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Does prosthetic humeral articular surface positioning associate with outcome after total shoulder arthroplasty?

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Background: The purpose of this study was to determine the effect of humeral articular component positioning on changes in patient-reported outcomes after anatomic total shoulder arthroplasty.
Methods: This was a retrospective series of consecutive patients at 2 high-volume referral centers. The study included patients with (1) a preoperative and postoperative radiograph demonstrating a perfect or nearly perfect profile of the humerus and implant and (2) Simple Shoulder Test, visual analog scale for pain, and American Society of Shoulder and Elbow Surgeons (ASES) Standardized Shoulder Assessment scores preoperatively and at greater than 2 years postoperatively. Head height, head diameter, tuberosity-to-head height distance, inclination, and medial offset of the center of rotation (COR) were measured preoperatively and postoperatively. Distance and direction from the ideal COR to the reconstructed center of rotation was measured. Measurements were correlated with improvement in functional outcomes.
Results: The study included 95 patients, aged 66 ± 9 years, with a mean follow-up of 4.3 ± 1.7 years. An a priori power analysis suggested that a sample size of 95 patients provided 80% power to detect correlations of $R^2 = 0.07$. The COR shift was >2 mm in 62% of patients and >4 mm 15%. Thirty-two percent had a change of ASES of <21 points. On multivariate analysis, there were no significant associations between any change in measured prosthetic radiographic parameters and changes in the visual analog scale, Simple Shoulder Test, or ASES scores ($P > .05$).
Conclusion: In this retrospective analysis of total shoulder arthroplasty in which most components were well positioned, humeral component positioning did not associate with change in postoperative outcomes. These findings should be prospectively confirmed.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Total shoulder arthroplasty; humeral component; shoulder arthroplasty; shoulder replacement; patient-reported outcomes; humeral anatomy

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This study was approved by the Institutional Review Boards of the University of Utah (protocol #65636) and Washington University in St. Louis Medical Center (protocol #201707043).

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Shoulder replacement frequency is increasing.[28] For instance, during 2011 and 2012 in the United States, more than 100,000 shoulder replacements were performed compared with just over 46,000 between 2001 and 2002.[28,43] The expansion is partly due to an increase in the use of total shoulder arthroplasty (TSA).[28] Clinical outcomes after TSA are predictably very good.[11,36,46] However, not all patients achieve optimal postoperative function and range of motion. For instance, an analysis of a recently published data set[12] found up to 8% of patients will not regain active forward elevation of >120° and up to 32% of patients will not regain an American Shoulder and Elbow Surgeons (ASES) score of >80 points, which is considered to be a "fair" outcome, but not a "good" or "excellent" outcome.[12] Not all patients are able to return to their preinjury activities.[9] In addition, implant longevity is suboptimal. Within 13 years after TSA, there are signs of rotator cuff dysfunction in 70% of patients and glenoid component loosening in 50%.[37] Possible reasons for poorer outcomes may be patient-related but also may be related to how well the arthroplasty was technically performed.

Humeral component design and positioning has long been considered to correlate with TSA outcome.[1,5,7,14-16,18-20,23,31-33,45,48] Humeral anatomy is highly variable[6,21,22,32,40,41] and can be technically challenging to accurately reconstruct.[1,32-35] This has prompted many prosthetic implant design changes since the advent of modern shoulder arthroplasty,[30] including modularity at the head/neck junction,[17] eccentricity within the humeral head replacement,[6,32] humeral heads of variable sizes and thicknesses,[20] and variable inclination implants.[6,32]

Multiple biomechanical studies have demonstrated that the biomechanics of the glenohumeral articulation is sensitive to even very small deviations in anatomy.[2,20,25,27,31,48] For instance, a change of 2.5 to 4 mm in the humeral center of rotation (COR) between the anatomic and the prosthetic heads increases glenoid edge loading, stiffness, and impingement.[14,17,32] These biomechanical data would suggest that shoulder function after anatomic shoulder arthroplasty should be very sensitive to humeral component position.

