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Joint contact areas after radial head arthroplasty: a comparative study of 3 prostheses

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Background: Contact stresses of radial head prostheses remain a concern, potentially leading to early capitellar cartilage wear and erosion. In particular, point contact or edge loading could have a detrimental effect. The purpose of this study was to compare 3 different types of radial head prostheses in terms of joint contact areas with each other and with the native situation. The hypothesis was that the joint contact areas would be lower after monopolar arthroplasty.
Methods: Seven fresh-frozen cadaveric upper limbs were used. Radiocapitellar contact areas of a monopolar design, a straight-neck bipolar design, and an angled-neck bipolar design were compared with each other and with the native joint. After standardized preparation, polysiloxane was injected into the loaded radiocapitellar joint to create a cast from which the joint contact area was measured. Measurements were performed at 3 angles of elbow flexion and in 3 different forearm positions.
Results: In the native elbow, contact areas were highest in supination. Elbow flexion had no significant effect on native and prosthetic joint contact areas. Contact areas were decreased for all types of arthroplasties compared with the native joint (from 11% to 53%). No significant contact area difference was found between the 3 designs. However, bipolar prostheses showed lateral subluxation in neutral forearm rotation, resulting in a significant decrease in the contact areas from pronation to the neutral position.
Conclusions: All types of radial head prostheses tested showed a significant decrease in radiocapitellar contact area compared with the native joint. Bipolar designs led to subluxation of the radial head, further decreasing radiocapitellar contact.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Elbow; arthroplasty; prosthesis; radial head; cadaveric study; radiocapitellar contact area

Institutional review board approval was not required for the basic science study.

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The use of a radial head arthroplasty is advocated in an unstable post-traumatic elbow associated with a radial head fracture that cannot undergo reconstruction.[21] Two main categories are available: monopolar and bipolar prostheses.[7] Most monopolar implants have a modularity to account for the variety in radial head and neck sizes.[14] The vast majority of radial head components have a round design, with only 1 anatomic design available.[1,15,24] Bipolar prostheses are modular by definition, but different design properties are available. There are variations in the angle of bipolarity and in the angle of the neck of the prosthesis, relative to the shaft, both developed to improve the orientation of the radial head component to the capitellum.[10]

Most radial head fractures occur in relatively young and active patients, the mean age being 43 to 46 years depending on the study, with the peak incidence in the male population occurring at a younger age than in the female population.[11,12,27,28] The choice of implant must then be made carefully to achieve a long-term functional result.[16] Despite a plethora of clinical outcome studies, no design has shown clinical superiority.[2,6,13] In general, short-term and midterm clinical outcomes are mostly good but long-term results are still poorly documented.[3,8] Some biomechanical studies have suggested less joint stability after the use of bipolar prostheses[5,18] with increased elbow valgus laxity.[20] On the other hand, bipolar models offer an adaptability that allows better radiocapitellar orientation.[32]

Both joint congruency and stability are likely to influence the longevity of radial head arthroplasty because of their consequences on radial head tracking, bone-implant interface stresses, and joint contact areas.[18,20,32] Decreased radiocapitellar joint contact areas will increase peak contact stresses and may lead to early capitellar cartilage wear with pain and stiffness.[29,31] In an in vitro study, Liew et al[17] showed a decrease in joint contact areas by two-thirds with the use of a monopolar modular prosthesis. Improved contact areas were reported in a cadaveric study with a more physiological design with the use of a bipolar prosthesis.[19]

The aim of this study was to compare the joint contact areas of 3 different types of radial head prostheses with each other and with the native radiocapitellar joint contact areas in different positions of elbow flexion and forearm rotation. We hypothesized that the joint contact areas would be decreased for all types of prostheses and would be further decreased after monopolar arthroplasty.

