Radial Head Reconstruction in Elbow Fracture-Dislocation

Monopolar or Bipolar Prosthesis?

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Abstract

Background Monopolar and bipolar radial head prosthetic arthroplasties have been used successfully to treat elbow fracture-dislocation with unsalvageable radial head fractures. The relative stability of these two designs in different clinical situations is a topic of ongoing investigation.

Questions/purposes We tested the effects of monopolar and bipolar fixed-neck prosthetic radial head implants on improvement in elbow coronal and axial plane laxity in a terrible triad biomechanical model that accounted for

lateral collateral ligament integrity and the presence of a transverse coronoid fracture.

Methods Kinematic data were collected on six fresh-frozen cadaveric upper extremities tested with passive motion throughout the flexion arc. Varus and valgus gravity stress were applied with the wrist in neutral position. A lateral collateral ligament reconstruction was simulated. We assessed instability after radial head resection and reconstruction with either a monopolar or bipolar implant in the presence of a transversely fractured (Regan and Morrey Type 2) or fixed coronoid process.

Results With collateral ligament integrity, no difference was detected, with the numbers available, in valgus laxity between implants under valgus stress ($p = 1.0$). Laxity improvement with each prosthesis was higher when the coronoid was fractured (mean $\pm$ SD: monopolar: $7.4^\circ \pm 1.6^\circ$, $p < 0.001$; bipolar: $6.4^\circ \pm 1.6^\circ$, $p = 0.003$) than when it was fixed (monopolar: $4.0^\circ \pm 1.6^\circ$, $p = 0.02$; bipolar: $4.2^\circ \pm 1.6^\circ$, $p = 0.01$). With the numbers available, there was no difference in external rotation laxity between implants under valgus stress ($p = 1.0$). The greatest stabilizing effect of the prostheses occurred when the coronoid was fractured (monopolar: $3.3^\circ \pm 1.2^\circ$, $p = 0.15$; bipolar: $3.3^\circ \pm 1.2^\circ$, $p = 0.17$). Radial head arthroplasty offered no substantial stability under varus stress for varus or internal rotation laxity.

Conclusions In our terrible triad cadaveric model, coronoid fixation was effective in improving varus laxity with a monopolar or bipolar prosthesis in place. Also, both types of prostheses were effective in improving valgus and external rotation laxity to the elbow, regardless of coronoid status. With collateral ligaments reconstructed, no large kinematic differences were noted between implants regardless of the varus-valgus position or whether the coronoid was fractured or fixed.

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Clinical Relevance The data from our cadaveric model support the use of either implant type in terrible triad injuries if the collateral ligaments are intact or reconstructed.

Introduction

In the setting of elbow fracture-dislocation, radial head arthroplasty is indicated when it cannot be reliably fixed. The relative value of metallic monopolar versus bipolar fixed-neck prostheses is a topic of ongoing discussion. Both designs have demonstrated acceptable clinical outcomes when used in the setting of elbow fracture-dislocation [2, 6, 7, 10, 15, 19]. Bipolar prosthetic implants have been recommended to improve capitellar tracking, increase radiocapitellar contact areas, and decrease joint contact pressures, especially in a setting in which the proximal radius does not align well with the capitellum [12, 14]. However, several problems specific to bipolar implants have been noted, such as dissociation [9], medial maltracking [12], and polyethylene-induced osteolysis [15].

Biomechanically, the effect on elbow stability of a bipolar versus monopolar prosthetic arthroplasty is somewhat controversial. Yian et al. [18] demonstrated that a bipolar implant resulted in large and significant improvements in radiocapitellar subluxation with only nonsignificant decreases in ulnohumeral laxity compared with monopolar implants in a terrible triad model. Conversely, both Schneeberger et al. [16] and Pomianowski et al. [14] demonstrated significant improvements in ulnohumeral laxity with a monopolar implant compared with a bipolar implant in terrible triad models. The bipolar implant has been demonstrated to provide less stability in an elbow with no ligamentous structures [4, 11]. The specific dependence and influence of the lateral collateral ligament has been shown to be more critical with a bipolar implant design [5].

