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Radiographic restoration of native anatomy: a comparison between stemmed and stemless shoulder arthroplasty

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Background: Shoulder arthroplasty is a reliable procedure for patients with degenerative glenohumeral disease, and reproduction of native shoulder anatomy leads to superior outcomes. The aim of this study was to compare the ability of stemmed and stemless implants to radiographically restore native glenohumeral anatomy.
Methods: Shoulder arthroplasties were performed in 79 patients, with 58 receiving a stemless implant and 21 receiving a stemmed implant. Preoperative and postoperative radiographs were assessed for humeral head height, humeral head centering, humeral head medial offset, humeral head diameter, humeral neck angle, and lateral humeral offset by 2 independent viewers. Measurements were scored and summed to identify the anatomic reconstruction index (ARI). Radiographic measurements were compared using the Student t test, and significance was set at $P < .05$ for all statistical analyses. Interobserver agreement of radiographic analyses was assessed using the intraclass correlation coefficient, finding excellent reliability (intraclass correlation coefficient, 0.92).
Results: Five of six radiographic measurements along with the calculated ARI demonstrated no differences between stemmed and stemless shoulder implants (humeral head diameter, $P = .651$; humeral head height, $P = .813$; humeral head medial offset, $P = .592$; lateral humeral offset, $P = .311$; humeral head centering, $P = .414$; and ARI, $P = .862$). Stemless implants showed improved restoration of the native humeral neck angle (0° for stemless vs. −3° for stemmed, $P = .017$).
Conclusion: Radiographic restoration of anatomy is similar for stemmed and stemless shoulder arthroplasty implants.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Stemmed implant; stemless implant; anatomic total shoulder arthroplasty; radiographic study; native anatomy restoration; glenohumeral disease

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This retrospective cohort study was approved by the University of Alabama at Birmingham Institutional Review Board (IRB-170609003).

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Total shoulder arthroplasty (TSA) is an effective treatment modality associated with significant pain relief, as well as the restoration of shoulder function in 95% of patients.[32] The prevalence of TSA has increased considerably over the past 2 decades, with its growth outpacing both hip and knee arthroplasty.[10,18] Shoulder arthroplasty has transitioned from the widespread use of large, stemmed humeral implants often to the use of stemless implants, first popularized in Europe following their release in 2004, with projections estimating that stemless implants will be more commonly used for primary TSA by 2025.[21,31] With this shift, there is a need for further investigation of the use and benefits of stemless implants, as well as radiographic comparisons to standard stemmed implants.[5]

A proposed difference between stemmed and stemless TSA is the restoration of the native glenohumeral relationship. Stemmed implants rely on diaphyseal fixation, and the glenohumeral relationship is determined by the head position and the alignment within the humeral shaft.[27] Although this has been improved with newer designs, it can generate difficulties in re-creating the anatomic relationship in patients who have abnormal anatomy of the diaphysis. Stemless designs are based on metaphyseal fixation; thus, the glenohumeral relationship is not dependent on the relationship between the diaphysis and the humeral head.[9,27,28] This difference in fixation leads to a theoretical anatomic reconstruction advantage for stemless implants, which is crucial for the restoration of the individual lever arms of the rotator cuff muscles and anatomic balance of the shoulder.[4,20] This ultimately leads to a successful long-term restoration of physiological patterns of movement and achievement of pain relief through preservation of the center of rotation (CoR) and appropriate tensioning of the overlying soft tissues.[30]

When planning for the anatomic balance of the glenohumeral joint, the surgeon must consider 3 important aspects: the geometry of the humerus, the geometry of the glenoid, and the position of both structures relative to each other. A deviation of the "centered position," whether it be alteration of geometry or alignment of the joint, leads to a decrease in contact area, increased joint pressure, and glenoid loosening due to eccentric loading.[2] Despite several studies showing favorable comparisons of the early outcomes between stemmed and stemless implants, there is a paucity of literature comparing long-term clinical outcomes, as well as radiographic analysis.[5]