Materials and methods

We used 7 fresh-frozen cadaveric upper extremities (3 paired). After thawing for 24 hours at room temperature, each specimen was clinically tested to define whether elbow stability and range of motion were within the normal range. Each specimen was prepared using a standardized method. The hand was disarticulated at the level of the wrist to set up a forearm rotation control device that was fixed to the ulnar head and distal radial joint surface. This device allowed the forearm to be reproducibly positioned at 80° of pronation, neutral rotation, and 80° of supination. Neutral forearm rotation was defined as the position in which the radial styloid and ulnar styloid were on a vertical line. The arm was then further prepared. The skin was removed up to the proximal quarter of the forearm. The biceps, brachialis, and triceps tendons were identified and preserved without any muscular tissue. The brachioradialis muscle was removed and an anterolateral capsulectomy was performed to allow for anterolateral access to the radiocapitellar joint while the annular ligament, lateral collateral ligament complex, and extensor tendon origin were preserved. Each upper limb was fixed to a setup device, and rigid sutures were tied to the 3 tendons to apply a static load along the anatomic axes of each of the 3 muscles: 25 N on the biceps, 25 N on the brachialis, and 50 N on the triceps tendons (Fig. 1).

Three prostheses were tested: a monopolar prosthesis (rHead; Small Bone Innovations [SBI], Morrisville, PA, USA), a straight-neck bipolar prosthesis (rHead Recon; SBI), and an angled-neck bipolar prosthesis (Judet with floating radial head; Tornier, Edina, MN, USA) (Fig. 2). All these implants are axisymmetrical head prostheses. To achieve comparison, only 1 head diameter was used for each prosthesis (Table I). The radius was prepared and the

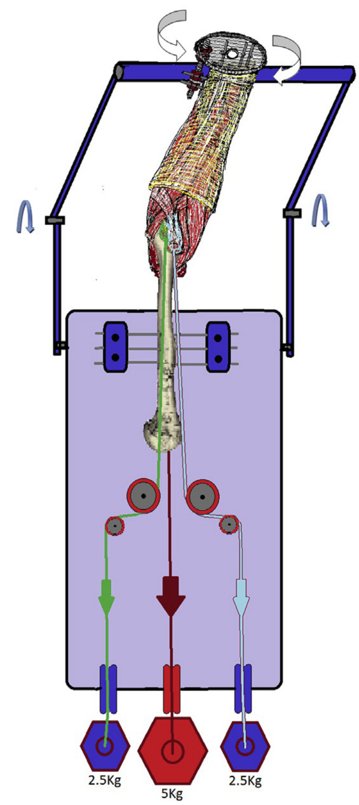

Figure 1 Illustration of experimental setup. The biceps ( ) and brachialis ( ) were loaded with 2.5 kg, and the triceps ( ) was loaded with a 5-kg weight. The setup device allowed control of the elbow flexion angle in 3 positions (30°, 60°, and 90°) ( ). It should be noted that the rotation control device was fixed at the distal extremity of the forearm and allowed us to define the neutral position, 80° of pronation, or 80° of supination ( ).

Figure 2 Prostheses assessed: Judet bipolar prosthesis (*left*), rHead Recon bipolar prosthesis (*middle*), and rHead monopolar prosthesis (*right*).

prosthesis implanted as described using each implant's surgical technique. Because the combined head and neck height in SBI implants is lower than that in the Judet prosthesis, less bony resection was needed for SBI implants. Therefore, these 2 prostheses were assessed first. A further 4.1 mm of the radial neck was then resected to accommodate the Judet bipolar implant, and its contact areas were tested last in all 3 elbow flexion angles and rotational positions.

The elbow and forearm were fixed in each selected position; the tendons were loaded; and a molding of the joint was performed using polysiloxane (Xantopren; Kulzer GmbH, Hanau, Germany) injected in and around the radiocapitellar joint, through the anterolateral window (Fig. 3). After hardening, each polysiloxane cast was gently removed via the anterolateral capsulectomy and photographed on a calibrated grid. The surfaces were measured using the UTHSCSA (University of Texas Health Science Center San Antonio) Image Tool computer software (version 3.0). Measurements were performed at 3 positions of elbow flexion (30°, 60°, and 90°) in 80° of pronation, in neutral rotation, and in 80° of supination successively in the native radial head, monopolar prosthesis, straight-neck bipolar prosthesis, and Judet bipolar prosthesis conditions.