The single most important clinical question is the relative value in restoration of elbow stability of the two prosthetic designs in the setting of a terrible triad injury after the collateral ligaments are repaired or reconstruction and after accounting for the status of the coronoid process. To our knowledge, this specific question has not been subjected to experimental analysis. Therefore, we evaluated the stabilizing effects of these two fixed-neck radial head designs under gravity valgus and varus loading conditions in a terrible triad model in which a 50% transverse coronoid fracture was present or had been fixed and the lateral ligaments were restored.

Materials and Methods

The kinematic pattern of the elbow was recorded and analyzed in the manner described in the first part of this study [8]. The detailed protocol is described in that work. To

summarize, (1) six cadaver specimens underwent simulated terrible triad injuries with a transverse fracture involving 50% of the coronoid, lateral collateral release, and resection of the radial head. (2) Standard Cartesian coordinate systems for the humerus and ulna were defined by the digitization of anatomic landmarks [8, 17]. Euler rotations were used to define ulnohumeral flexion-extension angle (first Euler rotation), varus-valgus angle (second Euler rotation), and internal-external rotation angle (third Euler rotation). Kinematic patterns of instability were measured under varus and valgus gravity stress through the flexion-extension arc with passive muscle forces applied to the biceps, brachialis, and triceps. The elbow was moved passively by hand by a single investigator (MLP) from full extension to full flexion with the forearm maintained in neutral pronation-supination position by holding the specimen gently at the wrist. (3) The specimens were then stabilized by 3.5-mm lag screw fixation of the coronoid and restoration of lateral collateral ligament integrity via fixation of the lateral epicondylar osteotomy, as previously described [8]. The effectiveness of these methods to restore stability of the elbow was documented [8]. (4) The effect on kinematic elbow stability of radial head arthroplasty was assessed utilizing a fixed-neck bipolar rHeadTM implant (Small Bone Innovations, Inc, Morrisville, PA, USA) and conversion of this device into a monopolar design.

The methodology for ligament release was osteotomy of the humeral origin of the lateral ligament attachment. Repair was achieved by two 3.5-mm lag screw fixation of the osteotomy from lateral to medial in the distal humerus.

The radial head arthroplasty consisted of first cementing the modular bipolar stem in place. A bipolar articulation was then inserted and the kinematic pattern defined. A monopolar implant was created by placing a circumferential wire around the neck of the bipolar device and tightening it in a way to remove all visual evidence of motion (Fig. 1). Proper angular alignment and implant length [1] were determined and confirmed by visual and fluoroscopic radiographic inspection (Fig. 2). Thus, the elbow was able to be tested as a monopolar or bipolar [4, 5] device without changing implant stems.

The testing protocol described in the first part of this study [8] was repeated and generated 12 test configurations: two coronoid conditions (fractured, fixed), three radial head conditions (absent, monopolar arthroplasty, bipolar arthroplasty), and two loading conditions (varus gravity, valgus gravity).

The kinematic methods were also described in detail in the first part of this study [8], with varus, valgus, internal, and external rotation laxity being defined using standard coordinate systems [15] and with the experimental condition compared to the intact state for each elbow [8].

As in the first part of this study [8] and as observed by other investigators [13], the greatest laxity occurred with the

Fig. 1 The bipolar implant may be converted to a monopolar prosthesis by eliminating the motion at the articulation.

Fig. 2 Visual and fluoroscopic inspection of the ulnohumeral joint resulted in accurate implant placement, as demonstrated by final complete dissection of each specimen at the conclusion of the experimental protocol.

elbow in the midflexion range, around 60°. This was the position at which the instability data were gathered and analyzed. A two-way repeated-measures ANOVA model with Tukey post hoc multiple comparisons was utilized with coronoid (two conditions) and radial head status (three conditions) as the main effects for six specimens (36 observations per model). Significance was defined as a likelihood of differences occurring by chance of less than 5%. A post hoc power analysis (G*Power; Universität Kiel, Kiel, Germany) performed using the repeated-measures ANOVA inputs as above and with an α of 0.05 demonstrated low power, 0.3 ($\beta = 0.7$), to detect a small effect size for this model (Cohen's $d = 0.2$).

