

Clinical and Radiographic Outcomes of Total Shoulder Arthroplasty With a Nonspherical Humeral Head and Inlay Glenoid in Elite Weight Lifters

A Prospective Case Series

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Background: Weight lifting after total shoulder arthroplasty (TSA) can place significant stresses on implants that could lead to instability, loosening, and increased wear. A TSA system with nonspherical humeral head resurfacing and inlay glenoid—which improves the biomechanics and thus reduces instability, wear, and potential loosening—may be able to tolerate repetitive loads from weight lifting.

Purpose: To determine clinical and radiographic outcomes after TSA in weight lifters.

Study Design: Case series; Level of evidence, 4.

Methods: We prospectively enrolled 16 weight lifters (mean \pm SD age, 57.2 ± 7.8 years; 15 male) undergoing primary anatomic TSA ($n = 17$ shoulders, 1 staged bilateral) with nonspherical humeral head resurfacing and inlay glenoid replacement for glenohumeral osteoarthritis between February 2015 and February 2019. Exclusion criteria were rotator cuff deficiency, revision TSA, post-traumatic arthritis, and inflammatory arthritis. Outcome measures included the rate of return to weight lifting, results of patient-reported outcome measures (Penn Shoulder Score, Kerlan-Jobe Orthopaedic Clinic, and 12-Item Veterans RAND Health Survey), radiographic outcomes, and complication rate.

Results: Follow-up was obtained on all patients at a mean of 38 months (range, 14-63 months). All patients returned to competitive weight lifting at 15.6 ± 6.9 weeks. Compared to the preoperative weight lifting level, at last follow-up patients reported performance at the following level: lighter weight, 1 (6%); same weight, 8 (50%); heavier weight, 7 (44%). Preoperative eccentric posterior glenoid wear was common (71% Walch B2 classification; 12/17), but posterior humeral subluxation improved at follow-up according to the Walch index (mean, 55.5% preoperative vs 48.5% postoperative; $P < .001$) and contact point ratio (mean, 63.9% preoperative vs 50.1% postoperative; $P < .001$). Pre- to postoperative improvements were seen in Penn Shoulder Score (44.3 vs 82.6; $P < .001$), Kerlan-Jobe Orthopaedic Clinic (50.6 vs 91.1; $P < .001$), and 12-Item Veterans RAND Health Survey physical component score but not mental component score. No signs of radiographic loosening were detected in follow-up images, nor were there any postoperative instability episodes or revision surgeries.

Conclusion: There were substantial improvements in shoulder function and a high rate of return to weight lifting after TSA with a nonspherical humeral head resurfacing and inlay glenoid component. Radiographically, the humeral head centralized on the glenoid after surgery, and there was no evidence of component loosening at a mean 38-month follow-up.

Keywords: total shoulder arthroplasty; humeral head resurfacing; weight lifting; return to sport; patient-reported outcomes

Weight lifting, both competitively and recreationally, is a popular activity utilized to improve fitness and health as well as body image. There is a growing population of patients

with glenohumeral osteoarthritis requiring surgical intervention at younger ages,^{3,29} especially in the group of patients who use heavy weight training. The number of shoulder arthroplasty procedures increased about 200% from 2003 to 2015,^{29,36} and the demand for total shoulder arthroplasty (TSA) in patients <55 years old is projected to increase 333% by 2030.^{12,38}

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Anatomic TSA has been shown to address glenohumeral osteoarthritis in the setting of a competent rotator cuff with satisfactory long-term results,^{3,4,6,10,21} and return to sport (RTS) after TSA has become a priority for many patients.^{28,35,40} In a study by Garcia et al¹⁴ of patients <55 years old, 67.7% stated that they underwent TSA to RTS. Although RTS after anatomic TSA has been examined in earlier studies,[‡] return to weight lifting was not consistently reported, and none of these studies were prospective. Also, the patient-reported outcome measures (PROMs) in these studies were not specific to weight lifting.