After resection of the native radial heads, a polysiloxane molding of the proximal surface of each head was obtained, and using the same method described earlier, each radial head cross-sectional area was measured to express the results of the joint contact areas as a function of the corresponding proximal radial head surface and to normalize the measurements. In addition, using a handheld caliper (accuracy, 0.1 mm), the long and short diameters of the radial heads, as well as the head and neck heights, were measured to assess potential lengthening or shortening after each prosthesis implantation.[30]

The reproducibility of these measurements has already been assessed and published in our previous study.[19] All data were collected using Excel software (Microsoft, Redmond, WA, USA). A 3-way repeated-measures analysis of variance followed by a post hoc LSD (least significant difference) test was perform for statistical analysis using Statistica software (TIBCO Software Inc., Palo Alto, CA, USA). Factors considered were elbow flexion angle, forearm rotation, and prosthetic replacement. $P < .05$ was considered significant.

Results

Radial head biometry

The mean radial head long and short diameters were 24.2 ± 2.1 mm (range, 21.3-26.6 mm) and 22.9 ± 1.9 mm (range, 20.3-24.5 mm), respectively. The mean radial head cross-sectional area was 442 ± 47 mm^2 (range, 368-494 mm^2), whereas the prosthetic head cross-sectional areas were 346 mm^2 for both SBI implants and 380 mm^2 for the Judet prosthesis. All prostheses were implanted within the acceptable variation of less than 2 mm of lengthening or shortening[26] (Fig. 4).

Joint contact areas

Among the 252 castings assessed, the largest joint contact area was 167.7 mm^2, which occurred in the native radial head condition at 80° of forearm pronation and 30° of elbow flexion. The smallest contact area was 11.3 mm^2, which occurred in the Judet condition at 90° of elbow flexion and in neutral forearm rotation. After radial head prosthesis implantation, the joint contact areas were

Table I Summary of design features of prostheses assessed

	SBI monopolar prosthesis	SBI bipolar prosthesis	Judet prosthesis
Head shape	Axisymmetrical	Axisymmetrical	Axisymmetrical
Head dish depth, mm	1	1	1
Head diameter, mm	21	21	22
Head height, mm	10.2	10.2	14.7
Neck orientation	Straight	Straight	Angled by 15°
Collar height, mm	6	6	Not applicable
Combined head and neck length, mm	18.4	18.4	22.5
Stem length, mm	16	16	55
Stem diameter, mm	6.4	6.4	6.5
Stem implantation	Press fit	Press fit	Cemented

All the prostheses are axisymmetrical; however, the head diameters differ by 1 mm between the SBI (Small Bone Innovations) implants and the Judet prosthesis, although the dish depths are the same. Because the combined head and neck lengths differ by 4.1 mm between the SBI prostheses and the Judet prosthesis, the SBI implants were assessed first; then, a 4.1-mm-long resection was performed before the implantation of the Judet prosthesis.