Very little evidence exists examining the relationship between accuracy of the humeral articular surface reconstruction and clinical outcome. For instance, failure to restore the COR of the humeral head has been demonstrated to be common after TSA.[1] Retrospective clinical comparisons have not demonstrated any difference in patient-reported outcome between second- and third-generation components[39] or between standard and eccentric humeral heads.[42] In addition, stemless components, which theoretically should offer the best anatomic restoration because they are not constrained by diaphyseal or metaphyseal anatomy,[10,26] have not demonstrated improved outcomes over more traditional stemmed components.[4]

Traditionally, many surgeons have suggested that TSA is a "soft tissue surgery" and that the outcome may thus be less dependent on implant selection and positioning.[17] However, analysis of failed anatomic arthroplasties has demonstrated a high proportion of malpositioned and malaligned humeral components, suggesting that accuracy of humeral reconstruction may play a role.[19] To date, only a single article has attempted to correlate humeral component position with postoperative outcome, and this study had >50% loss to follow-up and did not include radiographic quality criteria,[1] clouding the conclusions.[18]

The purpose of this study was to determine the effect of humeral component positioning on postoperative outcomes after anatomic TSA. We hypothesized that improved humeral component positioning would be associated with a greater improvement in postoperative patient-reported outcomes.

Materials and methods

This was a retrospective study. We included patients who underwent primary anatomic TSA for a diagnosis of primary glenohumeral osteoarthritis at the University of Utah or Washington University of St. Louis Medical Center after 2007 with a minimum of 2 years of follow-up, including preoperative and postoperative American Shoulder and Elbow Surgeons (ASES) Standardized Shoulder Assessment, Simple Shoulder Test (SST), and visual analog for pain (VAS) scores. We excluded patients with less than 2 years of follow-up available, patients without complete preoperative shoulder functional scores, patients without adequate quality radiographs as defined below, revision shoulder arthroplasty, history of a rotator cuff repair in the involved shoulder, patients with known postsurgical subscapularis insufficiency, and patients who underwent revision of their shoulder arthroplasty during the follow-up period. Postsurgical subscapularis insufficiency was determined based on migration of the lesser tuberosity fragment on the postoperative radiographs because all included patients underwent a lesser tuberosity osteotomy. Our goal was to exclude patients with known potential causes of lower postoperative outcome scores.

This cohort was part of a previous study of the minimal clinically important difference for the ASES score, SST, and VAS after shoulder arthroplasty.[44] Within this cohort and during the period studied, the surgeons who performed these procedures shared a very similar surgical technique with regards to exposure, subscapularis management, and implant positioning. During the study period, the surgeons aimed to place all humeral implants in 20° to 40° of retroversion and used corrective reaming to within 10° of neutral version for the management of glenoid deformity and retroversion. No augmented glenoid components or glenoid bone grafts were used. Because this is a retrospective study, case-to-case variation exists.

Data collection

Once the cohort was determined, the following information was collected for each patient: age, sex, body mass index, medical comorbidities sufficient for calculation of the Elixhauser score,[13] duration of follow-up, and preoperative and postoperative ASES, SST, and VAS scores. Preoperative radiographs were used to judge the pattern of glenoid erosion as described by Walch et al.[47]

Radiographic measurement protocol

Preoperative and postoperative true anterior-posterior radiographs obtained in the outpatient clinic were evaluated. Preoperative

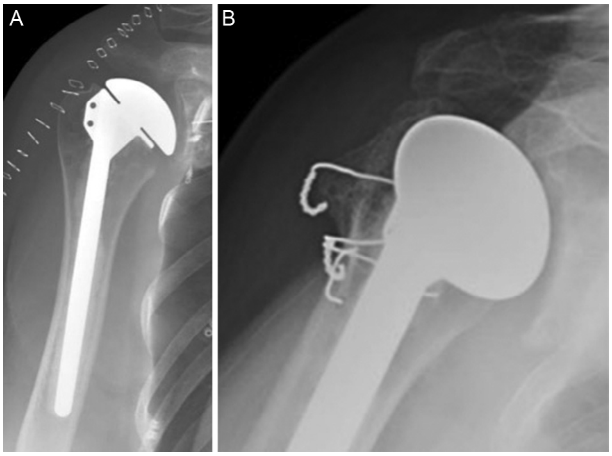

Figure 1 Anteroposterior radiographs demonstrate (**A**) adequate quality and (**B**) inadequate quality images for inclusion in the study.