Competitive weight lifters place particularly high demands on their shoulders, owing to repetitive performance of maximum or near-maximum effort lifts—an activity that theoretically places TSA components at high risk of loosening, premature wear, or other complications, including instability or periprosthetic fracture. Many providers therefore recommend against returning to weight-lifting activities and, in particular, heavy weight lifting after an anatomic TSA. However, a novel TSA implant system (Arthrosurface) has design features that may allow the components to tolerate the repetitive stresses seen with competitive weight lifting. Specifically, the implant system consists of a nonspherical humeral head, which improves the center of rotation of the implant,²⁷ and an inlay glenoid, which by its design theoretically reduces the rocking-horse effect on the glenoid component and decreases stress and loosening of the implants.¹¹ Excellent clinical outcomes have been reported after TSA with this implant system, including in patients with eccentric posterior glenoid wear.⁹

The purpose of the current study was to determine return to heavy weight lifting, patient-reported outcomes, radiographic outcomes, and complication rates in a weight-lifting group of patients after anatomic TSA using a combination of nonspherical humeral head resurfacing and inlay glenoid replacement. We hypothesized that this patient cohort would have high rates of return to weight lifting, high patient-reported shoulder function, and low rates of radiographic loosening or posterior humeral head subluxation.

METHODS

Setting and Study Population

Institutional review board approval was obtained before study initiation. All elite weight lifters undergoing TSA

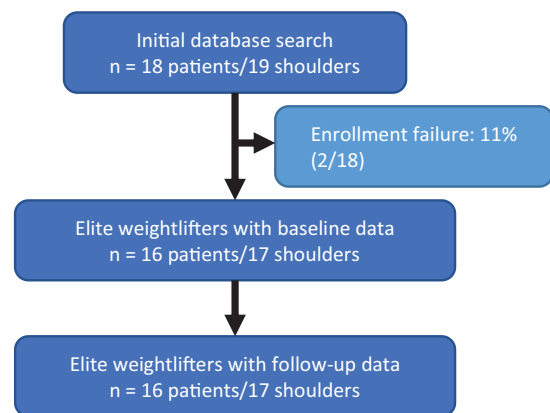


Figure 1. Flowchart of patient inclusion in the study.

using a combination of nonspherical humeral head resurfacing and inlay glenoid replacement for primary glenohumeral osteoarthritis between February 2015 and February 2019 by a single surgeon (A.M.) were prospectively enrolled in our ongoing prospective cohort. Despite differing definitions, we used the term *elite* to mean individuals who were involved in heavy weight lifting for the purposes of competitive body building or power lifting. Definitions are difficult to glean from the literature, and the term *elite*, as used among professional organizations and countries, generally represents the top 2.5% to 5% of athletes for their respective age and bodyweight class. Although we could not determine whether these individuals were within the top 5%, many competed at local, national, and international levels, and they did lift heavy weights for the purposes described and not for simple fitness or exercise.

Exclusion criteria were rotator cuff deficiency, revision TSA, post-traumatic osteoarthritis, inflammatory arthritis, and glenoid classified as Walch C and D. A total of 18 patients (19 shoulders) were eligible. Of these, 2 patients had enrollment failure, resulting in a study cohort of 16 patients (17 shoulders). Follow-up was obtained on all 16 patients (17 shoulders) (Figure 1).

Patient-Reported Outcome Measures

At baseline, patients completed a questionnaire regarding information on demographics, activity levels, and PROMs. The PROMs included in the current study were the Penn Shoulder Score (PSS; total score and pain, satisfaction, and function subscales),³⁰ 12-Item Veterans RAND Health Survey (VR-12) mental and physical component scores (MCS

[‡]References 1, 3, 8, 12, 15, 18, 25, 26, 28, 31, 33, 35, 37, 40, 42, 47.

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Ethical approval for this study was obtained from Cleveland Clinic (06-196).