Flurin et al[7] have described 5 radiographic measurements to evaluate an anatomic reconstruction: humeral head height (HHH), humeral head diameter (HHD), humeral head centering (HHC), humeral head medial offset (HHMO), and humeral neck angle (HNA). The HHH as it relates to the greater tuberosity affects shoulder abduction and alters the moment arm of the infraspinatus and subscapularis muscles.[26,29] The HHD, as measured along the anatomic neck, serves as a surrogate of humeral head size in which an increase or decrease in humeral head thickness by as little as 5 mm impacts the arc of motion in several planes.[11,14] HHC relative to the glenoid is the parameter with the highest correlation with both clinical outcome scores and range of motion.[8] The HHMO measures the distance from the center of the humeral head to the intramedullary axis in the anteroposterior (AP) plane and affects the moment arm and superior destabilizing action of the deltoid muscle.[19] Finally, the HNA reflects the angle between the humeral head and the intramedullary axis in the AP plane and expresses the humeral head inclination. In addition, the lateral humeral offset (LHO), described by Iannotti et al,[13] measures the distance from the medial edge of the coracoid process to the lateral edge of the greater tuberosity and has been used to determine the accuracy of re-creating the relationship between the rotator cuff and deltoid muscles.

The aim of this study was to compare stemmed and stemless TSA implants and analyze their radiographic restoration of the glenohumeral relationship, which is fundamental to superior functional outcomes and improved patient satisfaction following TSA.[8,17,34,35] Owing to the limited excursion of the glenohumeral joint and the delicate overlying soft tissues, minor changes in the anatomy may have important biomechanical consequences.[30] To date, no study has compared the variation in anatomic reconstruction between patients treated with stemmed implants and those treated with stemless implants.[5] Our hypothesis was that stemless implants would more accurately reproduce native glenohumeral anatomy on radiographic analysis.

Materials and methods

Patients with glenohumeral arthritis who underwent TSA performed by 2 fellowship-trained surgeons (B.A.P. and E.V.F.) between 2013 and 2017 were retrospectively identified using Current Procedural Terminology code 23472. In the patients included, conservative management had failed, and they demonstrated radiographic evidence of advanced glenohumeral arthritis and had an intact rotator cuff via radiographic imaging. Patients were excluded if they had evidence of rotator cuff arthropathy, had undergone hemiarthroplasty or reverse TSA, or had inadequate preoperative or postoperative radiographs.

Our cohort comprised 79 patients who received unilateral, anatomic TSA. Two types of implants were used: the Simpliciti Stemless Prosthesis (Wright Medical/Tornier, Bloomington, MN, USA) and the stemmed Aequalis Ascend Flex implant (Wright Medical/Tornier). All arthroplasties were performed through the deltopectoral approach, with a subscapularis tendon peel. All patients wore a sling immobilizer for 2 to 6 weeks after surgery. Patients received routine preoperative and 2-week postoperative AP shoulder radiographs with the arm in the neutral position by the patients' side.

Radiographic analysis was executed by 2 authors (M.C.P. and A.T.A.) using Medstrat software (Medstrat, Downers Grove, IL, USA). Each patient's preoperative and postoperative comparison was based on the 6 measurements of Flurin et al[7] and Iannotti et al[13] from the AP shoulder radiograph with the arm in neutral rotation, as illustrated in Figure 1 and Table I. The radiographic measurements of HHH, HHD, HHC, HHMO, and HNA were each

