can influence the radiocapitellar contact pressures when performing an isolated radial head replacement if the underlying instability is not addressed. Cadaveric models provide useful but limited information in the setting of more complex clinical scenarios; how these pressures affect the articular cartilage over time remains to be answered.

Deciding on the length of an implant during a radial head arthroplasty can have significant clinical consequences on a patient's outcome. Surgeons should adhere to the principles demonstrated in the literature regarding "overstuffing" the radiocapitellar joint, which can lead to hyaline cartilage erosion, synovitis, and osteoarthritis.[5–7] Our study suggests that placing an implant that is equal to or no larger than 2 mm compared with the amount of radial head resected does not significantly increase radiocapitellar joint contact pressures. Surgeons should use the information from our study in conjunction with clinical and radiographic data such as the implant's position relative to the coronoid, visual gapping of the ulnohumeral joint on radiographs, and elbow stability through a functional range of motion in order to make the best intraoperative decision regarding implant size.

REFERENCES

1. Tejwani NC, Mehta H. Fractures of the radial head and neck: current concepts in management. *J Am Acad Orthop Surg*. 2007;15(7):380–387.
2. Morrey BF, Tanaka S, An KN. Valgus stability of the elbow. A definition of primary and secondary constraints. *Clin Orthop Relat Res*. 1991;265:187–195.
3. Ring D, Quintero J, Jupiter JB. Open reduction and internal fixation of fractures of the radial head. *J Bone Joint Surg Am*. 2002;84(10):1811–1815.
4. Johnson JA, Beingessner DM, Gordon KD, Dunning CE, Stacpoole RA, King GJ. Kinematics and stability of the fractured and implant-reconstructed radial head. *J Shoulder Elbow Surg*. 2005;14(1 Suppl S):195S–201S.
5. Ring D. Load-sharing at the wrist following radial head replacement with a metal implant: a cadaveric study. *J Bone Joint Surg Am*. 2004;86(11):2569.
6. van Glabbeek F, van Riet RP, Baumfeld JA, et al. Detrimental effects of overstuffing or understuffing with a radial head replacement in the medial collateral-ligament deficient elbow. *J Bone Joint Surg Am*. 2004;86(12):2629–2635.
7. van Glabbeek F, van Riet RP, Baumfeld JA, et al. The kinematic importance of radial neck length in radial head replacement. *Med Eng Phys*. 2005;27(4):336–342.
8. Duggan JP Jr, Osadebe UC, Alexander JW, Noble PC, Lintner DM. The impact of ulnar collateral ligament tear and reconstruction on contact pressures in the lateral compartment of the elbow. *J Shoulder Elbow Surg*. 2011;20(2):226–233.
9. Morrey BF, An KN, Stormont TJ. Force transmission through the radial head. *J Bone Joint Surg Am*. 1988;70(2):250–256.
10. Kamineni S, Elattrache NS, O'Driscoll SW, et al. Medial collateral ligament strain with partial posteromedial olecranon resection: a biomechanical study. *J Bone Joint Surg Am*. 2004;86(11):2424–2430.
11. Herbertsson P, Josefsson PO, Hasserius R, Besjakov J, Nyqvist F, Karlsson MK. Fractures of the radial head and neck treated with radial head excision. *J Bone Joint Surg Am*. 2004;86(9):1925–1930.
12. Ikeda M, Oka Y. Function after early radial head resection for fracture: a retrospective evaluation of 15 patients followed for 3-18 years. *Acta Orthop Scand*. 2000;71(2):191–194.
13. Harrington IJ, Tourntas AA. Replacement of the radial head in the treatment of unstable elbow fractures. *Injury*. 1981;12(5):405–412.
14. Birkedal JP, Deal DN, Ruch DS. Loss of flexion after radial head replacement. *J Shoulder Elbow Surg*. 2004;13(2):208–213.
15. Amis AA, Dowson D, Wright V, Miller JH. The derivation of elbow joint forces, and their relation to prosthesis design. *J Med Eng Technol*. 1979;3(5):229–234.
16. van Riet RP, Sanchez-Sotelo J, Morrey BF. Failure of metal radial head replacement. *J Bone Joint Surg Br*. 2010;92(5):661–667.
17. Burkhart KJ, Mattyasovszky SG, Runkel M, et al. Mid- to long-term results after bipolar radial head arthroplasty. *J Shoulder Elbow Surg*. 2010;19(7):965–972.
18. Giannicola G, Sacchetti FM, Antonietti G, Piccioli A, Postacchini R, Cinotti G. Radial head, radiocapitellar and total elbow arthroplasties: a review of recent literature. *Injury*. 2014;45(2):428–436.
19. van Riet RP, van Glabbeek F, Baumfeld JA, et al. The effect of the orientation of the radial head on the kinematics of the ulnohumeral

joint and force transmission through the radiocapitellar joint. *Clin Biomech*. 2006;21(6):554−559.

20. King GJ, Itoi E, Niebur GL, Morrey BF, An KN. Motion and laxity of the capitellocondylar total elbow prosthesis. *J Bone Joint Surg Am*. 1994;76(7):1000−1008.
21. Gupta GG, Lucas H, Hahn DL. Biomechanical and computer analysis of radial head prostheses. *J Shoulder Elbow Surg*. 1997;6(1):37−48.
22. Kaas L, Turkenburg JL, van Riet RP, Vroemen JP, Eygendaal D. Magnetic resonance imaging findings in 46 elbows with a radial head fracture. *Acta Orthop*. 2010;81(3):373−376.
23. Kaas L, van Riet RP, Turkenburg JL, Vroeman JP, van Dijk CN, Eygendaal D. Magnetic resonance imaging in radial head fractures: most associated injuries are not clinically relevant. *J Shoulder Elbow Surg*. 2011;20(8):1282−1288.