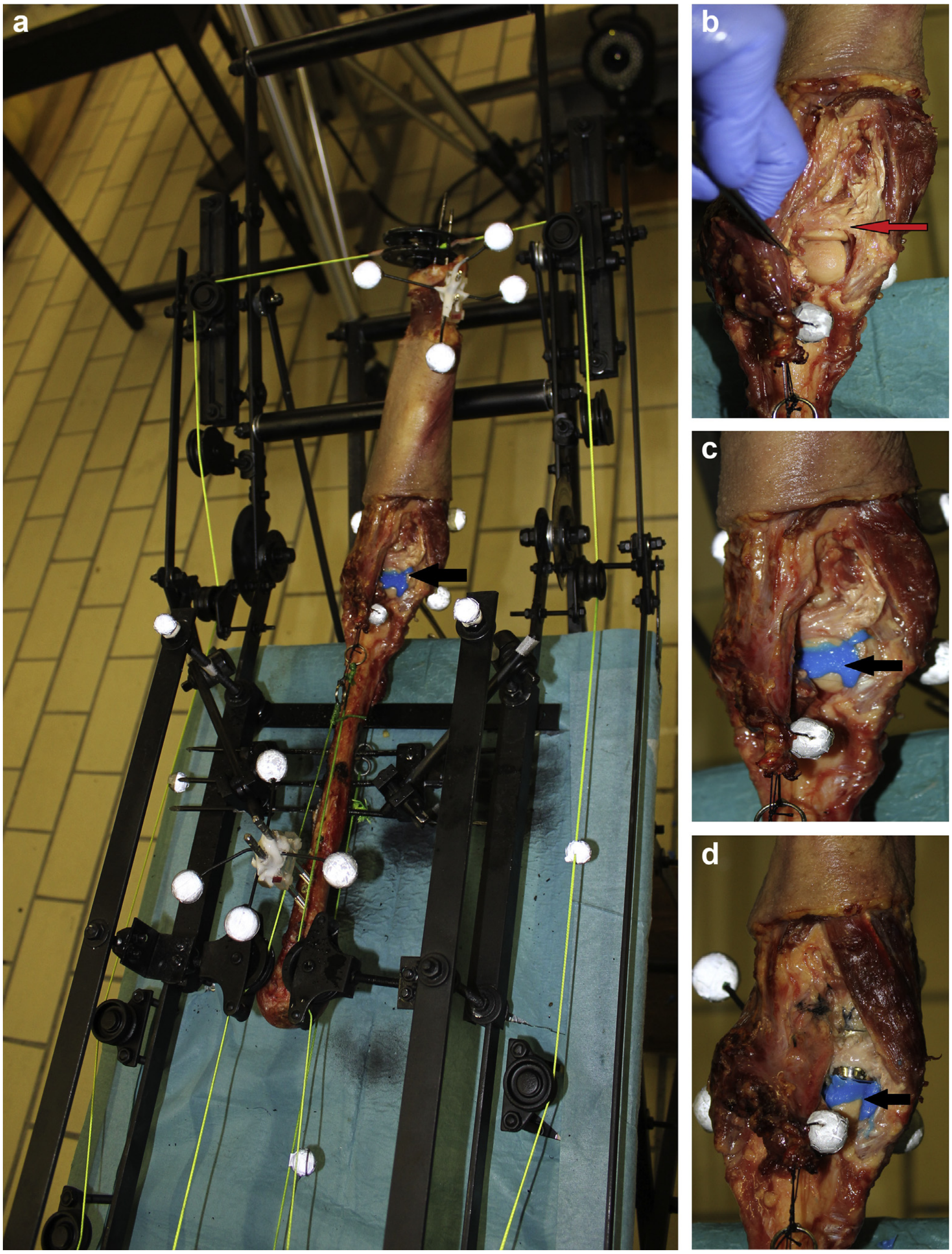

Figure 3 Setup device and specimen after polysiloxane (*blue*) application (**a**) via an anterolateral partial capsulectomy preserving the annular ligament (**b**). Right elbow after application of polysiloxane in the native joint (**c**) and after use of a bipolar prosthesis (**d**). The annular ligament preservation (→) and the polysiloxane mold in place (→) should be noted.

significantly lower than in the native joint ($P < .001$), with a minimal decrease of 11% and maximal decrease of 53% (Fig. 5). No significant differences were found between any of the prostheses in terms of joint contact areas. The elbow flexion angle had no significant influence on the joint contact areas.

In the native condition, the joint contact areas increased from the neutral position to supination ($P < .001$) and from the neutral position to pronation ($P = .002$) and decreased from supination to pronation ($P = .029$). The Judet prosthesis showed the opposite trend, with an increasing joint contact area from supination to pronation ($P = .01$) and the joint contact areas in the neutral position being significantly lower than those in pronation ($P = .001$). As an anatomic observation, lateral subluxation of the Judet prosthesis was found in the neutral position. In the straight-neck bipolar group, the joint contact areas significantly decreased only from pronation to the neutral position ($P = .036$), again with lateral subluxation of the prosthesis in neutral forearm rotation. No significant