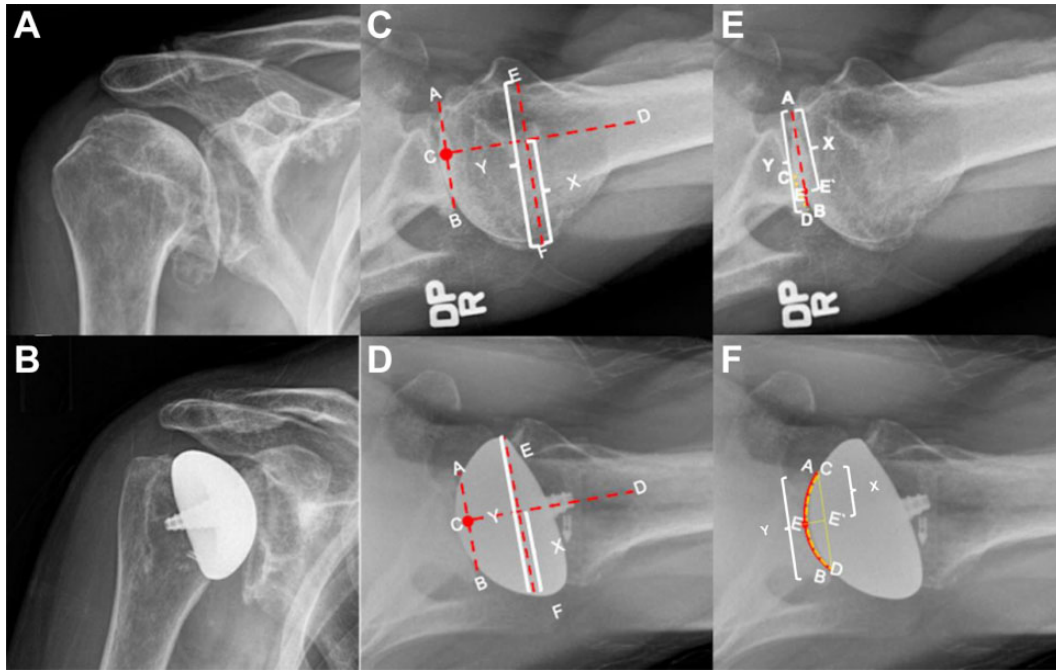


Figure 2. True shoulder views, Walch index measurement (X/Y) on axillary view, and Walch index contact point ratio measurement (X'/Y') on axillary view: (A, C, E) preoperatively and (B, D, F) postoperatively. The Walch index was measured using the Mediatrix method: the Glenoid joint surface (line) is bisected by a perpendicular line (line). The percentage of the subluxated humeral head is then measured by dividing the length of portion of the humeral head posterior to line (X) to the diameter of the humeral head (Y). The contact point ratio was measured by dividing the length of a line segment drawn from the anterior rim of the glenoid to the center of glenohumeral contact (X) to the length of the line segment connecting the anterior and posterior rims (Y). (C, D) Line represents the diameter of the humeral head. (E, F) Point E represents the midpoint of the contact surface on the glenoid, and E' represents the midpoint of line .

and PCS),⁴¹ and Kerlan-Jobe Orthopaedic Clinic (KJOC) score.² The PSS has been validated to measure shoulder function in the setting of various shoulder disorders³⁰ and has been applied in anatomic TSA outcomes research.²² The VR-12 MCS and PCS provide generalized measures of mental and physical functioning, which allows estimation of change in health-related quality of life attributed to the clinical intervention for use in future health-economic assessments.⁴¹ Finally, as the current study population consists of elite athletes, the KJOC was utilized as it is sensitive to changes in shoulder function in overhead athletes and less subject to the ceiling effects that may be observed with other shoulder PROMs when applied to a high-functioning population.²

RTS data were obtained from the patients, including time to return to weight lifting and level of return to weight lifting at final follow-up. Level of return to weight lifting was defined as the comparison of maximum weight lifting at final follow-up with the maximum weight lifting before the surgery and classified as follows: lighter weight, same weight, and heavier weight. The PSS, VR-12, and KJOC were again administered at final follow-up. Postoperative complications were noted, including but not limited to wound complications, infection, postoperative instability (subluxation or dislocation), fracture, nerve or vessel injury, stiffness, pain, or complications from anesthesia.

Radiographic Evaluation

Preoperative and follow-up true anteroposterior (Grashey view) and axillary view shoulder radiographs^{23,43} were taken (Figure 2). Preoperative glenoid wear pattern was categorized according to the Walch glenoid classification.⁴⁵ Competitive weight lifting places substantial stress on the posterior glenoid rim, and as a result, most competitive weight lifters with glenohumeral osteoarthritis present with an eccentric posterior glenoid wear pattern and posterior humeral head subluxation. Therefore, an important radiographic parameter in this population is centralization of the humeral head on the glenoid, as persistent posterior subluxation is a risk factor for accelerated implant wear and glenoid component loosening after TSA.^{16,46} Humeral head centralization was evaluated with the Walch index^{5,7,17,19,20,24,39,45} and contact point ratio described by Matsen and Gupta³⁴ (Figure 2, C-F); for both measures, a value closer to 50% is more centralized, and values $>50\%$ indicate greater posterior subluxation. Finally, component loosening was evaluated by the presence of periprosthetic lucency as categorized by the Sperling classification.⁴⁴