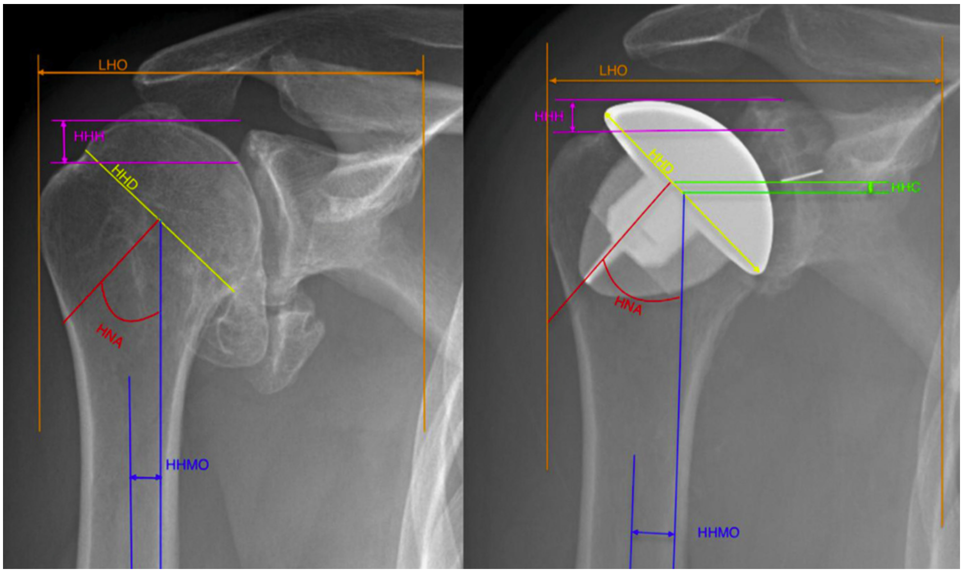

Figure 1 Radiographic measurements performed preoperatively (*left*) and postoperatively (*right*). *LHO*, lateral humeral offset; *HHH*, humeral head height; *HHD*, humeral head diameter; *HHC*, humeral head centering; *HNA*, humeral neck angle; *HHMO*, humeral head medial offset.

scored from 0 to 2 and summed to yield the anatomic reconstruction index (ARI), as shown in Table II.[8]

Demographic characteristics were compared between the implant types using *t* and χ^2 tests. Paired *t* tests were used to compare preoperative and postoperative measurements within each implant group. Generalized linear models were used to compare the change in preoperative to postoperative measurements between the implant groups. Interobserver agreement of radiographic analyses was assessed using the intraclass correlation coefficient (ICC). $P \leq .05$ (2-sided) was considered statistically significant. All statistics were performed using SAS software (version 9.3; SAS Institute, Cary, NC, USA).

Table I Parameters used to calculate ARI

Parameter	Definition
HHD	
Rating of 0	Pre and post difference > 6 mm
Rating of 1	Pre and post difference > 3 mm and < 6 mm
Rating of 2	Pre and post difference < 3 mm
HHH	
Rating of 0	Pre and post difference > 6 mm
Rating of 1	Pre and post difference > 3 mm and < 6 mm
Rating of 2	Pre and post difference < 3 mm
HHMO	
Rating of 0	Pre and post difference > 6 mm
Rating of 1	Pre and post difference > 3 mm and < 6 mm
Rating of 2	Pre and post difference < 3 mm
HNA	
Rating of 0	Pre and post difference > 8°
Rating of 1	Pre and post difference > 4° and < 8°
Rating of 2	Pre and post difference < 4°
HHC	
Rating of 0	>25% elevation of humeral head
Rating of 1	<25% elevation of humeral head
Rating of 2	Head perfectly centered
ARI	HHD + HHH + HHMO + HNA + HHC

ARI, anatomic reconstruction index; *HHD*, humeral head diameter; *Pre*, preoperative; *post*, postoperative; *HHH*, humeral head height; *HHMO*, humeral head medial offset; *HNA*, humeral neck angle; *HHC*, humeral head centering.

Results

A total of 79 patients fulfilled our inclusion criteria: 21 received stemmed implants (25%), whereas 58 received stemless implants (75%). No demographic differences were found between the groups, except that the stemmed implant group had a higher proportion of male patients than the stemless implant group (11 male and 10 female patients vs. 23 male and 35 female patients, $P < .001$).

Radiographic reproduction of preoperative anatomy within each implant type was similar. For the stemmed cohort, preoperative vs. postoperative radiographs demonstrated no differences in HHH (7.4 mm vs. 6.6 mm, $P = .468$), HNA (43° vs. 40°, $P = .104$), HHMO (6.2 mm vs. 7.0 mm, $P = .121$), LHO (81.7 mm vs. 79.7 mm, $P = .475$), and HHD (49.1 mm vs. 48.9 mm, $P = .636$). For the stemless cohort, no differences in HHH (6.1 mm vs. 5.9 mm, $P = .625$), HNA (44° vs. 44°, $P = .764$), HHMO (7.9 mm vs. 8.0 mm, $P = .567$), and LHO (85.5 mm vs. 85.7 mm, $P = .831$) were identified. A difference in the HHD of −1.7 mm (52.9 mm vs. 51.2 mm, $P = .002$) was identified, denoting an undersizing of the humeral head in the stemless group.

Radiographic reconstruction was also similar between the implant groups. No differences in HHH (−0.8 mm vs.