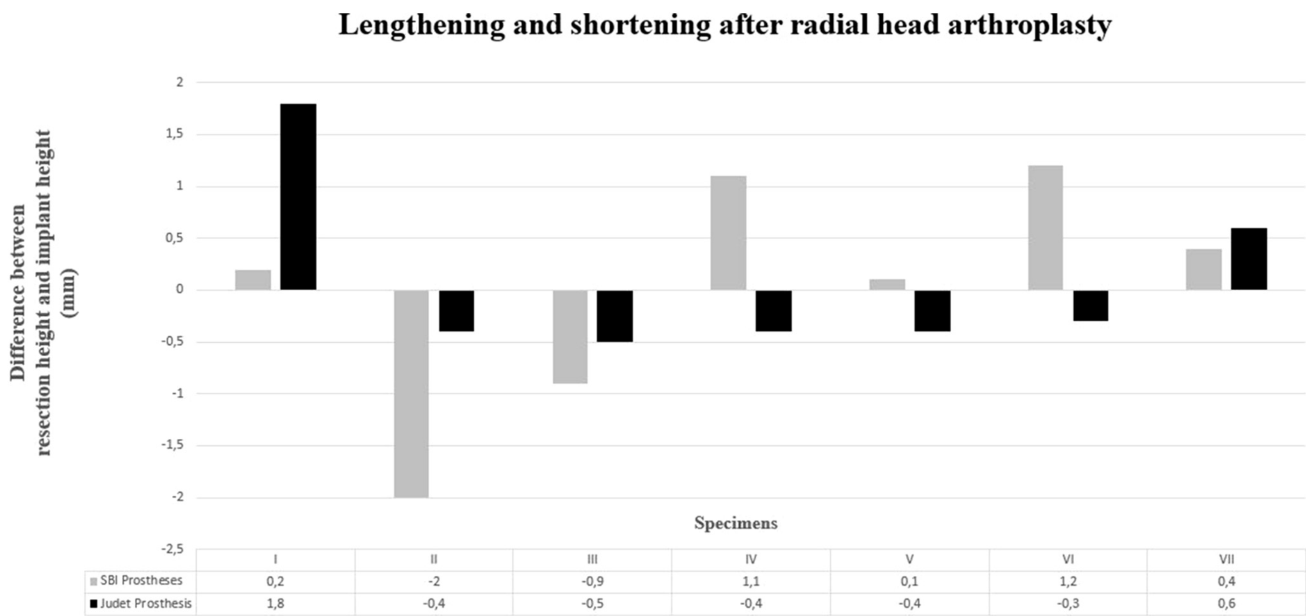

Figure 4 Summary of lengthening and shortening after different radial head arthroplasties. For each specimen, the difference between the combined prosthetic head and neck height and the height of the resected bone was defined. Positive and negative values represent lengthening and shortening, respectively. *Gray columns* represent SBI (Small Bone Innovations) prostheses, and *black columns* represent the Judet prosthesis. The combined head and neck height of the SBI prostheses is the same.

influence of forearm rotation was found when the monopolar prosthesis was used ($P > .7$). Figure 6 summarizes these findings. Besides the main contact area, an additional joint contact was found in 29 castings (11.5%): 16 in supination, 7 in pronation, and 6 in the neutral position (Fig. 7). This additional contact was observed in 6 native heads, 7 SBI monopolar prostheses, 10 SBI bipolar prostheses, and 6 Judet prostheses. The mean area of this additional joint contact was 10.8 ± 6.3 mm^2 (range, 2.5-28.7 mm^2).

We obtained all the aforementioned results by taking into account this additional contact while measuring the joint contact areas. When this additional contact was not taken into account, statistical analysis (post hoc LSD [least

