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Radiographic evaluation of humeral head reconstruction with stemmed and stemless spherical implants compared with stemless elliptical head implants

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Background: The purpose of this study was to compare the accuracy of anatomic reconstruction of three different humeral head designs after anatomic total shoulder arthroplasty.
Methods: Postoperative radiographs of 117 patients who underwent anatomic total shoulder arthroplasty with three different implant designs (stemmed spherical, stemless spherical, and stemless elliptical) were analyzed for landmarks that represented the prearthritic state and final implant position. We assessed the change in center of rotati7on and humeral head height on the anteroposterior view and the percentage of prosthesis overhang on the axillary lateral view. A modified anatomic reconstruction index, a compound score that rated each of the 3 parameters from 0 to 2, was created to determine the overall accuracy of the reconstruction.
Results: Excellent modified anatomic reconstruction index scores (5 or 6 points) were achieved by 68.1% of the cases in the stemless elliptical group compared with 33.3% of the cases in the stemless spherical group and by 28.3% of the cases in the stemmed spherical group ($P = .001$).The mean difference in restoration of humeral head height ($P < .001$) and percentage of prosthesis overhang ($P < .001$) was superior for the stemless elliptical group compared with the two other spherical head groups. There was no difference between groups for the shift in center of rotation ($P = .060$).
Conclusions: In this radiographic investigation comparing three different humeral head designs with respect to anatomic restoration parameters, the stemless elliptical implant more closely restored the geometry of the prearthritic humeral head as assessed by humeral head height, prosthesis overhang, and a compound reconstruction score.

Anatomic total shoulder arthroplasty (aTSA) is as a reliable solution for the treatment of end-stage glenohumeral arthritis. Long-term data support aTSA as an efficient and dependable strategy to alleviate pain and restore function.[13] The goal of anatomic humeral head arthroplasty is to restore the native anatomy of the humeral head geometry to the premorbid condition. Predominantly, it aims to reestablish essential parameters such as humeral head center of rotation, humeral and tuberosity height, and radius of curvature of the articular surface in the sagittal and axial planes.[3,9,11,14] Traditionally, humeral head arthroplasty uses stemmed modular implants in which the glenohumeral relationship is determined by humeral head position, yet ultimately influenced by the morphology of the humeral shaft. Recently, stemless designs have been introduced to mitigate the inherent restrictions placed on diaphyseal reliance to achieve anatomic reconstruction of the humeral head. However, even though the shape of the native humeral head is ellipsoid,[3,7,8] most stemmed and stemless designs have geometrically spherical heads. In 2016, an elliptical stemless humeral head arthroplasty implant was approved by the Food and Drug Administration for anatomic shoulder replacement. In this design, the radius of curvature in the superior-inferior axis is different from the medial-lateral axis to more closely mimic the ellipsoid anatomic profile of the native humeral head.[6]

The purpose of this study was to compare the accuracy of anatomic reconstruction of three different humeral head arthroplasty designs: (1) a stemmed spherical implant, (2) a

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stemless spherical implant, and (3) a stemless elliptical implant, based on postoperative anteroposterior and axillary radiographs. We hypothesized that the stemless elliptical implant would more accurately reproduce the normal geometry and anatomic relationships of the humeral head as compared with the other two implant designs.

Methods

This was a retrospective study based on prospectively collected data of patients who underwent aTSA at our institution by the senior author for the treatment of glenohumeral osteoarthritis between 2014 and 2018. Patients underwent aTSA with a stemmed spherical design (Comprehensive Total Shoulder System, Zimmer Biomet, Warsaw, IN, USA), a stemless spherical design (Comprehensive Nano, Zimmer Biomet, Warsaw, IN, USA), or a stemless ellipsoid design (Catalyst CSR, Catalyst Orthoscience, Naples, FL, USA).

The first 50 patients in 2014 who received the stemmed prosthesis (stemmed group), the first 50 patients in 2016 who received the stemless elliptical prosthesis (stemless elliptical group), and all 31 patients who received the stemless spherical prosthesis as part of a separate IDE trial (stemless spherical group) between 2013 and 2016 were reviewed for inclusion in the present study.[16] Inclusion criteria included a diagnosis of osteoarthritis with an intact rotator cuff. We excluded patients with post-traumatic arthritis, history of fracture, previous rotator cuff repair in the involved shoulder, revision shoulder arthroplasty, and patients with inadequate quality radiographs as defined in the following text. All available postoperative radiographs were evaluated, and the radiographs with the best profile of the implant, both in the anteroposterior and axillary views, were included and analyzed. Following criteria adopted by Alolabi et al[1] and Chalmers et al[4] for the anteroposterior view, we only included radiographs with minimal (< 2mm) overlap of the humeral head at the level of the osteotomy surface, those with a good profile of the greater tuberosity and calcar, and those without overlap between the prosthetic head and the tuberosity and calcar. For the axillary view, we adopted similar criteria of only including images with up to 2 mm of overlap between the humeral head implant and the glenoid vault, a superimposition of the superior and inferior glenoid fossa, and visualization of the lesser tuberosity.