Results

Valgus Gravity Stress Models

As reported in the first part of this study [8], coronoid fixation improved valgus laxity (mean $\pm$ SD: $1.7^\circ \pm 0.8^\circ$, $p = 0.04$), but radial head resection had a larger overall effect in increasing valgus laxity ($5.7^\circ \pm 1.1^\circ$, $p < 0.001$). In the current analysis, both monopolar ($5.7^\circ \pm 1.1^\circ$, $p = 0.002$) and bipolar ($5.3^\circ \pm 1.1^\circ$, $p < 0.001$) radial head arthroplasty improved valgus laxity (Fig. 3). In the post hoc analysis, the improvement in valgus stability was greater with the coronoid fractured (monopolar: $7.4^\circ \pm 1.6^\circ$, $p < 0.001$; bipolar: $6.4^\circ \pm 1.6^\circ$, $p = 0.003$) than with it fixed (monopolar: $4.0^\circ \pm 1.6^\circ$, $p = 0.02$; bipolar: $4.2^\circ \pm 1.6^\circ$, $p = 0.01$). Only very small differences were noted between monopolar and bipolar prostheses in either valgus testing configuration (coronoid fractured: 1.0° ; coronoid fixed: 0.2° ; both $p = 1.0$).

We previously reported [8] that coronoid fixation improved external rotation laxity under valgus loading conditions ($1.3^\circ \pm 0.6^\circ$, $p = 0.04$) and that radial head status was a significant main effect in our ANOVA model ($p = 0.02$). We also reported the increase in external rotation laxity caused by radial head resection ($2.1^\circ \pm 0.9^\circ$, $p = 0.08$). In the current post hoc analysis, radial head arthroplasty again resulted in greater improvements in external rotation laxity with the coronoid fractured (monopolar: $3.3^\circ \pm 1.2^\circ$, $p = 0.15$; bipolar: $3.3^\circ \pm 1.2^\circ$, $p = 0.17$) than with the coronoid fixed (monopolar: $1.0^\circ \pm 1.2^\circ$, $p = 1.0$; bipolar: $2.0^\circ \pm 1.2^\circ$, $p = 0.7$) (Fig. 4). Only very small differences were found between monopolar and bipolar heads for improvement in external rotation laxity for either status of the coronoid (coronoid fractured: 0.1° ; coronoid fixed: 1.0° ; both $p = 1.0$).

Varus Gravity Stress Models

As reported in the first part of this study [8], coronoid status plays the dominant role in affecting varus and internal rotation laxity of the elbow under varus gravity stress. This effect was again demonstrated in the current post hoc analysis, where coronoid fixation improved varus laxity with either monopolar ($4.7^\circ \pm 1.2^\circ$, $p = 0.01$) or bipolar ($4.6^\circ \pm 1.2^\circ$, $p = 0.01$) radial head arthroplasty (Fig. 5). Likewise, coronoid fixation improved internal rotation laxity with either monopolar ($3.9^\circ \pm 1.3^\circ$, $p = 0.07$) or bipolar ($4.1^\circ \pm 1.3^\circ$, $p = 0.05$) radial head arthroplasty (Fig. 6). Status of the radial head was not a significant main effect for varus or internal rotation laxity in the varus gravity stress ANOVA model ($p = 0.35$ and 0.42 , respectively). Finally, under varus stress, only very small kinematic differences were noted between monopolar and bipolar prostheses for

Fig. 3 Valgus ulnohumeral laxity is improved with use of either a monopolar or bipolar prosthesis.

Fig. 4 External rotation ulnohumeral laxity is improved with radial head arthroplasty. Only very small differences were seen between monopolar and bipolar implants.

any condition of the elbow (varus laxity: 0.7° , $p = 0.9$; internal rotation laxity: 0.5° , $p = 0.9$).

Discussion

Relative advantages and disadvantages exist for monopolar and bipolar prosthetic reconstruction in the setting of

unsalvageable radial head fractures associated with terrible triad injuries. Of principle concern is the ability of the bipolar implant to maintain joint stability sufficient for early active elbow motion, as the benefits of the implant are irrelevant if this criterion is not met. To date, no biomechanical model of the terrible triad injury has conclusively demonstrated the superiority of either design. We therefore evaluated the stabilizing effects of these two fixed-neck

Fig. 5 The dominant effect of coronoid fracture fixation on varus laxity is demonstrated, with little effect seen for radial head prosthetic implant.

