Total shoulder arthroplasty with nonspherical humeral head and inlay glenoid replacement: clinical results comparing concentric and nonconcentric glenoid stages in primary shoulder arthritis

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Background: Glenoid morphology can influence the outcomes of total shoulder arthroplasty. This study examines the results of a new technique according to preoperative glenoid staging. We hypothesized that there would be no statistically significant difference in outcomes between Levine concentric (Walch A) and Levine nonconcentric (Walch B) glenoids treated for primary glenohumeral arthritis using nonspherical humeral head and inlay glenoid replacement.

Methods: This retrospective case series included 31 shoulders in 29 patients (25 male, 4 female), with an average age of 58.5 years. Outcomes included the Penn Shoulder Score (PSS), visual analog scale for pain (VAS-Pain), range of motion, radiographic analysis, and complications. Inclusion criteria were primary glenohumeral arthritis, intact rotator cuff, and no prior open shoulder surgeries.

Results: Mean follow-up was 42.6 months (range, 24-74 months). The study included 7 concentric and 24 nonconcentric glenoids. Outcomes comparison showed no statistically significant differences in PSS domains including Pain ($P = .92$), Function ($P = .98$), Satisfaction ($P = .89$), and Total ($P = .98$); forward flexion ($P = .78$); external rotation ($P = .64$); and VAS-Pain ($P = 0.12$). At the last follow-up, the mean PSS Pain was 25.3/30, Function 52.7/60, Satisfaction 8.4/10, and Total 87.0/100. The mean forward flexion was 167.3°, external rotation 56.6°, and VAS-Pain 0.9. There were no signs of periprosthetic fracture, component loosening, osteolysis, and hardware failure, and no revisions or 90-day rehospitalizations were required. One patient was prophylactically treated with oral antibiotics for a history of prior infection and 1 patient required a later open biceps tenodesis after a traumatic proximal biceps rupture postoperatively.

Conclusion: Nonspherical shoulder arthroplasty with inlay glenoid replacement demonstrated excellent clinical benefits for both concentric and nonconcentric glenoids. The technique appears to be a promising option for glenohumeral arthritis even in the presence of posterior glenoid erosion.

Osteoarthritis (OA) of the glenohumeral (GH) joint, though not as commonly diagnosed as that of the hip or knee joint, can be a disabling condition resulting in pain and loss of function.[41] For patients who have not responded to conservative measures, many surgical options are available today including stemmed hemi-arthroplasty (HA), stemmed total shoulder arthroplasty (TSA) in conventional or reverse configurations, as well as stemless TSA, and humeral head (HH) resurfacing procedures with or without glenoid replacement. The broad arthroplasty landscape offers advantages for individual patient treatment, but registry results underline the dominant use of total shoulder procedures with a rapidly growing rate of reverse TSA.[2] A second trend shows renewed interest in less invasive procedures with the introduction of new stemless and resurfacing options in the United States market over the past decade. Their advantages include a short operative time, a low risk of periprosthetic fracture, diaphyseal bone preservation, and an easier revision compared with stemmed arthroplasty, which makes them particularly suited for primary arthroplasty in OA.[7,29,31,37,40] Resurfacing procedures avoid the HH osteotomy and preserve additional bone stock for implant fixation. This is contrasted with improved glenoid access in stemmed and stemless procedures when using conventional onlay preparation techniques. The

distinction between onlay and inlay or inset techniques is newer concepts in glenoid replacement.[12,14,15] The inlay goal is to improve component stability, avoid joint line lateralization, and intra-articular volume changes. On the humeral side, stemmed, stemless, and onlay resurfacing arthroplasty predominantly use spherical components despite a growing body of evidence that supports the use of nonspherical implants[12,15,21,25] that reflect the anatomic differences in the larger superior-inferior (SI) and smaller anterior-posterior (AP) dimensions.[18,20,24,44]

The purpose of our study was to examine the results of TSA with a nonspherical HH implant combined with an inlay glenoid replacement. The technique introduces a new off-axis glenoid preparation that reduces the challenges when combining HH resurfacing with glenoid replacement. To establish the clinical benefits across the most frequently encountered glenoid stages, we hypothesized that there would be no statistical significance in clinical and radiographic outcomes comparing patients with concentric vs. nonconcentric glenoid morphology, thus making the combination of nonspherical HH replacement and inlay glenoid arthroplasty an attractive option in primary shoulder OA.

Materials and methods

We performed a retrospective review of all patients who were treated with a combination of nonspherical HH resurfacing and inlay glenoid replacement (HemiCAP OVO/Inlay Glenoid Total Shoulder System; Arthrosurface, Franklin, MA, USA) by a single surgeon from 2011 to 2016.

Patient population

Inclusion criteria were based on a diagnosis of primary GH arthritis, an intact rotator cuff, and no prior shoulder surgeries other than an arthroscopic débridement. Thirty-three patients were initially identified. Two patients had staged bilateral procedures, 2 were excluded because of prior open procedures, 1 was lost to follow-up, and 1 was excluded with a Walch type C glenoid leaving 31 shoulders in 29 patients. All patients provided informed consent and were contacted via phone to complete a last follow-up assessment, which determined postoperative Penn Shoulder Score (PSS) and visual analog scale for pain (VAS-Pain) scores. Range of motion measurements and final radiographic images were obtained from the most recent in-person clinical encounter, all at a minimum of 24 months postoperatively.