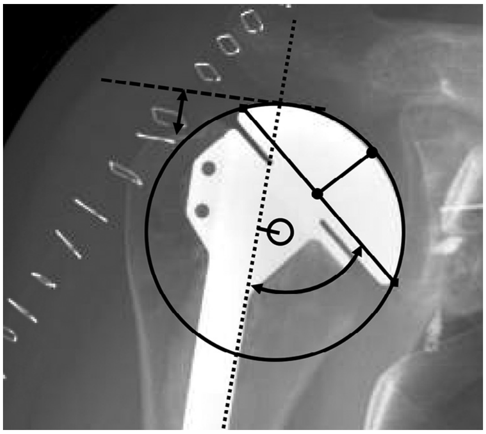

Figure 2 This anteroposterior radiograph demonstrates each of the measurements, including head height (*line with circle ends*), head diameter (*line with square ends*), tuberosity-to-head height (*double-sided straight arrow*), inclination (*double-sided curved arrow*), and medial offset (*solid line with blunt end*).

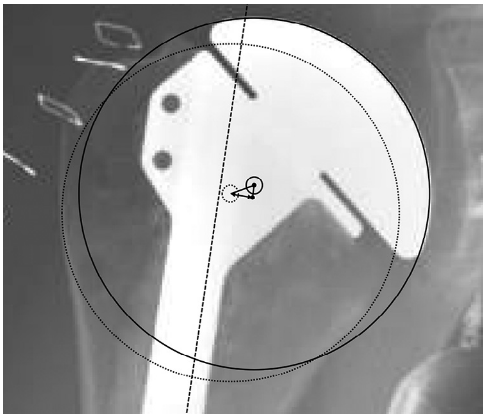

Figure 3 This anteroposterior radiograph demonstrates the method for measurement of the distance (*straight solid line*) between the center of rotation from ideal (*dotted large and small circles*) to postoperative (*solid large and small circles*), as previously described by Alolabi et al[1] and Youderian et al.[49] Based upon a Cartesian plane defined by the intramedullary axis (*dashed line*), each shift was defined as superolateral, superomedial, inferolateral, or inferomedial.

radiographs were only included if a nearly perfect profile of the greater tuberosity and calcar were visible. All available postoperative radiographs were evaluated, and the radiograph with the best profile of the implant was measured. We only included those that met quality criteria previously defined by Alolabi et al.[1] Specifically, we only included those with very minimal (<2 mm) overlap of the head at the level of the osteotomy surface, a good profile of the greater tuberosity and calcar, and no overlap between the prosthetic head and the tuberosity and calcar. For implants with collars, the collar had to be visible for the radiograph to be included (Fig. 1). The following measurements were then made: humeral head height, as measured from the humeral neck osteotomy, humeral head diameter, tuberosity-to-head height, as measured along a line parallel to the intramedullary canal, medial offset, and inclination (Fig. 2). The implant head size was recorded to allow correction for magnification based on the known implant head size. In addition, we used methods previously described by Alolabi et al[1] and validated by Youderian et al[49] to measure the distance from the COR of the articular surface of the implant to the ideal COR using a previously validated best-fit circle with the following 3 landmarks: the lateral cortex of the greater tuberosity, the medial calcar inflection point, and the medial edge of the greater tuberosity (Fig. 3).

Patients were grouped according to the position of the prosthetic head COR in relation to the ideal COR: those with a superolateral shift, those with a superomedial shift, those with an inferolateral shift, and those with an inferomedial shift in the COR. Radiographic distances were corrected for magnification. The radiographically measured implant head height and width were converted to implant diameter by using the geometric formula: $\text{diameter} = 2 \times [(4 \times \text{height}^2 + \text{width}^2)/(8 \times \text{height})]$.

Statistical analysis

We conducted an a priori power analysis which demonstrated that a sample size of 95 patients would provide 80% power to detect an R^2 of 0.07 while controlling for 2 additional variables, each of which had an R^2 of 0.05. All analyses were conducted by the Study Design and Biostatistics Center at the University of Utah by individuals with advanced training in statistical analysis.