Fig. 6 The effect of coronoid fracture fixation is seen by comparing solid with dashed lines. Little effect is seen on internal rotation laxity with either radial head prosthesis.

radial head designs under gravity valgus and varus loading conditions in a terrible triad model in which a 50% transverse coronoid fracture was present or had been fixed and the lateral ligaments were restored.

We note several limitations to this model, in addition to those described in the first part of this study [8]. First, only one well-fixed neck implant design was tested. These

results may not be applicable to other bipolar [2, 3] or smooth-stemmed [10] radial head prostheses. Second, the lateral soft tissue injury and reconstruction performed in this study were performed via lateral epicondyle osteotomy and lag screw fixation. The lateral ligaments are the primary varus stabilizer of the elbow, the integrity of which has been shown to affect the results of biomechanical

testing of radial head prostheses [5]. Hence, our results showing no kinematic differences between bipolar and monopolar implants may differ if the ligament restoration is not as robust as in the experimental model. In addition, we were only able to test one size and type of coronoid fracture and fixation. It is possible that a difference might be detected between the stabilizing effects of the two designs if unfixed coronoid fractures were greater than 50%. Another limitation is that the instability forces in our model were only applied by gravity and the applied passive muscle loading. It is likely that forces other than those applied in our model act on the elbow in vivo under normal physiologic rehabilitation after terrible triad fracture surgery. Lastly, the number of specimens in this study was small, and our results may be subject to Type II error, especially in light of the post hoc power analysis demonstrating our low power to detect a small effect size. On the other hand, it should be emphasized that the largest differences in joint angle between the monopolar and bipolar prostheses were around 1°, which would likely be clinically insignificant, even if they were found to be statistically significant with testing of a large number of specimens. Even with the small number of specimens, we were able to show numerous statistically significant differences between various conditions of the elbow, such as the improvement in laxity with coronoid fracture fixation and both types of radial head prosthetic reconstruction.

Recently, several studies have demonstrated that a bipolar radial head prosthesis provides substantially less resistance to posterior radiocapitellar joint subluxation than a monopolar prosthesis [4, 5, 10]. These studies were performed with deficient collateral ligaments. It should also be noted that our biomechanical model differed substantially from these studies in that we measured ulnohumeral joint kinematics, which we believe has greater clinical applicability in determining the stability of the surgically reconstructed elbow. We also observed values for valgus and external rotation angles smaller than those found by previous authors [16]. This difference may be explained by the use of applied valgus and supination forces versus gravity stress in our model. Furthermore, we kept the wrist in neutral rotation, which may have increased the stability of the joint compared with models that incorporated pronation or supination during testing [14].

With the numbers available, our model suggests that, in the setting of adequate lateral ligament reconstruction and intact medial collateral ligaments, radial head arthroplasty with either a monopolar or bipolar prosthesis improves coronal plane and axial rotational stability of the elbow. This is consistent with the results of Yian et al. [18]. Furthermore, bipolar reconstruction was not more unstable in the setting of coronoid fracture (approximately 50%) or coronoid fracture fixation in our model. We believe this study

represents the most clinically relevant biomechanical model reported to date, since the implant was tested in the setting of collateral ligament repair/reconstruction and with or without coronoid fixation. Further clinical and biomechanical studies would be required to determine whether our findings are design-specific. Nonetheless, our results support the continued use of both monopolar and bipolar radial head arthroplasties to treat the unsalvageable radial head fracture in the terrible triad injury with characteristics simulated in this study. In the era of cost containment, without specific information to the contrary, our data do not support the use of the more expensive implant design philosophies for the clinical circumstances simulated in this study.