Surgical technique

All procedures were performed by a single surgeon (A.M.), using a combination of nonspherical HH and inlay glenoid replacement. HH sizes have a varying mismatch to simulate an ovoid shape; these sizes range from 42 × 46 mm to 54 × 58 mm with a 4-mm nonspherical mismatch between the larger SI and smaller AP dimensions with a varying radius of curvature in both planes. The undersurface of HH implants is spherical to allow for surface reaming. Cobalt-chromium alloy HH components are connected to a cannulated titanium alloy taper post. Screw fixation combined with subchondral bone support provides rigid fixation. The inlay glenoid component is made of ultrahigh-molecular-weight polyethylene that is cemented into place. Sizes include 2 diameters (a single 20 and a double with a 15- and 20-mm bilobed implant) with 2 different curvatures to match HH convexities.

Patients underwent general anesthesia and were placed in a beach chair position. A standard deltopectoral approach was used. A subscapularis tenotomy was performed approximately 1.5 cm medial to the insertion on the lesser tuberosity, stay sutures were
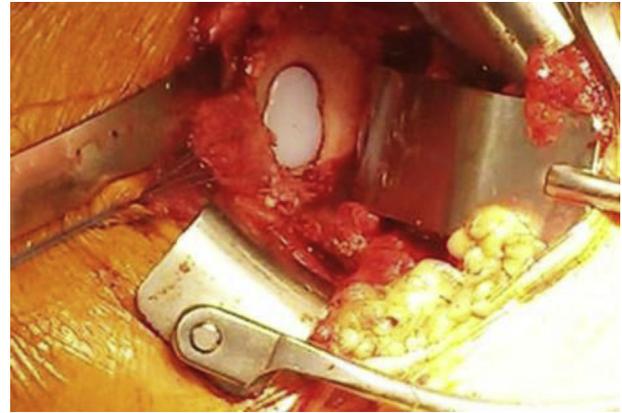
Figure 1 Intraoperative image of the final inlay glenoid component.

placed in the leading edge of the tendon, and the joint was exposed through a capsulotomy passed the 6 o'clock position on the inferior glenoid border. The arm was externally rotated and the HH was exposed. To identify the center of the HH articular surface, templates were used to mark the largest dimension in the AP plane. The integrated 4 mm mismatch provides a suggestion for a corresponding SI template. Once the largest SI dimension was reconfirmed, the AP/SI intersection marked the center of the articular surface. AP dimensions are less likely to be influenced by osteophytes, thereby providing a better starting point for calibrating HH size. A guide pin was inserted perpendicular to the surface into the marked intersection and a centering shaft was then placed with the stop set at the level of the humeral surface. If there is collapse of the humeral articular surface, the centering shaft can be left proud to allow for this. We felt it was always better to undersize to prevent "overstuffing." A surface reamer, based on the smaller AP dimension, was placed over the centering shaft and the HH was reamed to match the undersurface of the prosthesis. All periarticular osteophytes were carefully removed to optimize postoperative range of motion. A trial implant of corresponding diameter and offsets allowed verification of proper fit, and a fixation post was placed using calibrated depth control.

Attention was then turned to the glenoid, and a guide pin was inserted using a 30° off-axis drill guide. The guide wire was set posterior, not central, as the glenoid is reamed at an angle using a semicircular paddle reamer to a depth stop. The angled guide and reamer were designed to allow access to the glenoid without resecting the HH. In cases with glenoid damage extending superiorly, a secondary ream was performed to accommodate the larger component. A trial was inserted to verify placement with slight recession to the glenoid periphery. Cement holes were made in the glenoid vault and a central peg hole was drilled. Cement was pressurized multiple times inside the implant bed with meticulous attention to a proper technique that included additional backside cement application before placing the implant with digital compression and an impactor. An intraoperative image of the final inlay glenoid component is shown in Figure 1. The final HH prosthesis was then placed on the taper screw and impacted until the 2 components engaged with the morse taper and were firmly seated on the prepared bone bed. A standard closure with subscapularis repair was performed to conclude the procedure.

Postoperative care and physical therapy

Postoperatively, patients were placed into a sling and passive-assisted motion was allowed immediately in all planes except

Table I
Clinical outcomes comparison at the last follow-up

Domain	Type I concentric (A1 + A2) (n = 7): mean ± SD; CI	Type II nonconcentric (B1 + B2) (n = 24): mean ± SD; CI	P value type I vs. type II	B2 glenoids (n = 15): mean ± SD; CI, P value: comparison with concentric glenoids
PSS-Pain (maximum 30)	26.0 ± 4.7; 21.6, 30.4	25.8 ± 4.8; 23.8, 37.8	.92	25.0 ± 5.5; 22.0, 28.0, P = .68
PSS-Function (maximum 60)	52.6 ± 6.5; 46.7, 58.6	52.7 ± 7.1; 49.7, 55.7	.98	53.0 ± 6.5; 49.4, 56.6, P = .90
PSS-Satisfaction (maximum 10)	8.3 ± 2.2; 6.2, 10.3	8.4 ± 2.2l; 7.5, 9.3	.89	8.0 ± 2.7; 6.5, 9.5, P = .81
PSS-Total (maximum 100)	86.9 ±12.3; 75.5, 98.3	87.1 ±12.9; 81.6, 92.5	.98	86.3 ± 14.0; 78.6, 94.0, P = .92
VAS-Pain (maximum 10)	0.3 ± 0.8; −0.4, 1.0	1.1 ± 1.3; 0.6, 1.7	.12	1.4 ± 1.5; 0.6, 2.2, P = .07
Forward elevation	168.6 ± 9.0; 160.3, 176.9	167.0 ± 13.9; 161.0, 173.0	.78	165.4 ± 16.2; 156.0, 174.7, P = .63
External rotation	59.3 ± 14.8; 45.6, 78.0	55.7 ± 18.2; 47.6, 63.8	.64	56.1 ± 17.9; 45.7, 66.4, P = .69

SD, standard deviation; *CI*, confidence interval; *PSS*, Penn Shoulder Score; *VAS-Pain*, visual analog scale for pain.

external rotation (ER), which was limited to 20° for the first 6 weeks to protect the subscapularis repair. At 6 weeks postoperatively, patients began a rotator cuff strengthening program and terminal stretches with increasing exercises for shoulder strength.