For the anteroposterior radiographs, we used exclusively postoperative views to measure the distance between the anatomic prearthritic and the prosthesis center of rotation (CoR) and humeral head height (HHH). Youderian et al[18] demonstrated that preserved extra-articular landmarks can be used to accurately predict prearthritic humeral CoR, HHH, and humeral head diameter in the setting of glenohumeral osteoarthritis. Precisely, the authors showed that a prearthritic humeral head could be depicted by drawing a best-fit circle using three points that were placed on the following landmarks: the lateral cortex of the greater tuberosity, the medial calcar at the inflection point where the calcar meets the articular surface, and the medial edge of the greater tuberosity at the medial supraspinatus insertion. This representation was compared with a second circle that matched the exact curvature of the prosthetic humeral head (Fig. 1). For the axillary radiographs, the anterior-posterior overhang of the implant was calculated as a percentage figure, by dividing the anterior to posterior dimension of the implant over the anterior to posterior extent of the prepared osteotomy (Fig. 2). For the axial plane, we used a percentage ratio as we believe it gives more practical and useful information than a numeric measurement. In addition, it excludes the necessity of adjusting magnification, which could be challenging for the nonspherical implant in the axillary view. Radiographic analysis was performed by three fellowship-trained shoulder surgeons using Medstrat picture archive and communication system software (Medstrat, Downers Grove, IL, USA). The measured distances in the anteroposterior radiographs were normalized using a magnification coefficient that was calculated by dividing the diameter of the implanted head size (recorded in the operative log) by the diameter of the humeral head measured in the software. Studies have demonstrated reliable intraobserver and interobserver reliability using this methodology.[15]

To objectively quantify and assess the quality of the humeral head reconstruction, we modified the anatomic reconstruction index (ARI) described by Flurin et al[5] to generate a new score that accounted for two validated key parameters in the coronal plane (CoR and HHH), as well as an additional parameter in the axial plane (percentage of prosthesis overhang). The total score is a maximum of 6 points − the sum of a score of 0, 1, or 2 for each of the three parameters. Specifically, for the measurements in the anteroposterior plane, the CoR and HHH differences between the pre-arthritic state and final implant position within 3 mm were given a score of 2; for a difference between 3 and 6 mm was given a score of 1; and for a difference greater than 6 mm was given a score of 0. For the lateral axillary view, the percentage of prosthesis overhang of less than five percent was given a score of 2, between five and ten percent was given a score of 1, and greater than ten percent was given a score of 0. We named this score the modified ARI (Table I). A modified ARI of 5 or 6 was considered excellent, 3 or 4 was considered satisfactory, and 1 or 2 was considered poor.

Continuous variables including the difference in CoR and HHH, as well as the ratio of overhang, were compared using analysis of variance, followed by a Sidak post hoc test. Categorical variables, including the modified ARI, were compared using chi-squared test followed by Sidak post hoc test. Interobserver agreement of radiographic measurements was assessed using the intraclass correlation coefficient. Significance level was set at as 0.05. Statistics were conducted using SPSS (v26; IBM, Armonk, NY, USA).

Results

A total of 117 patients met the inclusion and exclusion criteria, comprising 47 shoulders in the stemless elliptical group, 46 shoulders in the stemmed group, and 24 shoulders in the stemless spherical group. Three patients in the stemless elliptical group, four patients in the stemmed group, and seven patients in the stemless spherical group were excluded from the study for having imperfect anteroposterior or axillary lateral postoperative radiographs. The mean ages for the stemless elliptical, stemmed, and stemless spherical groups were 66.3 ± 11.3 years, 69.2 ± 8.7 years, and 64.3 ± 7.9 years, respectively ($P = .120$). The percentage of men in each group was 59.6%, 50.0%, and 62.5%, respectively ($P = .516$).

Radiographic measurements among the three observers were shown to be consistent and reproducible. The interclass correlation

Table I
Reconstruction index scoring system.