First, patient characteristics and radiographic characteristics were summarized descriptively (Table I), as were patient-reported outcome measures (Table II). Of these, distance/direction in change in COR was designated as the primary independent variables, and change in the ASES score was designated as the primary dependent variable. We thus performed 4 multivariate linear regressions measuring the associations between distance/direction of change in COR and change in (1) the ASES score (Table III), (2) the VAS score (Table IV), and (3) SST score (Table V), and (4) change in each radiographic measurement and the change in ASES score (Table VI). Each of these models included the center in which the arthroplasty was performed and length of follow-up as covariates. As a sensitivity analysis, these regression models were repeated with age, body mass index, Walch grade, and Elixhauser scores included as covariates. The results were no different, and thus, only the logistic regression analyses are presented. P values were adjusted for multiple comparisons using the false discovery rate adjustment.[3]

Table I Data summary

Variable	Mean	SD	Range
Age	66.4	8.9	42-89
BMI, kg/m^2	30.9	5.9	18.2-47
Elixhauser score	1.4	4.7	−7 to 22
Follow-up, y	4.3	1.7	2-10.6
Shift in COR, mm	2.6	1.6	0.1-10.2
Change in			
Head height, mm	−2.8	2.3	−10.6 to 1.5
Head diameter, mm	−5.0	3.9	−14.9 to 3.2
Tuberosity height, mm	0.5	3.1	−11.1 to 10.5
Medial offset, mm	0.8	3.3	−6.1 to 17.8
Inclination, °	2.3	5.4	−12.6 to 15
	No.		%
Female sex	45		47
Right side	52		55
Walch grade			
A1	50		53
A2	9		9
B1	11		12
B2	24		25
D	1		1
Direction of COR shift			
Inferolateral	12		13
Interomedial	18		19
Superolateral	41		43
Superomedial	24		25

SD, standard deviation; *BMI*, body mass index; *COR*, center or rotation. For reference, the negative change in head height signifies that head height was smaller postoperatively than preoperatively and a negative change in head diameter means that the head diameter was smaller postoperatively than preoperatively. Positive values for change, such as for medial offset, suggest that the medial offset postoperatively was larger than the medial offset preoperatively.

Results

During the referenced study period, 215 SAs met our inclusion and exclusion criteria. Of the 215 patients, 74 were lost to follow-up, and thus, the rate of loss of follow-up was 34%. Of the remaining 141 patients, 44 had adequate clinical follow-up but did not have adequate preoperative and postoperative radiographs for inclusion, and thus, the radiographic exclusion rate was 31%. Two patients had adequate clinical follow-up and radiographs but had no documented implant size, and thus radiographic magnification could not be determined. Thus, 95 patients met our inclusion criteria.

Demographically, the cohort was 47% female, with a mean ± standard deviation age of 66.4 ± 8.9, and 45% of arthroplasties had been performed on the right side. The mean BMI was 30.9 ± 5.9 kg/m^2, and the mean Elixhauser score was 1.4 ± 4.7. Follow-up was a mean of 4.3 ± 1.7 years (range, 2-10.6 years).

A cemented Bigliani/Flatow humeral stem was used in 82 of 95 patients (86%), a cemented short Bigliani/Flatow humeral stem was used in 3 (3%), and a Trabecular Metal stem was used in 11 (12%), all of which are manufactured by Zimmer-Biomet (Warsaw, IN, USA), and 3 patients (3%) received an Ascend Flex Stem (Wright Medical, Memphis, TN, USA). Of the 95 included patients, 50 (53%) had an A1 glenoid, 9 (9%) had an A2 glenoid, 11 (11%) had a B1 glenoid, 24 (25%) had a B2 glenoid, and 1 (1%) had a D glenoid (Table I).

Compared with the preoperative humeral head height, the postoperative humeral head height was decreased, head diameter was decreased, tuberosity-to-head height was increased, medial head offset was increased, and the inclination angle had shifted to be more valgus (Table I). The mean distance from the reconstructed prosthetic COR to the ideal COR was 2.6 ± 1.6 mm and was >2 mm in 59 of 95 patients (62%), >3 mm in 28 (29%), and >4 mm in 14 (15%). The shift was superolateral in 41 of 95 patients (43%) and was superomedial in 24 (25%), and thus the overall shift in 68% was superior. The shift was inferolateral in 12 of 95 patients (13%) and was inferomedial in 18 (19%), and thus the overall shift was inferior in 32% of patients.