Radiographic assessment

Preoperative glenoid staging was based on axillary radiographs as advanced imaging was not obtained on all patients. Aronowitz et al[1] found substantial agreement between axillary radiographs and computed tomography scans and concluded that plain film axillary radiographs can be used for glenoid staging. All glenoids were divided according to the Levine classification.[28] A type I glenoid was defined as a concentric bony surface with no flattening or significant bone loss. A type II glenoid was no longer concentric as a result of an uneven bone loss in addition to the cartilage surface loss and was characterized by a posterior bone loss with a shift of the articulation posteriorly.[28] Radiographs were also assessed according to the Walch classification,[42] which divides glenoid morphology into 5 types based on symmetry, wear, and glenoid retroversion. Stages A1 and A2 were considered concentric, and B1 and B2 nonconcentric.

Periprosthetic radiolucency assessment was performed according to a modified method described by Lazarus et al[26] to accommodate a single pegged glenoid. The same grading system was used for humeral components. The periprosthetic radiolucency grade was defined by the thickness of lucent lines and their extent surrounding each component (complete vs. incomplete). This resulted in 6 grades from "no radiolucency" (grade 0) to "complete radiolucency >2 mm" (grade 6) (Tables I and II). The assessment was performed on AP and axillary radiographs at the last follow-up.

Radiographs were also reviewed for signs of osteolysis, which was defined as focal or extended periprosthetic lobulated radiolucency representing bone loss due to implant-associated inflammatory processes at the implant-bone interface.[9] Implant subsidence and tilt were compared on first postoperative and last follow-up films.[38] Subsidence was defined as translational motion of the implant relative to the humerus or glenoid cavity leading to sinking or impaction with or without tilt. Clinically relevant thresholds were defined as 5 mm for subsidence and 10 mm for tilt.[38] SI HH translation comparing preoperative and last follow-up radiographs was assessed according to Poppen and Walker[34] measuring HH excursion defined as the distance between the center of the HH and the glenoid cavity along the glenoid axis.

Radiographs were reviewed for signs of periprosthetic fracture, and hardware failure including component dislocation, fracture, or disengagement comparing preoperative with postoperative AP and axillary views (Fig. 2). All radiographic assessments were completed by the lead (A.C.E) and senior (A.M.) authors.

Outcomes assessment

A descriptive analysis of the overall study population included summaries for demographics, diagnosis, improvement in range of motion, and last follow-up patient-reported outcomes.

The last follow-up PSS and subdomains, VAS-Pain, range of motion, and radiographic results were compared between the preoperative Levine and Walch glenoid stages as the primary study endpoint.[28,42] The PSS has shown to be a reliable and valid measure for reporting patient outcomes with various shoulder disorders including shoulder arthroplasty.[27] The instrument is based on a 100-point self-reported questionnaire consisting of a total score (PSS-T) and its 3 subscales: Function (60 points), Pain (30 points), and Satisfaction (10 points).[27] The visual analog scale for pain (VAS-Pain, 0-10) was used with 0 describing "no pain" and 10 the "worst pain imaginable." Range of motion measurements included active forward flexion (FF) and active ER with the elbow at the side. Differences in intraoperative complications, transfusion requirements, hospital stay, 90-day rehospitalization rate, reoperations, and any related revisions were reviewed.

Further subgroup analysis was performed to assess the overall improvement in patient-reported outcomes comparing preoperative with postoperative PSS (n = 16) and VAS-Pain scores (n = 16).

PSS outcomes were evaluated against the published reference of the minimal clinically important difference (MCID) and substantial clinical benefit (SCB), benchmarks to describe a patient's treatment experience comparing preoperative with postoperative changes.[32]

Table II
Comparison of periprosthetic radiolucency and humeral head translation

Radiographic measurement	Type I Concentric (n = 7), n/%	Type II Nonconcentric (n = 24), n/%
Humerus: periprosthetic radiolucency	Mean grade: 1.14	Mean grade: 1.21
Grade 0: no lucent lines	0/0	0/0
Grade 1: incomplete <1 mm	6/85.7	19/79.2
Grade 2: complete <1 mm	1/14.3	5/20.8
Grade 3: incomplete 1-2 mm	0/0	0/0
Grade 4: complete 1-2 mm	0/0	0/0
Grade 5: incomplete >2 mm	0/0	0/0
Grade 6: complete >2 mm	0/0	0/0
Glenoid: periprosthetic radiolucency	Mean grade: 2.0	Mean grade: 1.71
Grade 0: no lucent lines	0/0	0/0
Grade 1: incomplete <1 mm	3/42.9	13/54.2
Grade 2: complete <1 mm	2/28.6	7/29.2
Grade 3: incomplete 1-2 mm	1/14.3	2/8.3
Grade 4: complete 1-2 mm	1/14.3	2/8.3
Grade 5: incomplete >2 mm	0/0	0/0
Grade 6: complete >2 mm	0/0	0/0
Superior/inferior humeral head translation (pre to post) (mm), mean ± SD	3.6 ± 1.6 (pre) 2.8 ± 2.0 (post) (change P = .4)	4.5 ± 1.7 (pre) 3.7 ± 1.6 (post) (change P = .11)