Parameter	Score	Definition
Humeral head height	0	>6 mm difference between anatomic and prosthetic
	1	3-6 mm difference between anatomic and prosthetic
	2	0-3 mm difference between anatomic and prosthetic
Center of rotation	0	> 6 mm difference between anatomic and prosthetic
	1	3-6 mm difference between anatomic and prosthetic
	2	0-3 mm difference between anatomic and prosthetic
Overhang	0	>10% anterior-posterior overhang of the implant
	1	5-10% anterior-posterior overhang of the implant
	2	0-5% anterior-posterior overhang of the implant

Table II
Reconstruction scores, percent per implant type.

Reconstruction score	Stemless elliptical	Stemless spherical	Stemmed
Poor score, 0-2	0.0%	4.2%	8.7%
Satisfactory score, 3-4	31.9%	62.5%	63.0%
Excellent score, 5-6	68.1%	33.3%	28.3%

coefficient was 0.897 for the difference in CoR, 0.867 for the difference in HHH, and 0.802 for prosthesis overhang.

Overall, the stemless elliptical group achieved significantly superior modified ARI reconstruction scores compared with the other two groups ($P = .001$). In total, 68.1% of the cases for the stemless elliptical group reached a score of 5 or 6 points (maximum tier) and were graded excellent, compared with 33.3% of the cases for the stemless spherical group and 28.3% of cases for the stemmed group. Moreover, none in the stemless elliptical group were graded poor with a modified ARI of 1 or 2, compared with 4.2% poor reconstructions in the stemless spherical group and 8.7% of the reconstructions in the stemmed group (Table II). Post hoc analysis revealed significant differences in the modified ARI between the stemless elliptical group as compared with the stemmed group ($P < .001$) and the stemless spherical group ($P = .036$). There was no difference between the stemmed and stemless spherical groups ($P = 1.0$).

There was no detected difference in the accuracy of the restoration of the CoR between the premorbid humeral head and the implanted component for all three prosthesis designs ($P = .060$). The mean difference and standard deviation for the stemless elliptical group were 3.88 ± 1.75 mm, compared with 3.34 ± 2.20 mm for the stemless spherical group and 3.00 ± 1.56 mm for the stemmed spherical group (Table III).

Regarding the accuracy of restoration of the HHH, the stemless elliptical group most closely reproduced the original anatomy compared with the stemless spherical and the stemmed groups ($P < .001$, Table III). Post hoc analysis revealed significant differences between the stemless elliptical and stemless spherical groups ($P < .001$) and between the stemless spherical and the stemmed spherical groups ($P < .001$), but not between the stemless elliptical and the stemmed spherical groups ($P = .160$).

Finally, the percentage of overhang assessed by lateral axillary radiographs showed the stemless elliptical implant to most closely reproduce the original anatomy of the humeral head, compared with the stemless spherical and the stemmed spherical groups ($P < .001$, Table III). Reconstructions with overhang greater than 10% for the stemless elliptical group, the stemmed group, and the stemless spherical group were 0%, 52.2%, and 29.2% ($P < .001$, Table IV). Post hoc analysis revealed significant differences among all groups (stemless elliptical vs. stemless spherical, $P < .01$; stemless spherical vs. stemmed spherical, $P < .01$; and stemless elliptical vs. the stemmed spherical, $P = .03$).

Table III
Mean measurements.

Paramenter	Stemless elliptical	Stemless spherical	Stemmed spherical	*P* value
Change in humeral head height, mm	1.28 ± 0.72	2.85 ± 1.68	1.76 ± 1.26	<.001
Shift in center of rotation, mm	3.88 ± 1.75	3.34 ± 2.20	3.00 ± 1.56	.060
Percent overhang	1.04 ± 0.02	1.08 ± 0.04	1.10 ± 0.04	<.001

Table IV
Score per parameter, percent based on implant type.

Parameter	Score	Stemless elliptical	Stemless spherical	Stemmed spherical
Humeral head height	0	0.0%	4.2%	2.2%
	1	2.1%	37.5%	10.9%
	2	97.9%	58.3%	87.0%
Center of rotation	0	6.4%	8.3%	8.7%
	1	63.8%	37.5%	30.4%
	2	29.8%	54.2%	60.9%
Overhang	0	0.0%	29.2%	52.2%
	1	34.0%	41.7%	30.4%
	2	66.0%	29.2%	17.4%

Discussion

The purpose of this study was to compare the accuracy of anatomic reconstruction of three different humeral head designs. Our principal finding was that the ellipsoid stemless humeral head implant design most closely reproduced the geometry of the native humeral head, as compared with a stemmed and a stemless design with spherical heads, with a greater overall modified ARI score, improved restoration of the HHH, and less prosthesis overhang in the axial plane. There was no difference detected among the groups analyzed for the change in the CoR.