Table II Stemmed vs. stemless shoulder arthroplasty

	Stemmed		Stemless		Stemmed vs. stemless (*P* value)
	Preoperative /postoperative	Preoperative to postoperative difference (*P* value)	Preoperative /postoperative	Preoperative to postoperative difference (*P* value)	
HHD, mm	49.1/48.9	−0.2 (.636)	52.9/51.2	−1.7 (.002)	.651
HHH, mm	7.4/6.6	−0.8 (.468)	6.1/5.9	−0.2 (.625)	.813
HHMO, mm	6.2/7.0	0.8 (.121)	7.9/8.0	0.1 (.567)	.592
HNA, °	43/40	−3 (.104)	44/44	0 (.764)	.017
LHO, mm	81.7/79.7	−2.0 (.475)	85.5/85.7	0.2 (.831)	.311
HHC, %	8.4*		9.9*		.414
ARI score	7.3*		7.3*		.862

HHD, humeral head diameter; *HHH*, humeral head height; *HHMO*, humeral head medial offset; *HNA*, humeral neck angle; *LHO*, lateral humeral offset; *HHC*, humeral head centering; *ARI*, anatomic reconstruction index.
* Only postoperative measurements were performed.

−0.2 mm, *P* = .813), HHMO (0.8 mm vs. 0.1 mm, *P* = .592), LHO (−2.0 mm vs. 0.2 mm, *P* = .311), HHD (−0.2 mm vs. −1.7 mm, *P* = .651), HHC (8.4% vs. 9.9%, *P* = .414), and ARI (7.3 vs. 7.3, *P* = .862) were found. The HNA varied between implant groups, as stemless implants showed no difference between preoperative and postoperative imaging whereas stemmed implants showed a 3° decrease (*P* = .017). A graphic summary of measurements is shown in Table II.

HHD, HHH, HHC, LHO, and postoperative HHMO demonstrated excellent interobserver reliability (ICC, 0.93-1), HNA showed good reliability (ICC, 0.88 preoperatively and 0.89 postoperatively), and preoperative HHMO revealed moderate reliability (ICC, 0.73), as shown in Table III.

Table III Intraclass correlation coefficients for inter-rater reliability

	Preoperative	Postoperative
HHD	0.99	1.00
HHH	0.99	0.98
HHMO	0.73	0.94
HNA	0.88	0.89
LHO	0.96	0.93
HHC	0.99*	
ARI	0.8*	

HHD, humeral head diameter; *HHH*, humeral head height; *HHMO*, humeral head medial offset; *HNA*, humeral neck angle; *LHO*, lateral humeral offset; *HHC*, humeral head centering; *ARI*, anatomic reconstruction index.
* Only postoperative measurements were performed.

Discussion

Accurate restoration of native glenohumeral anatomy is essential for successful TSA.[8,16,34,35] Stemmed and stemless implants both have limitations and benefits, but no prior study has compared radiographic anatomic restoration between these 2 cohorts.[5] This study highlights the close reapproximation of native anatomy with both stemmed and stemless implants in patients receiving anatomic TSA.

Both the stemmed and stemless implants showed excellent re-creation of the measured anatomic parameters. Stemmed implants showed no significant differences between preoperative and postoperative measurements, whereas stemless implants only demonstrated a 1.7-mm smaller HHD compared with the native anatomy (*P* = .002)—an amount smaller than the margin of difference between implant sizes and a difference that likely has no clinical significance.

In comparing the same parameters between stemmed and stemless implants, we found a difference in the HNA, with stemmed implants being 3° less accurate in restoring the native anatomy (*P* = .017). Although there was a statistically significant difference in the average HNA favoring more accurate restoration of the HNA in the stemless cohort, this may not represent more precise reproduction of the preoperative HNA, as there was a greater range of varus and valgus cut angles in the stemless group (range, −12° to 17°) compared with the stemmed group (range, −8° to 15°). This suggests there may be greater precision with the HNA angles in the stemmed group that may be a result of the ability to modify the humeral head osteotomy cut based on the alignment of the broach within the humeral metaphysis. Although this difference is of statistical significance, professional judgment, along with the absence of relevant literature, suggests that a difference in the HNA of 3° is unlikely clinically relevant. In addition, the ARI (7.3 for stemmed and 7.3 for stemless) showed no difference between the 2 implant designs (*P* = .862). Of all the radiographic measurements, only HHC and the ARI have been correlated with improved clinical outcomes and both were the same in this series.[10,20]

Until the introduction of eccentric humeral heads in third-generation shoulder arthroplasties, the ability to restore anatomy by adjusting for the difference in the CoR in the humeral head with the humeral shaft was limited.[30-32] When performing stemless arthroplasty, the surgeon may replace the post-osteotomy arthritic humeral head with a concentric implant, whereas in stemmed implants, an appropriately sized head may need to be eccentrically dialed to restore the native anatomy. Outside of a few degrees in the HNA, radiographic analysis did not demonstrate any notable differences in this series from 2 fellowship-trained surgeons.