Surgical Technique and Rehabilitation

All surgical procedures were performed by the senior author (A.M.). The surgical technique for implantation of

TABLE 1
Baseline Demographics and Glenoid Wear Pattern

	No. (%) or Mean \pm SD (Range)
Patients:shoulders	16:17
Weight lifter:power lifter	15:1
Age, y	57.2 \pm 7.8
Sex, male:female	15:1
Body mass index, kg/m ²	26.9 \pm 3.6
Shoulder, right:left	9:8
Follow-up, mo	37.8 (14-63)
Walch glenoid classification ^a	
A2	1 (5.9)
B1	3 (17.6)
B2	12 (70.6)
B3	1 (5.9)

^aA2, glenoid with major central erosion; B1, glenoid with narrowing of the joint space with glenoid retroversion and posterior humeral head subluxation; B2, glenoid with biconcave shape with retroversion and major glenoid erosion posteriorly and posterior humeral head subluxation; B3, monoconcave glenoid with posterior wear in addition to $>15^\circ$ of retroversion and/or $>70\%$ posterior humeral head subluxation.

the anatomic TSA components (Arthrosurface) utilized in the current study is described in detail in a previous publication.⁹ In brief, a standard deltopectoral approach was used, and the subscapularis was tenotomized 1.5 cm medial to the lesser tuberosity insertion. After removal of marginal osteophytes, the center of the humeral head was identified, and the humeral head implant (HemiCAP; Arthrosurface) was sized per the anteroposterior dimensions; the nonspherical humeral head implant is 4 mm larger in the superoinferior diameter than it is in the anteroposterior diameter. After reaming of the humeral head, a humeral head trial implant was placed, and the glenoid was then prepared. A key aspect of the procedure is meticulous application of cement for glenoid implant fixation; this includes cement pressurization of the glenoid recipient bed multiple times as well as application of cement to the back side of the implant. The implant was then held in place with steady application of manual pressure while the cement cured. The inlay polyethylene component with a single central peg was implanted within the central glenoid such that it was surrounded circumferentially by native glenoid bone and the implant surface was slightly recessed relative to the peripheral glenoid. It should be noted that neither central glenoid reaming nor the inlay glenoid was designed to change the version of the glenoid but rather to maintain it.

After glenoid implantation was completed, the humeral head trial implant was removed, and the actual humeral head resurfacing implant was placed and impacted. A standard closure with a subscapularis repair was performed.

Postoperatively, patients were placed into a sling, and passive-assisted motion was allowed immediately after surgery in all planes except for external rotation, which was limited to 20° for 6 weeks to protect the subscapularis

TABLE 2
Data on Return to Weight Lifting (N = 16 Patients)

	Mean \pm SD or No. (%)
Time to return, wk	15.6 \pm 6.9
Level of return to weight lifting	
Lighter weight	1 (6)
Same weight	8 (50)
Heavier weight	7 (44)

repair. After 6 weeks, patients began a rotator cuff-strengthening program with gradual progression of activities. Weight-lifting progression was allowed at 10 to 12 weeks, with no restrictions placed on maximum weight.

Statistical Analysis

For the shoulder-specific scales used in the current study, previously published standard deviations were 19.6 points for the PSS³⁰ and 18.7 points for the KJOC.⁴⁸ According to a power analysis, the study sample size (n = 17 surgical procedures) was adequate to detect a large effect size change (1.0 SD) in the PSS and KJOC at 80% power and an alpha of .05. This effect size was in excess of the minimal clinically important difference of 11.4 points for the PSS³⁰ and was more likely to represent a substantial clinical benefit (the minimal clinically important difference has not been reported for KJOC).

Continuous variables (eg, age and body mass index at surgery) and PROMs were summarized using mean and standard deviation/range. Walch classification and level of return to weight lifting were reported as number and percentage. Pre- and postoperative PROMs, Walch index, and contact point ratio were compared using 2-sample *t* tests. All statistical analyses were performed with a standard statistical package (SPSS Version 25.0; IBM). Significance was set at $P < .05$.

RESULTS

Study Population

A total of 16 patients (17 shoulders) were available at the final follow-up. The mean follow-up period was 37.8 months (range, 14-63 months). Preoperative glenoid wear according to the Walch classification was A2 in 1 shoulder (5.9%), B1 in 3 (17.6%), B2 in 12 (70.6%), and B3 in 1 (5.9%). Baseline demographic data are shown in Table 1.