Specifically, our data revealed that the stemless elliptical group achieved significantly lower outliers (ie, poor modified ARI scores, between 0 and 2) and the highest percentage of cases that achieved an excellent modified ARI score (5 or 6). The elliptical stemless prosthesis was especially more accurate in reproducing the original anatomy in the category of HHH, with 98% of cases achieving less than 3 mm of difference compared with the premorbid state. Postoperative anteroposterior radiographs have been shown to be accurate and consistent for detecting prearthritic parameters of the humeral head (CoR and HHH).[1,2,4,10,17,18]

We used good-quality axillary radiographs to calculate overhang of the humeral head implant in relation to the osteotomized metaphyseal bone. As expected, the elliptical stemless implant was demonstrated to be significantly more accurate ($P < .001$) than the other groups, achieving a mean prosthesis overhang of 4%, compared with 8% for the stemless spherical design and 10% for the stemmed spherical design, with two-thirds of the elliptical cases achieving less than 5% of overhang. Although there are no data to support this hypothesis, we believe that prosthesis overhanging in the axial plane could potentially influence subscapularis tendon malfunction, overstuffing, tearing, and insufficiency. To this end, an ellipsoid humeral head design could be advantageous.

To our knowledge, only three previous radiographic comparative studies have examined the effect of stemless vs. stemmed anatomic humeral head implants.[1,2,12] Alolabi et al[1] compared 125 stemmed and 43 stemless humeral implants, both with spherical designs. These authors measured only CoR between the prearthritic state and final implant position, using the same technique as our study, and found a higher deviation for stemless implants vs. stemmed (3.8 ± 2.1 mm vs. 2.5 ± 1.6 mm), with twice as many stemless implants having a deviation > 3 mm (65.1% vs. 31.2%). This contradicts our data, which showed no significant differences between implants in CoR. In this study, multiple surgeons (4) and multiple implant manufacturers (8) were included, possibly hindering the internal validity of the conclusions. Pinto et al[12] also compared only spherical designs, with 21 stemmed designs and 58 stemless designs. The authors used five different radiographic parameters and an ARI to compare implants. They discovered no differences between the two groups for most of the parameters analyzed or for the ARI index, similar to

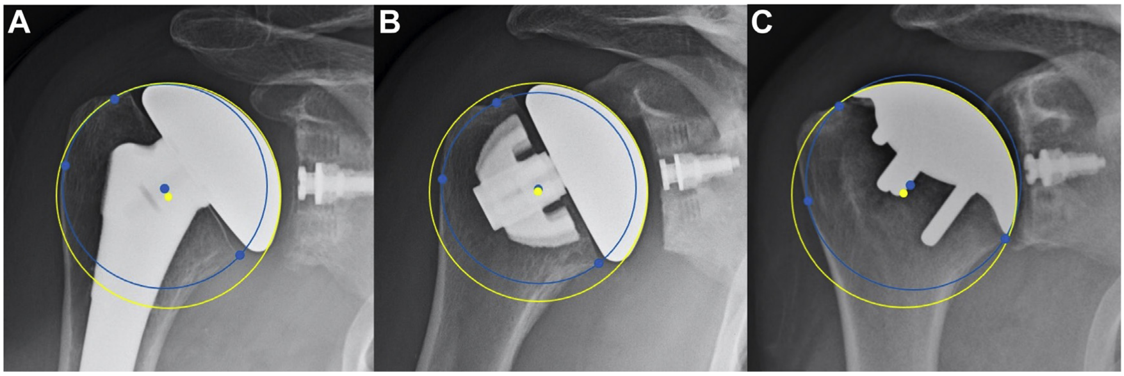

Figure 1 Postoperative true AP radiographs for each implant desingn revealing the anatomic circle with its CoR (*blue circle*) using three preserved bone landmarks (*blue dots*) according to Youderian et al,[18] and the postoperative implant circle and its CoR (*yellow circle*).

our findings, and concluded that radiographic restoration of anatomy is similar for stemmed and stemless spherical designs. Finally, Baroneck et al[2] compared the accuracy of restoration of CoR in 55 stemmed spherical implants and 55 stemless elliptical implants. The authors showed better anatomic restoration for the stemless elliptical implant compared with the stemmed implant (difference in CoR of 1.7 ± 1.2 mm vs. 2.8 ± 1.5 mm), and a significant lower percentage of outliers (14.5% vs. 40.0%, $P = .005$), again contradicting our null findings for CoR. The deviation in CoR for the stemless elliptical design in our study (3.88 ± 1.75 mm) was higher than that reported by Baroneck et al; the reason for these differing results is unclear.