SD, standard deviation.
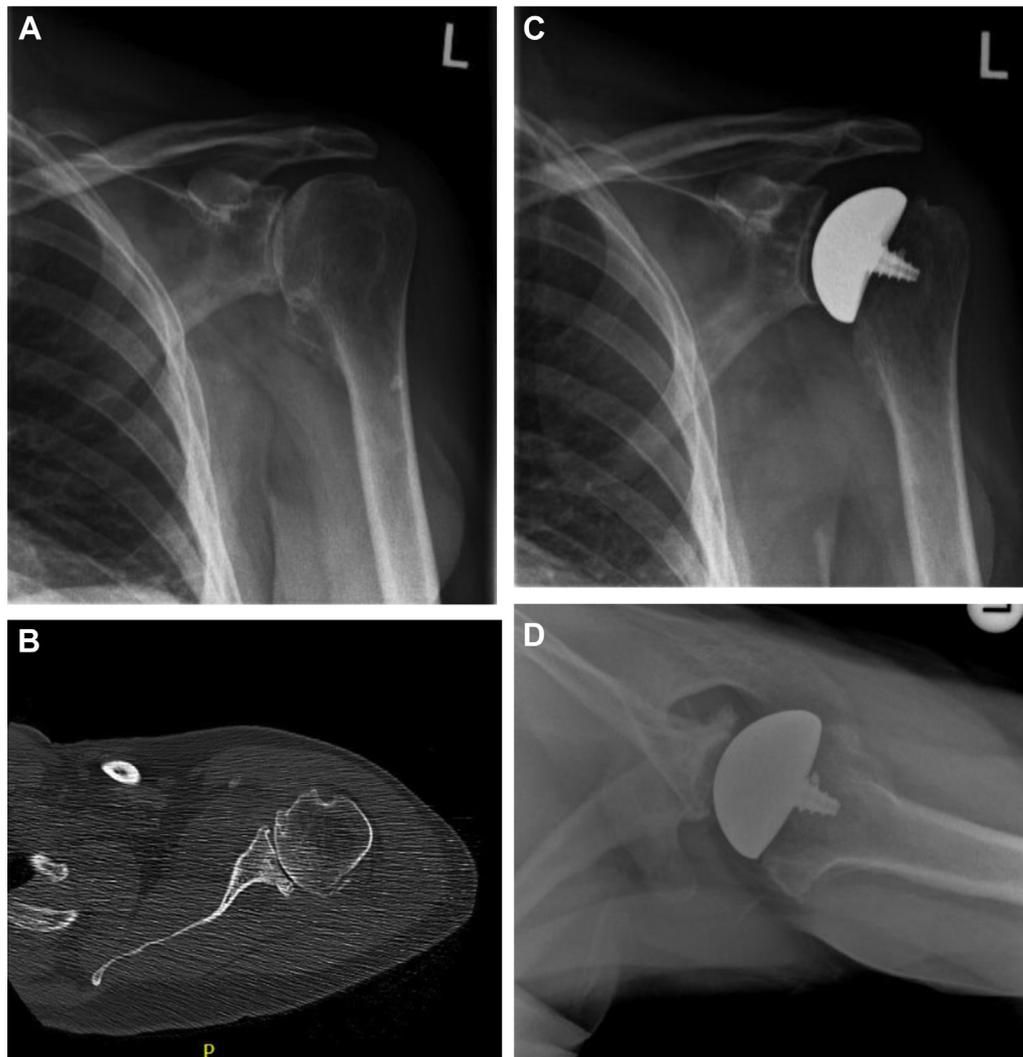
Figure 2 (**A, B**) Preoperative anterior-posterior radiograph and axial computed tomography of a nonconcentric B2 glenoid. (**C, D**) Twenty-six months' follow-up imaging.

A previous study established an improvement threshold of 11.4 points on the PSS-T; the minimal detectable change was ± 12.1 scale points.[27] The maximal possible improvement in the Penn Total Score was determined using the formula 100% × (score at follow-up − preoperative score)/(maximum score − preoperative score).[32] A 30% threshold indicates the MCID and a 50% improvement represents a SCB.[32] Patient-reported outcomes were analyzed according to the 2 glenoid component sizes used in the study, as well as the American Society of Anesthesiologists (ASA) score that was used to determine the physical status of patients before surgery. ASA 1 corresponds to normal, healthy patients, ASA 2 includes patients with a mild systemic disease, and ASA 3 includes patients with a severe systemic disease.[11]

Statistical analysis

Data were analyzed using SPSS software version 25.0 (IBM, Armonk, NY, USA). Continuous data were tested for normality using the Shapiro-Wilk test. Descriptive statistics of categorical variables were reported with frequencies and percentages, and results were analyzed using the Pearson χ^2 test. Continuous variables were reported with mean, standard deviation, and confidence interval (CI) providing 95% confidence that the true mean is between the lower and upper bound for each variable. Analysis of continuous variables was performed using the Student *t*-test and the Wilcoxon rank-sum test depending on the normality of data distribution. Significance was determined at $P < .05$ for all assessments.

Hypothesis testing of clinical outcomes parameters included postoperative PSS scores, VAS-Pain, FF, and ER. The distribution of these variables was assessed using the independent samples Mann-Whitney *U* test (95% CI, significance level .05) for variables with 2 groups and the Kruskal-Wallis test for variables with more than 2 groups.

Results

The study included 31 shoulders in 29 patients (25 males, 86.2%; 4 females, 13.8%) with a mean age of 58.5 years (range, 42-71 years). The preoperative diagnosis for all shoulders was OA with a grade 4 Kellgren Lawrence (KL) stage in 25 shoulders (80.6%), grade 3 in 5 shoulders (16.1%), and grade 2 in 1 shoulder (3.2%). The mean follow-up was 42.6 months (24-74 months).