Return to Weight Lifting

All patients were able to return to competitive weight lifting at final follow-up. The mean \pm SD time to return to training with free weights was 15.6 \pm 6.9 weeks. When compared with the preoperative weight-lifting level, at final follow-up, patients reported performance at the following levels: lighter weight, 1 (6%); same weight, 8 (50%); and heavier weight, 7 (44%) (Table 2, Figure 3).

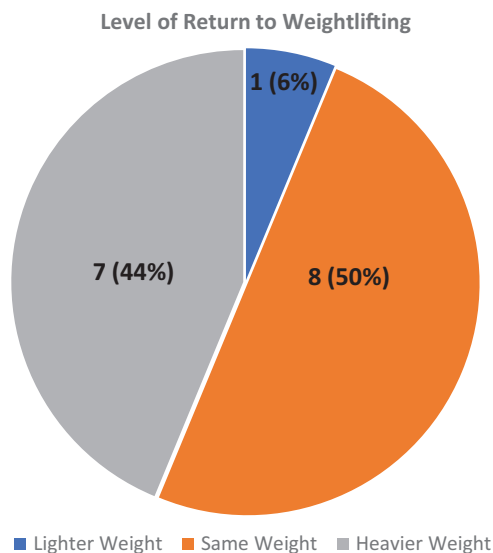


Figure 3. Rates of levels of return to weight lifting. KJOC, Kerlan-Jobe Orthopaedic Clinic; MCS, mental component score; PCS, physical component score; PSS, Penn Shoulder Score; VR-12, 12-Item Veterans RAND Health Survey.

TABLE 3
Comparison of Pre- and Postoperative PROM Scores^a

Outcome Measure	Mean ± SD	P Value
PSS pain		.005
Preoperative	13.7 ± 6.9	
Final follow-up	42.3 ± 29.0	
PSS satisfaction		<.001
Preoperative	2.1 ± 2.6	
Final follow-up	21.7 ± 16.9	
PSS function		<.001
Preoperative	28.5 ± 10.9	
Final follow-up	53.5 ± 6.0	
PSS total		<.001
Preoperative	44.3 ± 20.5	
Final follow-up	82.6 ± 17.5	
VR-12 PCS		.001
Preoperative	40.4 ± 10.5	
Final follow-up	53.8 ± 6.7	
VR-12 MCS		.140
Preoperative	47.7 ± 19.6	
Final follow-up	56.0 ± 9.0	
KJOC		<.001
Preoperative	50.6 ± 8.7	
Final follow-up	91.1 ± 8.9	

^aBold P value indicates statistically significant pre- to postoperative difference ($P < .05$). KJOC, Kerlan-Jobe Orthopaedic Clinic; MCS, mental component score; PCS, physical component score; PROM, patient-reported outcome measure; PSS, Penn Shoulder Score; VR-12, 12-Item Veterans RAND Health Survey.

Patient-Reported Outcome Measures

With the exception of VR-12 MCS, there were significant improvements in all PROMs from presurgery to

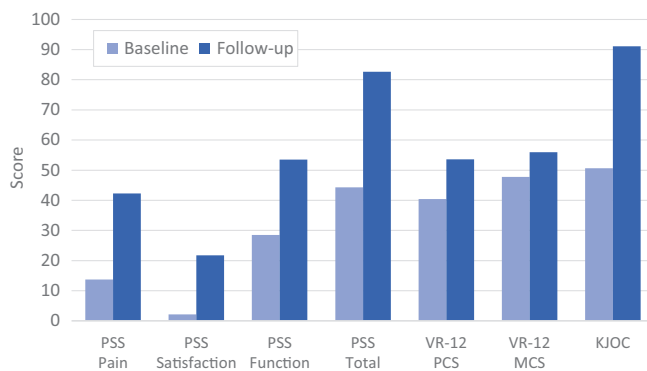


Figure 4. Patient-reported outcome scores. KJOC, Kerlan-Jobe Orthopaedic Clinic; MCS, mental component score; PCS, physical component score; PSS, Penn Shoulder Score; VR-12, 12-Item Veterans RAND Health Survey.