Preoperative, postoperative, and change in outcomes are reported in Table II. Compared with previously established minimum clinically important differences for this population,[44] clinically significant improvements were noted in the SST score for 87 of the 95 patients (92%), in the VAS pain score for 92 (97%), and in the ASES score for 65 (68%).

No significant associations were found between the measured demographics or radiographic parameters and change in ASES score (Table III), change in VAS pain score (Table IV), or change in SST score (Table V). In a model incorporating change in each of the radiographic measures, none was significantly associated with change in ASES score (Table VI).

Discussion

Not all patients achieve optimal postoperative function and range of motion after TSA. Humeral component design and positioning has long been thought to correlate with TSA outcome.[1,5,7,14-16,18-20,23,31-33,45,48] Despite multiple biomechanical studies having demonstrated that the biomechanics of the glenohumeral articulation is sensitive to even very small alterations in implant position, very little clinical evidence exists to examine the connection between accuracy of the humeral reconstruction and postoperative outcome.[2,20,25,27,31,48] This retrospective analysis of TSA found no association between humeral component articular surface positioning and change in patient-reported outcomes. The prosthetic humeral head COR in most of the patients of this cohort did not deviate from the ideal COR by >4 mm. The conclusions of this study may thus not apply when the final COR deviates beyond this point.

Our preoperative measurements are similar to many prior studies performed examining proximal humeral anatomy, although variation exists in the literature (Table VII).[6,21,22,24,32,41] The similarity between our measurements and previous

Table II Summary of outcomes

Variable	Preoperative		Postoperative		Change	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
SST score	3.4 ± 2.4	0-10	9.8 ± 2.1	4-12	6.4 ± 2.4	0-11
VAS for pain	7.1 ± 2.1	0.5-10	1 ± 1.8	0-8	−6 ± 2.5	−10 to 1.5
ASES score	57.2 ± 21.8	1.7-93.3	87.4 ± 15.7	28.3-100	30.2 ± 23.7	−36.7 to 96.3

SD, standard deviation; *SST*, Simple Shoulder Test. *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons.

Table III Comparison of change in the center of rotation with change in American Society of Shoulder and Elbow Surgeons outcome

Predictors	β (95% CI)*	*P* value
COR shift distance	1.2 (−1.7 to 4.1)	.42
Shift direction		
Inferomedial	−0.3 (−17.1 to 16.5)	.97
Superolateral	−7.1 (−21.9 to 7.7)	.34
Superomedial	6.4 (−9.5 to 22.4)	.43

CI, confidence interval; *COR*, center of rotation.

* Inferolateral shift is excluded because it is statistically explained by the remaining shifts.

Table IV Comparison of change in center of rotation with change in visual analog scale for pain

Predictors	β (95% CI)*	*P* value
COR shift distance	0 (−0.3 to 0.4)	.83
Shift direction		
Inferomedial	0.4 (−1.4 to 2.2)	.65
Superolateral	0.2 (−1.4 to 1.8)	.83
Superomedial	0.6 (−1.1 to 2.3)	.48

CI, confidence interval; *COR*, center of rotation.

* Inferolateral shift is excluded because it is statistically explained by the remaining shifts.

Table V Comparison of change in center of rotation with change in Simple Shoulder Test

Predictors	β (95% CI)*	*P* value
COR shift distance	0.1 (−0.3 to 0.4)	.68
Shift direction		
Inferomedial	0.8 (−1 to 2.6)	.39
Superolateral	0.6 (−1.1 to 2.2)	.5
Superomedial	1 (−0.7 to 2.7)	.25

CI, confidence interval; *COR*, center of rotation.

* Inferolateral shift is excluded as it is statistically explained by the remaining shifts.