The concentric, Levine type I group consisted of 7 shoulders (22.6%) (all male) with a mean patient age of 56.9 ± 8.2 years (range, 47-68; median, 58). According to the Walch classification,

Table III
Improvement in patient-reported outcomes

Domain	Preoperative, n = 16	Last follow-up, n = 16	Change, n = 16	P value
PSS-Pain (maximum 30)	13.8 ± 5.4 (10.9, 16.6)	26.9 ± 3.3 (25.1, 28.6)	13.1 ± 5.6 (10.1,16.1)	<.001
PSS-Function (maximum 60)	26.7 ± 11.7 (20.4, 32.9)	53.2 ± 6.3 (49.9, 56.6)	26.6 ± 12.6 (19.9, 33.3)	<.001
PSS-Satisfaction (maximum 10)	1.8 ± 1.6 (0.9, 2.6)	8.5 ± 2.1 (7.4, 9.6)	6.8 ± 2.7 (5.3, 8.2)	<.001
PSS-Total (maximum 100)	42.2 ± 17.1 (33.1, 51.3)	88.6 ± 9.9 (83.3, 93.9)	46.5 ± 19.2 (36.2, 56.7)	<.001
VAS-Pain (maximum 10)	6.4 ± 2.0, 6.5 (5.3, 7.5)	1.0 ± 1.4, 0.5 (0.3, 1.7)	−5.4 ± −2.4, −5.5 (−6.7, −4.1)	<.001

PSS, Penn Shoulder Score; *VAS-Pain*, visual analog scale for pain.
Data reported as mean ± standard deviation (confidence interval).

there were 3 A1 (9.7%) and 4 A2 glenoids (12.9%). The non-concentric Levine type II group consisted of 24 shoulders (77.4%) (20 male, 4 female) with a mean age of 59.0 ± 7.2 years (range, 42-71; median, 58). This group included 9 Walch B1 (29.9%) and 15 B2 glenoids (48.4%).

Hypothesis testing of clinical outcomes at the last follow-up included postoperative PSS scores with its subdomains for pain, function, and satisfaction; VAS-Pain; FF; and ER. The distribution of these variables was the same across concentric and nonconcentric preoperative glenoid Levine stages retaining the null hypothesis for all parameters ($P > .05$ for all tests) with no statistically significant differences among the 2 Levine groups and the different Walch glenoid stages. B2 glenoids, the largest subgroup, showed similar outcome scores to concentric A1 and A2 glenoids (Table I).

Analysis of humeral implant fixation showed an average grade of 1.14 for the concentric and 1.21 for the nonconcentric group. None of the humeral lucent lines were graded higher than grade 2 (complete, <1 mm) in either group. The average glenoid-sided periprosthetic radiolucency was graded as 2.0 for concentric and 1.71 for nonconcentric shoulders. None of the glenoid components had any radiolucency of >2 mm. The highest observed grade in the concentric group was "complete 1-2 mm" in 1 of 7 patients and 2 of 24 patients in the nonconcentric group. The average radiolucency grade for all humeral implants was 1.19 and 1.77 for all glenoids (Table II). No patient in either group showed component subsidence (5 mm) or tilt (10 mm) that was clinically relevant according to Sanchez-Sotelo et al.[38] There was no evidence of implant failure including dislocation, fracture, or disengagement. No patients exhibited signs of periprosthetic fracture, osteolysis, component loosening, or failure. HH translation along the glenoid axis in the SI plane was reduced on postoperative imaging in both groups (Table II).

Overall clinical results

The patients' ASA gradings were as follows: ASA 1 (n = 4, 12.9%), ASA 2 (n = 20, 64.5%), and ASA 3 (n = 3, 9.7%). The ASA grading was not available for 4 patients (12.9%). Clinical outcomes at the last follow-up (PSS, VAS-Pain, FF, ER) were also tested across ASA Classifications, sex, and preoperative KL grade, resulting again in the same distribution across both sexes, and all 3 ASA and KL OA grades ($P > .05$ for all tests). Clinical outcomes of the 2 glenoid component sizes showed the same distribution in all variables, except for FF (20 mm, n = 21, median FF 170°; 25 mm, n = 10, median FF 160°).

Comparison of preoperative with postoperative range of motion showed a significant improvement in FF by 52.3° (from 114.6° to 167.3°) and ER by 37.2° (from 16.2° to 56.6°) ($P < .001$). At the last follow-up, the mean PSS Pain was 25.8 ± 4.7, PSS Function was 52.7 ± 6.9, PSS Satisfaction was 8.4 ± 2.2, PSS-T was 87.0 ± 12.6, and VAS-Pain was 0.9 ± 1.2.

Preoperative scores were available for 16 shoulders (51.6%) (15 male and 1 female), with an average age of 56.4 years (range, 42-69 years). The mean VAS-Pain score improved from 6.4 to 1.0, and the mean Penn Total Score more than doubled from preoperative levels. Changes in PSS domains and VAS-Pain are summarized in Table III. The individual improvement in PSS-T (range, 14.0-85.9) indicated that all patients with baseline scores surpassed the PSS MCID (11.4 scale points) and minimal detectable change (12.1 scale points) thresholds for TSA.[27] The maximal possible improvement[32] in the Penn Total Score showed that all patients surpassed the MCID of >30% and 94% achieved a significant clinical benefit of >50% improvement (Fig. 3).