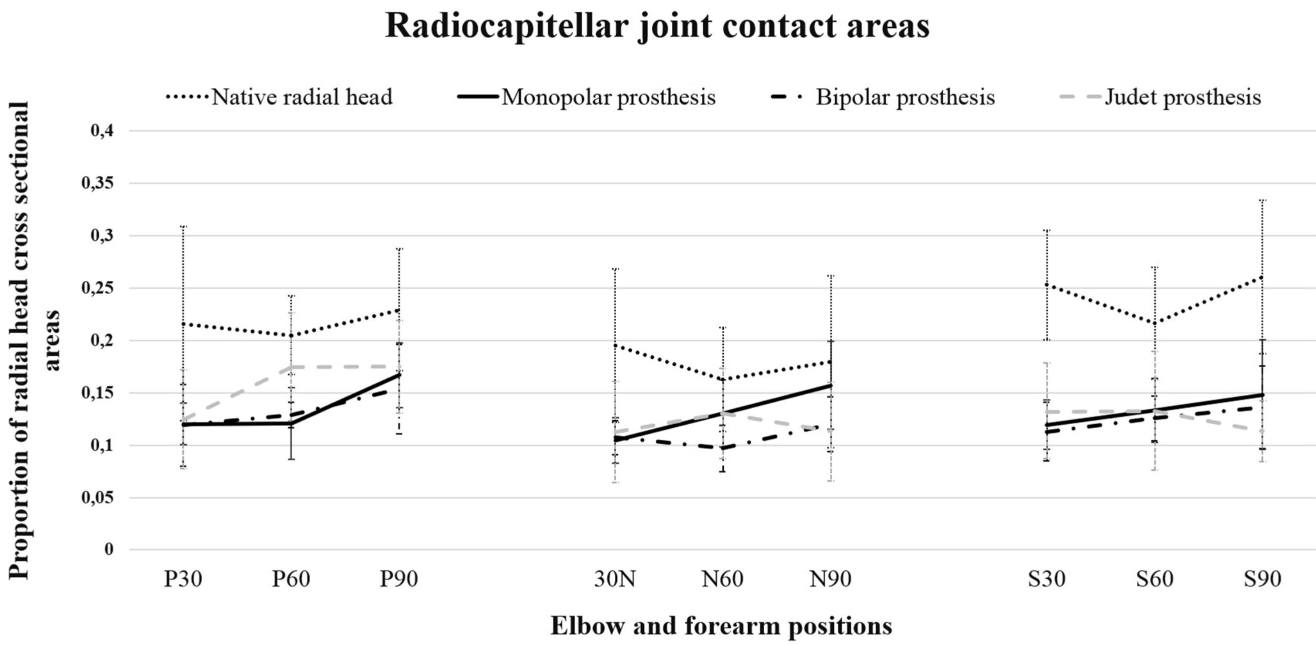

Figure 5 Joint contact areas expressed as a proportion of the radial head cross-sectional area (mean and standard deviation) as a function of the elbow position (30° of elbow flexion [*30*], 60° of elbow flexion [*60*], and 90° of elbow flexion [*90*]) and forearm rotation (pronation [*P*], neutral position [*N*], and supination [*S*]).