Table VI Comparison of each positional measure with change in American Society of Shoulder and Elbow Surgeons outcome

Predictors	β (95% CI)	*P* value
Shift direction		
Inferomedial	0.2 (−16.5 to 16.9)	—
Superolateral	−6 (−20.5 to 8.5)	—
Superomedial	6.4 (−9.5 to 22.3)	.53
Change in		
Head height	1.4 (−0.6 to 3.3)	.37
Head diameter	−0.2 (−1.4 to 1)	.7
Tuberosity height	0.5 (−1 to 2)	.61
Medial offset	1 (−0.5 to 2.4)	.37
Inclination	1 (0.1-1.8)	.17

CI, confidence interval.

measurements made with 3-dimensional methods suggest that the measurement methods used in our study are accurate. This suggests that future studies using the radiographic inclusion/exclusion criteria developed by Alolabi et al[1] can accurately measure head diameter, head height, tuberosity-to-head height, inclination, and medial offset. Proximal humeral anatomic measurements made without these rigorous inclusion/exclusion criteria based on radiographic technique may not be reliable, calling into question previous studies performed without them.[18]

Within our study, a shift in the COR >2 mm occurred in 62% of patients, a shift >3 mm occurred in 29%, and a shift of >4 mm occurred in 15%. In a previously published analysis with a variety of third-generation prostheses, Alolabi et al[1] described remarkably similar results, with a shift of >2 mm in 54.4%, a shift of >3 mm in 31.2%, and a shift of >4 mm in 14.4% using a stemmed implant. Within their cohort of resurfacings, however, the center of rotation was shifted >2 mm in 76.7% of cases, >3 mm in 65.1%, and >4 mm in 44.2%.[1]

Flurin et al[18] performed a radiographic analysis in which the overall reconstruction was graded taking into account whether the head height was within 3 mm, whether the head was perfectly centered, whether the head diameter was within 3 mm, whether the medial offset was within 3 mm, and whether the head-neck angle was within 4°. The authors stated that they were able to achieve this goal for 88% of cases for head height, 88% of cases for head centering, 71% of cases for medial offset, 76% of cases for head diameter, and 69% of cases for head-neck angle, again suggesting that up to 30% of cases may have a nonanatomic reconstruction.[18]

Kadum et al[26] performed a prospective radiographic analysis of a stemless device. They measured the unidimensional distance from the edges of the articular arc to the COR preoperatively and postoperatively and demonstrated that 19% of

Table VII Proximal humeral anatomy measurements in our study and in those previously published

Variable	Our study	Boileau[6]	Hertel[21]	Ianotti[22]	Jeong[24]	Knowles[29]	Pearl[32]	Robertson[41]
Head height, mm	19 ± 2.6	15.2 ± 1.6	17 ± 1.7	20 ± 2.0	18 ± 1.2	18 ± 2	NA	19
Head diameter, mm	52.5 ± 9.7	43.3 ± 4.3	44.5 ± 4.0	44 ± 3.4	NA	NA	40-60	NA
Tuberosity height, mm	7.5 ± 2.1	NA	NA	8 ± 3.2	8.0 ± 2.7	NA	NA	NA
Medial offset, mm	4 ± 2.4	6.9 ± 2.0	6.0 ± 1.8	NA	5.6 ± 1.8	NA	4-14	7
Inclination, °	46.9 ± 4.8	50 ± 3	43 ± 3.6	45 ± 5	46.6 ± 6.2	NA	30-55	41

NA, not available.

Values are presented as mean ± standard deviation unless otherwise specified. Inclination measurements have been converted via complementary angles for comparison.

shoulders had a shift of >3 mm, which is similar to our findings and those of Alolabi et al.[1] However, the Kadum et al[26] study did not measure the geometric location of the COR by using the same landmarks preoperative and postoperatively, and thus, their data cannot be directly compared with our own or those of Alolabi et al.[1] These authors also measured head height, which was >5 mm different in 11% of shoulders, and neck-shaft angle, which was >50° in 36% of shoulders.[26]

In a prior computer simulation study, Pearl and Kurutz[33] demonstrated that second-generation prostheses shift the center of rotation 14.7 mm, which is substantially larger than observed here or radiographically measured elsewhere, although the results of radiographic studies and computer simulations may not be directly comparable.

Overall data from our own and the 3 mentioned studies suggest that imperfect humeral component position remains relatively common even though these radiographs were gathered from cases performed by high-volume, fellowship-trained shoulder surgeons. Despite the frequency of imperfect positioning in the current series, most patients had significant improvement in patient-reported outcomes.