No intraoperative complications were encountered, and no patient required perioperative transfusions. Thirty of 31 (96.8%)
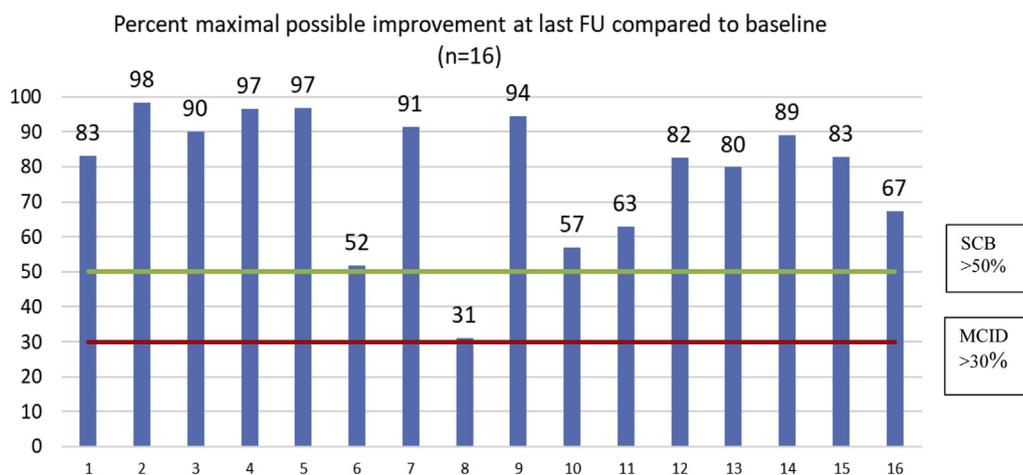
Figure 3 Percent maximal possible improvement on the Penn Total Score. *FU*, follow-up; *SCB*, substantial clinical benefit; *MCID*, minimal clinically important difference.

Table IV
Literature comparison of concentric and eccentric glenoid morphology

| | Hussey 2015[*] | | Current study[†] | |
	Concentric	Eccentric	Concentric	Eccentric
Follow-up (mo)	49.2	52.3	36.7	44.3
Age, mean (range) (yr)	67.0 (37-88)	66.0 (42-82)	56.9 (47-68)	59.0 (42-71)
FF (°) (mean ± SD)				
Preoperative	87.9 ± 36.8	96.6 ± 35.7	118.6 ± 30.2	113.2 ± 38.9
Postoperative	155.8 ± 31.5	156.7 ± 33.0	168.6 ± 9.0	167.0 ± 13.9
ER (°) (mean ± SD)				
Preoperative	21.0 ± 25.5	22.4 ± 23.4	20.0 ± 24.0	15.3 ± 19.1
Postoperative	58.9 ± 37.7	59.0 ± 27.0	59.3 ± 14.8	55.7 ± 18.2
VAS-Pain/10 (mean ± SD)	1.7 ± 2.7	2.2 ± 2.7	0.3 ± 0.8	1.1 ± 1.3
PRO (mean)	ASES (80.8 ± 20.8)	ASES (77.6 ± 21.2)	Penn Total Score (86.9 ± 12.3)	Penn Total Score (87.1 ± 12.9)
Revision (%)	2	2	0	0
Glenoid loosening (%)	5.6	12.2	0	0

FF, forward flexion; SD, standard deviation; ER, external rotation; VAS, visual analog scale; PRO, patient-reported outcomes; ASES, American Shoulder and Elbow Surgeons. VAS-Pain and PRO = Postoperative only.
Endpoint reporting was aligned according to Hussey et al.[22]
[*] Foundation/Turon Total Shoulder System (DJO Global, Vista, CA, USA)
[†] HemiCAP OVO/Inlay Glenoid (Arthrosurface Inc., Franklin, MA, USA)

procedures were performed on an outpatient basis with a hospital discharge within 23 hours. One patient required a postoperative endocrine consult (concentric) because of pre-existing adrenal insufficiency and stayed for 2 nights in the hospital. No patient underwent rehospitalization within 90 days of surgery, and no implant revisions were performed during the follow-up period. One patient (nonconcentric) was treated as a precaution with postoperative antibiotics regimen due to a history of methicillin-resistant *Staphylococcus aureu*s infection. Another patient (nonconcentric) suffered a biceps tendon rupture at 16 months' follow-up during weightlifting and underwent an open biceps tenodesis.

Discussion

We examined the outcomes combining an inlay glenoid component with nonspherical HH resurfacing at a mean follow-up of 42.6 months. Results showed no significant differences in patient-reported outcomes including pain relief, function, and satisfaction comparing preoperative concentric with nonconcentric glenoid morphology. We found a significant improvement in range of motion that was consistent across glenoid stages. All patients with baseline Penn scores surpassed the 30% MCID threshold on their maximal possible improvement, and 94% met or exceeded the SCB mark (≥50%). At the last follow-up, our results demonstrated excellent pain relief and patient satisfaction combined with a low-risk profile and no revisions during the study period.

TSA has shown to be effective in reducing pain and improving function in numerous studies;[5,19,23,35,41] however, there is a paucity in the literature comparing TSA outcomes for concentric and eccentric glenoids. To the best of our knowledge, no glenoid stage–specific investigations have been reported using stemless or onlay resurfacing implants. Hussey et al[22] reported the clinical and radiographic results of 344 shoulders in 309 patients treated with a stemmed, modular total shoulder system for primary GH OA and assessed outcomes of concentric and eccentric preoperative glenoid wear patterns. Their clinical results were similar in both groups, but eccentric glenoids demonstrated a more than 2-fold increase in component loosening. In comparison, our study showed no clinically relevant glenoid loosening regardless of the preoperative glenoid morphology, and the mean VAS-Pain in our patients was half of those reported by Hussey et al[22] (Table IV). Greiner et al[13] studied the influence of the Walch glenoid type on the clinical and radiographic results of 113 glenoids in stemmed

TSA. The amount and extent of radiolucent lines were significantly higher in Walch glenoid types B2 and C in comparison with A1, A2, and B1. No significant differences in the Constant scores were found between the 2 groups. Other studies reconfirmed these findings after stemmed TSA in patients with glenoid erosion reporting a periprosthetic radiolucency rate ranging from 21% to 48%.[8,33,43]