References

1. Athwal GS, Frank SG, Grewal R, Faber KJ, Johnson J, King GJ. Determination of correct implant size in radial head arthroplasty to avoid overlengthening: surgical technique. *J Bone Joint Surg Am.* 2010;92(suppl 1, pt 2):250–257.
2. Berschback JC, Lynch TS, Kalainov DM, Wysocki RW, Merk BR, Cohen MS. Clinical and radiographic comparisons of two different radial head implant designs. *J Shoulder Elbow Surg.* 2013;22:1108–1120.
3. Burkhart KJ, Mattyasovszky SG, Runkel M, Schwarz C, Kuchle R, Hessmann MH, Rommens PM, Lars MP. Mid- to long-term results after bipolar radial head arthroplasty. *J Shoulder Elbow Surg.* 2010;19:965–972.
4. Chanlalit C, Shukla DR, Fitzsimmons JS, An KN, O'Driscoll SW. The biomechanical effect of prosthetic design on radiocapitellar stability in a terrible triad model. *J Orthop Trauma.* 2012;26:539–544.
5. Chanlalit C, Shukla DR, Fitzsimmons JS, Thoreson AR, An KN, O'Driscoll SW. Radiocapitellar stability: the effect of soft tissue integrity on bipolar versus monopolar radial head prostheses. *J Shoulder Elbow Surg.* 2011;20:219–225.
6. Doornberg JN, Parisien R, van Duijn PJ, Ring D. Radial head arthroplasty with a modular metal spacer to treat acute traumatic elbow instability. *J Bone Joint Surg Am.* 2007;89:1075–1080.
7. Harrington IJ, Sekyi-Otu A, Barrington TW, Evans DC, Tuli V. The functional outcome with metallic radial head implants in the treatment of unstable elbow fractures: a long-term review. *J Trauma.* 2001;50:46–52.
8. Hartzler RU, Llusa-Perez M, Steinmann SP, Morrey BF, Sanchez-Sotelo J. Transverse Coronoid Fracture: When Does It Have to Be Fixed? *Clin Orthop Relat Res.* 2014 March 1 [Epub ahead of print].
9. Herald J, O'Driscoll S. Complete dissociation of a bipolar radial head prosthesis: a case report. *J Shoulder Elbow Surg.* 2008;17:e22–e23.
10. Leigh WB, Ball CM. Radial head reconstruction versus replacement in the treatment of terrible triad injuries of the elbow. *J Shoulder Elbow Surg.* 2012;21:1336–1341.
11. Moon JG, Berglund LJ, Zachary D, An KN, O'Driscoll SW. Radiocapitellar joint stability with bipolar versus monopolar radial head prostheses. *J Shoulder Elbow Surg.* 2009;18:779–784.
12. Mounsgondo F, El Kazzi W, van Riet R, Feipel V, Rooze M, Schuind F. Radiocapitellar joint contacts after bipolar radial head arthroplasty. *J Shoulder Elbow Surg.* 2010;19:230–235.
13. Pollock JW, Brownhill J, Ferreira L, McDonald CP, Johnson J, King G. The effect of anteromedial facet fractures of the coronoid

- and lateral collateral ligament injury on elbow stability and kinematics. *J Bone Joint Surg Am.* 2009;91:1448–1458.
14. Pomianowski S, Morrey BF, Neale PG, Park MJ, O'Driscoll SW, An KN. Contribution of monoblock and bipolar radial head prostheses to valgus stability of the elbow. *J Bone Joint Surg Am.* 2001;83:1829–1834.
 15. Popovic N, Lemaire R, Georis P, Gillet P. Midterm results with a bipolar radial head prosthesis: radiographic evidence of loosening at the bone-cement interface. *J Bone Joint Surg Am.* 2007;89:2469–2476.
 16. Schneeberger AG, Sadowski MM, Jacob HA. Coronoid process and radial head as posterolateral rotatory stabilizers of the elbow. *J Bone Joint Surg Am.* 2004;86:975–982.
 17. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, Nagels J, Karduna AR, McQuade K, Wang X, Werner FW, Buchholz B; International Society of Biomechanics. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion. Part II. Shoulder, elbow, wrist and hand. *J Biomech.* 2005;38:981–992.
 18. Yian E, Steens W, Lingenfelter E, Schneeberger AG. Malpositioning of radial head prostheses: an in vitro study. *J Shoulder Elbow Surg.* 2008;17:663–670.
 19. Zunkiewicz MR, Clemente JS, Miller MC, Baratz ME, Wysocki RW, Cohen MS. Radial head replacement with a bipolar system: a minimum 2-year follow-up. *J Shoulder Elbow Surg.* 2012;21:98–104.