This retrospective analysis of TSA found no association between humeral component articular positioning and change in patient-reported outcomes. Multiple prior cadaveric and finite element studies have demonstrated that even small changes in humeral component position can affect glenohumeral biomechanics. In a cadaveric model, Blevins et al[5] demonstrated that a change of even 2.5 mm in humeral head diameter affected translation, rotation, and elevation range of motion.[5] Büchler et al[8] demonstrated in a finite element model that second-generation components generate excess contact forces at the superior glenoid over 8-fold higher than the normal shoulder. In another finite element model, Favre et al[14] demonstrated that even a 2.5-mm change in superior/inferior humeral component position can create subacromial impingement. Harryman et al[20] demonstrated in a cadaveric model that a 4-mm increase in humeral head diameter reduced laxity and motion. A biomechanical study by Nyffeler et al[31] demonstrated that a 5-mm alteration in humeral head height altered range of motion and rotator cuff moment arms. In a finite element model, Terrier et al[45] demonstrated that a 5-mm superoinferior malpositioning of the humeral component led to impingement and subluxation. A cadaver study by Williams et al[48] demonstrated that a 4-mm malpositioning of the COR of the humeral component altered translation, range of motion, and impingement.

These experimental results suggest that achieving an anatomic restoration of humeral anatomy should play a large role in postoperative function after TSA. However, only 2 previously published clinical studies are available in support of this hypothesis. Flurin et al[18] demonstrated an association between postoperative outcomes and a compound score developed to determine the overall accuracy of the humeral reconstruction, although >50% of patients were lost to follow-up, and no radiographic exclusion criteria were used. Franta et al,[19] in an analysis of 282 failed shoulder arthroplasties that presented to the senior author, demonstrated that 67% had component malalignment and 65% had component malposition, most specifically, that a proud component relative to the greater tuberosity was the most common problem. Replacements were considered malaligned in the Franta et al[19] series if the articular surface was >1 cm above the greater tuberosity. These levels of malalignment were outside the range reported in the current series and may be the reason we did not see a relationship between outcomes and implant position.

Our current findings suggest that the in vivo relationship between restoration of the COR and shoulder function is not absolute, suggesting factors other than re-creation of proximal humeral anatomy influence postoperative shoulder function. Although extremes in deviation of the optimal COR have been shown to influence in vitro glenohumeral biomechanics, shoulder function is not affected in vivo when the proximal humeral COR is re-created to a nearly ideal situation (ie, within our cohort 85% fell within 4 mm of ideal COR).

Strengths of the current study include the large sample size, stringent radiographic inclusion criteria, and comparison of preoperative to postoperative outcome scores allowing assessment of change in function rather than postoperative function alone.

Our study has several limitations. Multiple surgeons were included, which may limit internal validity. Humeral reconstruction was measured retrospectively on plain radiographs. Although this method may be inferior to 3-dimensional methods such as computed tomography, it does provide clinical applicability so that future surgeons can interpret their postoperative radiographs within the framework of our results.

We also applied strict inclusion/exclusion criteria to reduce measurement variability. Because of the exclusion criteria applied, there may be a selection bias. Only short-term follow-up was included, and certainly with longer follow-up, outcomes can change. Because our results are limited to short-term follow-up, we are, unfortunately, not able to comment on the influence of humeral reconstruction accuracy and prosthesis survival, specifically glenoid loosening. Other authors have theorized that the typical superomedial shift in the center of rotation with an inadequate humeral reconstruction may increase eccentric forces upon the glenoid and increase glenoid loosening.[14,17,19,32] Future studies with longer-term follow-up will be necessary to test this hypothesis.

An additional limitation is the exclusion of patients with failure of the subscapularis repair or revision. Series with a wider variation in postoperative implant positioning may also have different results. However, there was a shift of COR of >3 mm in 29% of patients in our series and a shift of >4 mm in 15%. Given the substantial biomechanical effects of small alterations in humeral anatomy predicted by prior finite element[8,14,38,45] and cadaveric studies,[5,20,25,27,31,48] changes in patient-reported outcomes even at these shifts of COR and this short-term of follow-up would be expected.

Conclusion

In this retrospective analysis of total shoulder arthroplasty in which most components were well positioned, humeral component positioning was not associated with change in postoperative outcomes. These findings should be prospectively confirmed.

Disclaimer

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