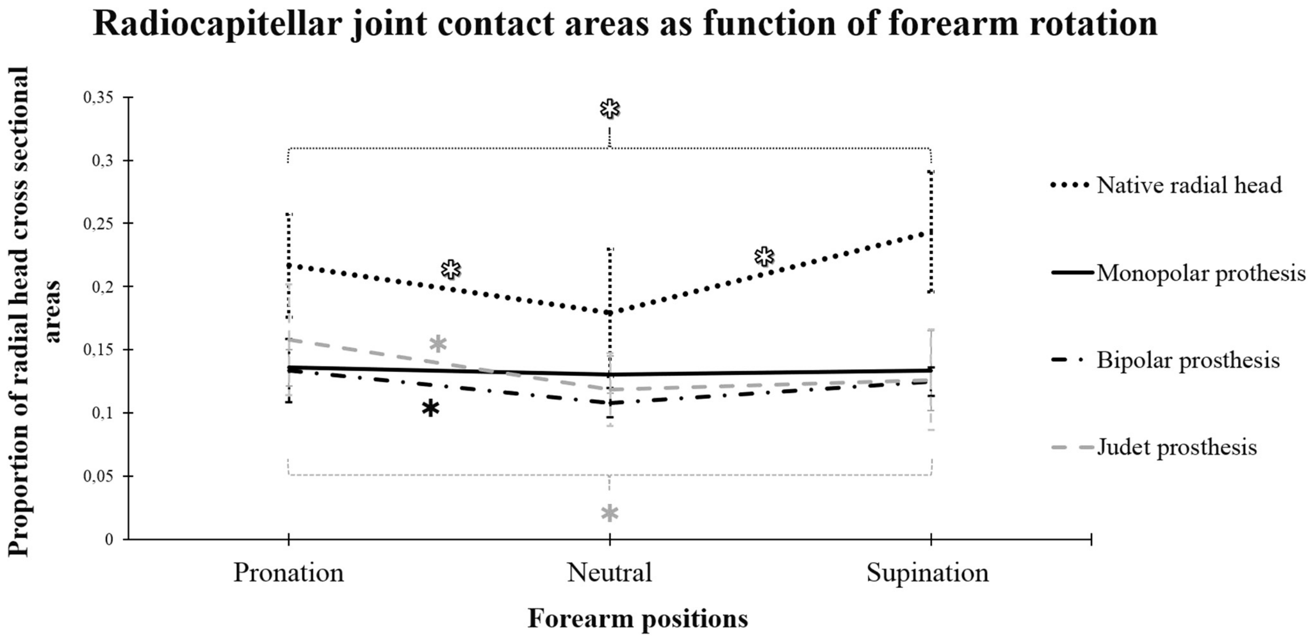

Figure 6 Joint contact areas expressed as a proportion of the radial head cross-sectional area (mean and standard deviation) without elbow flexion being taken into account. In the native condition, the joint contact areas were greater than after arthroplasties in all forearm positions. The joint contact areas in the neutral position were smaller than those in pronation, and both of these were smaller than the joint contact areas in supination. After use of the Judet prosthesis, the joint contact areas were higher in pronation than in the neutral position and supination. After use of the straight-neck bipolar prosthesis, the joint contact areas were higher in pronation than in the neutral position. * indicates 2 forearm rotations with significantly different joint contact areas ($P < .05$) in the native joint (❃), after use of the straight-neck bipolar prosthesis (✱), and after use of the Judet bipolar prosthesis (✱).

significant difference] test) showed that the overall effect of supination on joint contact areas was not significant anymore compared with pronation ($P = .075$) and the neutral position ($P > .4$).

Discussion

This study shows that there is a joint contact decrease after radial head arthroplasty. However, we observed that this decrease never exceeded 53% after radial head arthroplasty and that there was no difference between monopolar and bipolar designs.

In a cadaveric model, a two-thirds decrease in radiocapitellar joint contact area was reported by Liew et al[17] using an intentionally loose monopolar radial head prosthesis (Evolve; Wright Medical Technology, Orlando, FL, USA). In a previous in vitro study, we found a decrease in joint contact areas of less than 50% after implanting the Judet bipolar arthroplasty.[19] A true comparison of these 2 studies is not possible because of their different study designs. In the present study, 3 different types of prostheses were compared, using a more physiological model (with the ligaments being respected and constraints being applied by physiological loading of the tendons).

Sahu et al[22] showed a significant increase in contact pressures during simulated subluxation for the native radial head and an anatomic radial head design. Although an increase was also found in the bipolar design, it was small and not significant.[22] In our previous study using the Judet bipolar implant, lateral subluxation of the prosthetic head was observed in the neutral position but was not quantified.[19] It was believed to be related to the 15° angulation of the neck, which is not anatomic.[30] In comparison with the Judet prosthesis, the SBI bipolar implant has a straight neck; however, the present study confirmed this lateral subluxation in both types of bipolar radial head designs, resulting in a significant decrease in contact area. These observations suggest that the angulated neck of the Judet prosthesis is probably not the main determining factor responsible for this lateral subluxation. In an in vitro study, Pomianowski et al[20] have reported increased elbow valgus laxity in the neutral forearm position with the Judet bipolar prosthesis. Other studies have tested radiocapitellar stability after radial head arthroplasty comparing monopolar and bipolar designs and have shown greater radiocapitellar instability with bipolar designs.[5,18] Sahu et al[23] compared joint contact areas and pressures after placement of monopolar anatomic, monopolar circular, and bipolar designs of radial head prostheses. They observed a decrease in joint contact areas associated with an increase in joint contact pressure after prosthetic implantation. They found a significant difference between circular (monopolar and bipolar) designs and the anatomic design, with the anatomic design more closely approaching the native condition. The Judet implant head diameter was 1 mm larger than that of the other implants used in our study, but the radial depth of the articulating dish was 1 mm for every tested prosthesis. No significant joint contact difference was found between the prostheses. This contrasts with the findings of Liew et al,[17] who observed that smaller implants had better contact because of their lower radius of curvature.