Independent of preoperative glenoid morphology, long-term results of stemmed TSA with onlay glenoids have shown periprosthetic radiolucency rates ranging from 32% to 82% using various components.[3,10,37,39] Stemless arthroplasty[16] and onlay HH resurfacing[30,36] combined with onlay glenoids have shown similar rates from 53% to 89%. Inset or inlay glenoids are more recent designs and therefore lack long-term assessment to date. Our results showed that 80.6% of all glenoids had lucent lines less than 1 mm and none had greater than 2 mm, though longer term follow-up is needed to conclude implant stability for inlay or inset glenoid components as in other reports.[12,14,15]

Both inset[15] and inlay[12] glenoids follow a similar placement concept that lies within the original glenoid joint line that provides protection from the rocking-horse phenomenon and shear forces during GH translation and results in a significantly lower risk of loosening in basic science studies.[12,15] In 2017, Gagliano et al[12] compared the loading characteristics of onlay and inlay glenoid components after TSA in 8 matched cadaveric shoulder pairs. The study showed that the combination of a nonspherical HH and inlay glenoid component achieved similar contact forces as seen in the native glenoid periphery, whereas onlay specimens were exposed to increased edge loading leading to loosening. The authors concluded that the inlay glenoid showed superior results for biomechanical stability and resistance to loosening.

Glenoid component stability is not only affected by its design and fixation method, but also by the shape, volume, and position of the HH component. The vast majority of humeral components in TSA are spherical. However, nonspherical HH implants have demonstrated a 3 times better fit,[25] and finite element analysis showed a restoration of physiological shoulder motion, a limitation in eccentric glenoid loading and 8 times lower bone stress[6] compared with spherical head replacement. Mechanical testing reconfirmed these results placing the center of rotation closer to normal in nonspherical HH implants,[17] thereby providing better contact mechanics and a limitation in eccentric loading. The reduced risk of intra-articular volume changes with a more anatomical substitution on both sides of the joint may provide less stress on the subscapularis repair, rotator cuff, and other soft
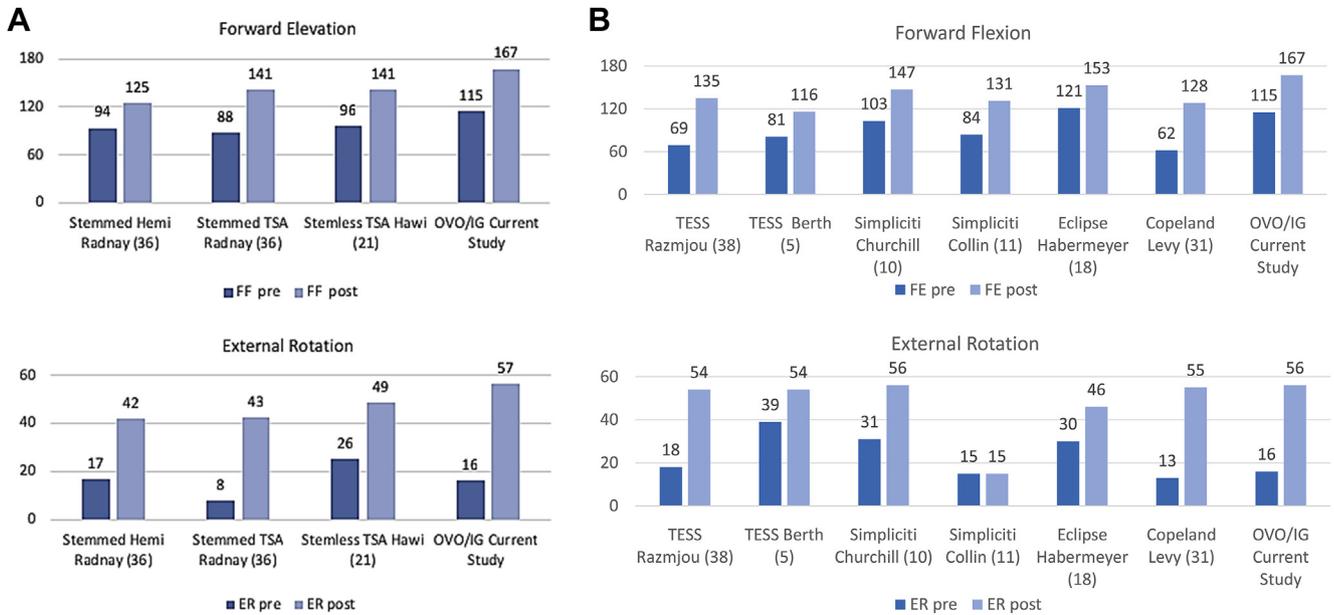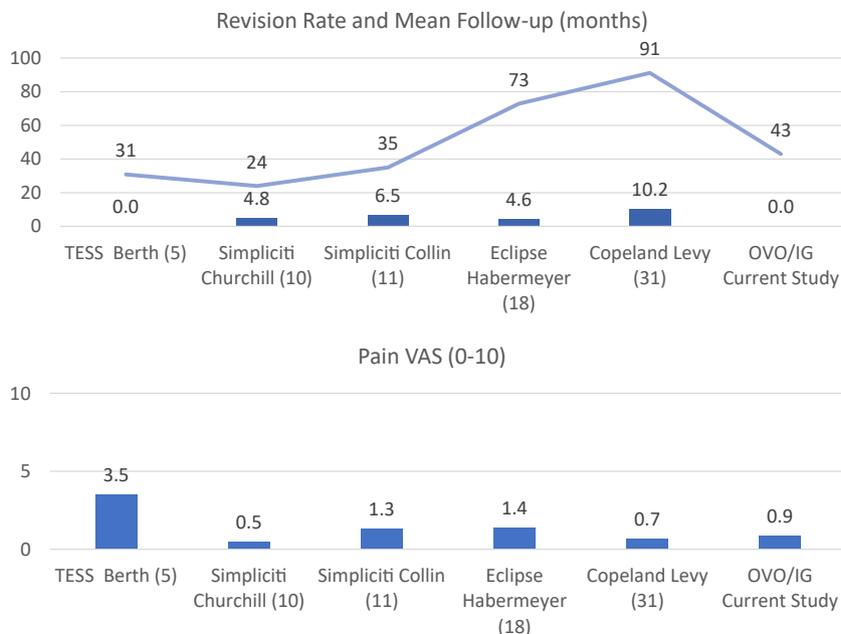
Figure 4 (**A**) Literature comparison of range of motion from systematic reviews. (**B**) Literature comparison of range of motion for nonstemmed total shoulder arthroplasty (TSA). *FF*, forward flexion; *ER*, external rotation; *TESS*, Total Evolutive Shoulder System; *FE*, forward elevation.