Overall, radiographic parameters after anatomic total shoulder replacement from our data as well as from the studies mentioned previously demonstrate that perfect restoration of the humeral head is challenging to achieve even in the hands of well-trained and experienced shoulder surgeons. However, small shortcomings in shoulder arthroplasty reconstructions may not influence outcomes. Chalmers et al[4] showed that a variation in the CoR between the prearthritic and reconstructed shoulder of up to 4 mm was not associated with a difference in postoperative outcomes in a cohort of 95 patients with shoulder arthritis that underwent anatomic total shoulder replacements. To this matter, there is a paucity of good-quality evidence in the current literature on the effect of anatomic replication of the humeral head in shoulder arthroplasty and clinical outcome scores. We acknowledge that variations between groups for the assessed parameters (HHH, CoR, and overhang) were often small and are possible that those differences may not lead to changes in outcomes, reoperations, or complications. Further research is needed to determine the clinical relevance of our findings.

Strengths of the present study include the fact that we were able to compare three different designs performed by a single high-volume surgeon; previous radiographic studies only focused on comparing stemless vs. stemmed implants. We were able to compare a stemmed and stemless design with an identical modular head as well as a stemless variable radius of curvature implant. Moreover, this is the first study to include axillary lateral radiographs to look at overhang in the anterior to posterior direction, which is a critical parameter when determining the ability of an implant to replicate the normal articular anatomy and also may relate to joint overstuffing and subscapularis tendon over-tensioning.

This study has several limitations. First and most importantly, the radiographic nature of this study does not allow any clinical outcome conclusions. Second, the percent overhang in the anterior to posterior direction is a new parameter that has not been validated by previous studies. There are no validated extra-articular landmarks on the axillary radiograph similar to the anteroposterior radiograph that can act as a proxy to obtain the radius of curvature or CoR in this plane. Finally, while the fact that a single surgeon using only one implant design per group strengthens the internal validity of this study, results may not be able to be extrapolated to other shoulder replacement systems or to lower-volume or less-experienced surgeons.

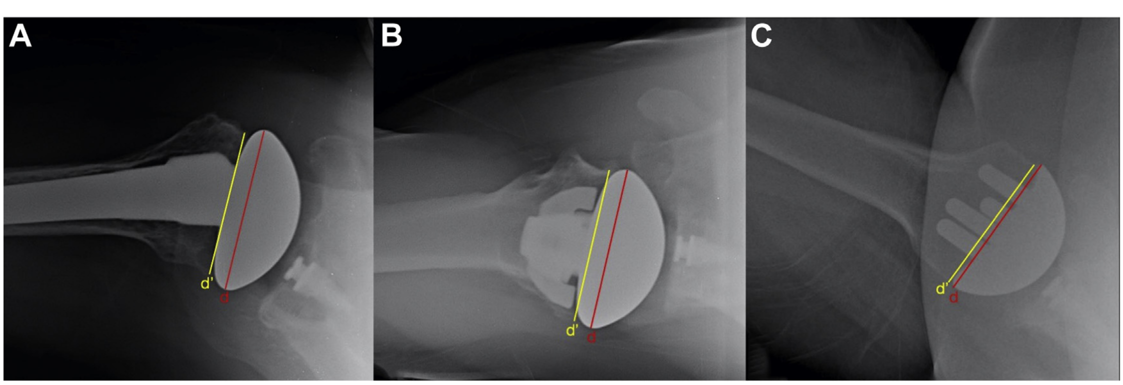

Figure 2 Postoperative axillary radiographs for each implant design used to calculate the percentage of overhang of the each implant by dividing the anterior to posterior dimension of the implant “d” (*red line*) divided by the anterior to posterior extend of the prepared osteotomy “d” (*yellow line*).

Conclusion

In this radiographic investigation comparing three different humeral head designs with respect to anatomic restoration parameters, the stemless elliptical implant more closely restored the geometry of the prearthritic humeral head as assessed by HHH, prosthesis overhang and a compound reconstruction score.

Disclaimers:

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