Despite the excellent outcomes with stemmed humeral components in TSA, there are theoretical benefits with stemless humeral implants. The use of only humeral metaphyseal fixation decreases the amount of bone removal, lessens the potential for intraoperative and postoperative humeral fractures, and may reduce complications associated with stem removal during revision surgery.[1,3,12] Stemmed components relying heavily on diaphyseal fixation have a reported risk of intraoperative fractures as high as 1.6% and carry an increased risk of postoperative periprosthetic fracture, stress shielding, and osteolysis, resulting in additional bone loss requiring a longer stem in revision arthroplasty.[8,26,27] Furthermore, the removal of well-fixed humeral components often requires the use of a cortical window or longitudinal split osteotomy, resulting in further bone loss.[24]

Accurate restoration of native anatomy is associated with improved surgical outcomes.[2,8,15,30,34,35] The anatomic reconstruction of the glenohumeral joint, specifically the humeral head, restores physiological motion, muscle alignment, glenohumeral contact position, and bone stress distribution and prevents glenoid loosening via eccentric glenoid loading.[6] As in our study, showing that stemmed and stemless implants have equivalent radiographic outcomes, prior studies have highlighted the equivalent short-term functional outcomes between implant types.[22,23,25,32,33]

No previous studies have compared the restoration of native glenohumeral anatomy between stemmed and stemless implants; studies have instead performed radiographic analyses for a specific stemless implant while using fewer radiographic measures. Kadum et al[15] performed a geometrical analysis of 70 stemless TSAs using AP radiographs, finding the CoR within 1 ± 2 mm; HHH, -1 ± 3 mm; and HNA, $-3° \pm 12°$. Using computed tomography for a similar assessment of 66 shoulders, Kadum et al[17] found a closer re-creation of the preoperative anatomy, with the CoR within 0 ± 2 mm; HHH, 1 ± 2 mm; HNA, $-2° \pm 10°$; and LHO, 1.3 ± 5 mm. Von Engelhardt et al[34] similarly analyzed 21 stemless TSAs using AP radiographs and revealed a restoration of CoR within 1 ± 3 mm; lateral glenohumeral offset, -3 mm; acromiohumeral distance, 3.6 mm; and HNA, 1°. Furthermore, although Kadum et al and von Engelhardt used different parameters to measure the reproducibility of native anatomy by stemless TSA, the similarities between their radiographic measures and those in our study are encouraging, with our findings validating the findings of these prior studies. However, in addition to more comprehensively evaluating the radiographic anatomic reconstruction of stemless TSA, this study also identified comparable reconstructive results between both stemmed and stemless TSAs.

This study has several limitations. The ability to reconstruct the proximal humeral anatomy was only assessed in 2 dimensions on plain AP radiographs. Although our study had excellent preoperative and postoperative reliability (ICCs of 0.96 and 0.93, respectively), Kadum et al[16] have highlighted the superiority of computed tomography when measuring LHO owing to the low interobserver reliability of plain radiographs in their series. In addition, our assessment did not include any clinical outcomes to better appreciate which radiographic variables may be associated with superior outcomes in stemless TSA. Finally, all prostheses were placed by experienced shoulder surgeons, possibly making it difficult to generalize the results to lower-volume or inexperienced surgeons.

Conclusion

This study was a retrospective cohort study evaluating the radiographic anatomic restoration of the glenohumeral joint after both stemmed and stemless humeral arthroplasty. The results showed that only the HNA slightly differed between stemmed and stemless implants, with a slightly more anatomic reconstruction with the stemless design. Regarding preoperative to postoperative differences, apart from a small difference in the HHD, no other statistical differences were found within stemless or stemmed designs. However, each of these findings has limited clinical significance because of very small dissimilarities between cohorts. We contend that, in the hands of experienced surgeons, both stemmed and stemless arthroplasty options reliably reproduce the glenohumeral relationship following TSA.

Disclaimer

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