tissues, which may lead toward better motion and more accurate replication of the normal shoulder.[25]

Radnay et al[35] performed a systematic review comparing stemmed TSA with HA in the treatment of primary GH arthritis. The study included 1952 patients with a mean follow-up of 43.4 months. The mean age was 66 years. There were 1238 TSA procedures and 712 hemiarthroplasties. The study showed better forward elevation in TSA compared with HA, whereas ER was similar. These results are comparable with stemless TSA reported by Hawi et al[19] in a systematic review of 11 studies and 929 patients with a mean follow-up of 26 months. Our range of motion results compare favorably with stemmed, stemless, and onlay resurfacing procedures—a benefit that is of particular interest to our relatively

young patient population (Fig. 4, A, B). A comparison of pain relief and revision rate by follow-up using a less invasive arthroplasty provides further support for our arthroplasty choice in primary OA (Fig. 5).

The strengths of the study included the use of validated methods and metrics assessing clinical and radiographic outcomes of TSA with a new technique. The study design was comparative highlighting risks and benefits across the most frequently encountered preoperative glenoid stages. The primary purpose of the study was assessed on multiple variables using subjective and objective parameters. Overlapping CIs across all clinical outcomes comparing concentric and nonconcentric glenoids support the similarities for both groups (Table I). Despite our relatively small

Figure 5 Literature comparison of visual analog scale for pain (VAS-Pain) and revision rate for nonstemmed total shoulder arthroplasty. *TESS*, Total Evolutive Shoulder System.

sample size, narrow CIs for pain relief and range of motion indicate limited variability in these results and support the consistency of our data. Selection bias was limited entering all subjects who agreed to participate in the study during a specified treatment window. The most frequently encountered glenoid stages (types A and B) were included in the treatment group. Transfer bias was limited keeping the loss to follow-up below a 20% threshold. Channeling bias was reduced by assigning patients to comparative groups based on glenoid morphology rather than treatment decisions.

The weaknesses in our study include those that are inherent to all retrospective investigations and are related to the clinical documentation, radiographic imaging, cohort size determination, and follow-up. Clinical outcomes were lacking Penn baseline outcomes scores in approximately half of our cohort. Before 2014, preoperative PSS scores were not available for inclusion in this retrospective study. Since then, PSS metrics have been included in our questionnaire and database for routine assessment of all shoulder procedures. Radiographic imaging followed a standard clinical protocol and lacked in control of precise beam orientation a prospective study could have achieved; hence axillary preoperative and postoperative comparison of humeral subluxation in the AP plane was not feasible. The variability in radiographic angles may have also influenced imaging assessment. The inlay glenoid component used in this study lacks a metal marker that makes the radiographic visualization more challenging. However, our positive clinical results, combined with strong basic science evidence, support the stability of the inlay glenoid and offset this limitation. Establishing a prospective radiographic assessment protocol to ensure consistent Grashey views and axillary projections that include the full length of the scapula would have been beneficial in tracking periprosthetic radiolucency with varying degrees of glenoid retroversion.

Future studies with preoperative computed tomography imaging would provide further insight into the effects of glenoid retroversion on patient-reported outcomes, complications, and radiographic fixation strength on mid- and long-term follow-up. The overall cohort size in our study was relatively small, thereby weakening subgroup analysis. Therefore, we opted to primarily use the binary Levine glenoid classification and incorporated the original Walch classification rather than the 2016 update by Bercik et al,[4] which included additional B3 and D stages that require 3-dimensional imaging. The retrospective study was limited to last follow-up comparison for the primary endpoint and follow-up was short term. This cohort will continue to be followed and longer term clinical and radiographic results will need to be evaluated to confirm implant stability and longevity. Future studies should explore prospective data to reconfirm and augment the risks and benefits of this technique.

Conclusion

Our initial results show that nonspherical HH resurfacing combined with inlay glenoid replacement is a viable outpatient technique for primary GH arthritis across patients with concentric and eccentric glenoid morphology. The results in both groups suggest that this total shoulder construct may be considered a reasonable alternative to treating shoulder arthritis even in the presence of posterior bone erosion and subluxation. We feel that both the HH design and the inlay component contribute to these results. Meaningful and SCBs included excellent functional results and pain relief, high patient satisfaction, and low risk in patients with and without preoperative glenoid erosion. No 90-day rehospitalization was required, and no implant failures were noted at a mean follow-up of 42.6 months. Further research with larger

cohorts and longer follow-up is warranted, as this technique provides a unique option for primary GH OA.

Disclaimer

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