We noted an additional contact between the radial head and the humerus. Anatomically, this contact corresponded to the ''zona conoidea'' of the humerus described by Jeon et al[9] (Fig. 7). This finding highlights the fact that the radiocapitellar contact is not the only contact between the radius and humerus. This ''radio-conoideal'' contact is an additional contact between the 2 bones. Our results showed that this individual contact is not constant. It was most frequently found in supination. When these additional contacts were not taken into account, supinating the forearm no longer had a significant effect on the joint contact areas. This finding highlights the importance of this radio-conoideal joint in axial force transmission from the forearm to the arm in supination. Captier et al[4] described this contact as a function of the forearm position and of the radial head shape. They found this contact in neutral rotation. Jeon et al reported a greater radio-conoideal contact in supination on radiologic assessment and found increased cartilage wear on this zona conoidea and the bevel part of radial heads in cadavers. We found this contact in both the native and radial head replacement conditions. In an in vitro study, Bachman et al[1] similarly observed this additional contact after anatomic and circular radial head arthroplasties. They described this articulation as being between the prosthesis and the lateral ridge of the trochlea and its adjacent sulcus. They reported that this contact was more frequently observed after anatomic than after circular prosthesis implantation. This contact was described in

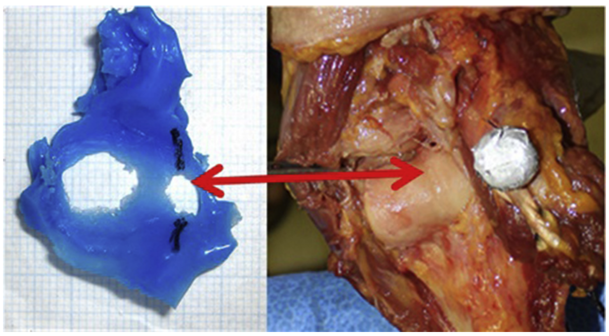

Figure 7 Polysiloxane cast on calibrated grid (*left*) and anatomic elbow after partial anterior capsulectomy (*right*). The contact area is the area devoid of molding material. One should note the second smaller joint contact located at the part of the molding corresponding to the contact between the radial head bevel and the humeral zona conoidea (*arrow*).

neutral forearm rotation and elbow extension; however, they did not assess other forearm or elbow positions.

In our current study, we did not find a significant effect of elbow flexion on joint contact areas. This contradicts the findings of our previous study, in which we found a decreased contact area in 90° of flexion.[19] This can probably be explained by the fact that, in the present study, the lateral collateral ligament complex including the annular ligament was fully preserved, improving the radiocapitellar orientation in all flexion angles.

This study has some limitations. The low number of specimens impacts the statistical power. The polysiloxane that was used to quantify joint contact areas does not give the exact joint contact areas. Performing measurements on the photographed moldings gives values of a flat projection from a curved surface. This introduces some underestimation of the joint contact. This consideration may be balanced by the finding of Stormont et al[25] who observed that silicone has a trend to overestimate the joint contact because of the formation of a meniscus around the contact edges.

Conclusion

Our study confirms that the joint contact areas are significantly decreased when the radial head is replaced by an implant and points to some forearm positions at which the contact is lower after use of a bipolar design. This is likely due to the radiocapitellar instability induced by these implants. Joint contact area preservation is not an argument to use a bipolar design instead of a monopolar design.

This study also highlights that the radiocapitellar joint is the principal but not the only joint contact between the humerus and the radius: There is a second contact—the radio-conoideal contact—that is mainly present in supination and seems to be the position of the best radiohumeral stability.

Disclaimer

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