TABLE 4
Radiographic Outcomes^a

	Mean ± SD	P Value
Walch index		<.001
Preoperative	55.5 ± 5.5	
Final follow-up	48.5 ± 5.3	
Contact point ratio		<.001
Preoperative	63.9 ± 8.9	
Final follow-up	50.1 ± 2.7	

^aBold P value indicates statistically significant pre- to postoperative difference ($P < .05$).

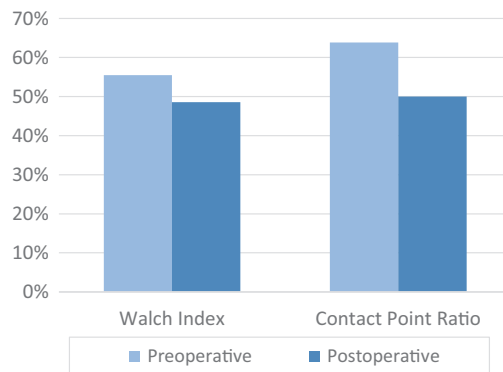


Figure 5. Radiographic outcomes.

final follow-up (Table 3, Figure 4). The PSS total score increased from a mean 44.3 ± 20.5 to 82.6 ± 17.5 ($P < .001$). The KJOC score increased from a mean 50.6 ± 8.7 to 91.1 ± 8.9 ($P < .001$).

Imaging Results

Preoperative imaging demonstrated mean posterior subluxation of the humeral head (mean Walch index, 55.5%; mean contact point ratio, 63.9%) with significant

improvement in humeral head centralization at final follow-up (mean Walch index, 48.5%; mean contact point ratio, 50.1%; $P < .001$ for both comparisons) (Table 4, Figure 5). The humeral head was centralized on the glenoid in all patients. No sign of radiographic loosening was detected in any patient at follow-up images.

Complications and Revisions

No patient experienced postoperative complications or dislocation or required revision surgery during the follow-up period. All patients had full subscapularis strength (5/5) at final follow-up.

DISCUSSION

Competitive weight lifters can develop symptomatic glenohumeral arthritis that is difficult to treat because of the high demands placed on the shoulder with continued activity. Of particular concern is the substantial posterior shear stress placed on the glenoid with certain upper extremity competitive lifts; for this reason, TSA has been discouraged in athletes who wish to continue competitive weight lifting because of the risk of glenoid implant loosening. However, in the current prospective study, we have demonstrated excellent clinical and radiographic outcomes in competitive weight lifters after TSA with implants with design features that minimize glenoid implant stresses.^{11,27} Rates of RTS were excellent, and many patients reported maintenance or even improvement in their competitive levels after surgery. Humeral head centralization was improved at final follow-up despite uniform return to heavy lifting, and there were no postoperative instability events.

Return to Weight Lifting

RTS has been an important aspect of shoulder arthroplasty with increasing demands by patients.³³ Several studies reported high rates of RTS after TSA, hemiarthroplasty (HA), and reverse TSA,⁸ but none of these described this high-risk group of weight lifters in returning to that activity.

Magnussen et al³² sent an online survey including questions about 37 activities and asked members of the American Shoulder and Elbow Surgeons (ASES) and the European Society for Surgery of the Shoulder and Elbow for their recommendations about RTS after shoulder arthroplasty. Of 47 American and 52 European experienced shoulder surgeons, 29% and 80%, respectively, stated that they would not allow weight lifting after TSA (regardless of amount of weight). Also, 14% and 74% of American and European surgeons, respectively, indicated that they would not allow weight lifting after HA, with an additional 6% of European surgeons reporting that they were undecided. Shoulder surgeons have not been surveyed regarding return to heavy weight lifting or competitive weight lifting after TSA.

Other than the current study, the shoulder arthroplasty literature does not cite RTS rates after competitive weight lifting and is limited to studies of RTS for weight lifting regardless of amount of weight. Garcia et al¹²⁻¹⁵ conducted a series of studies on RTS after shoulder arthroplasty. In a recent article,¹² they stated that 7 of 7 (100%) patients after TSA and 11 of 12 (91.6%) patients after HA using a ream-and-run technique returned to weight lifting. In that study, the overall rate of RTS was 86.4%, with 72.7% at the same or higher level. In a matched cohort study,¹³ they reported the rate of return to lightweight training. The overall rate of return to fitness sports (lightweight training + resistance band training) was 93.3% (14/15) and 66.6% (4/6) in TSA and HA cohorts, respectively. In a study of patients ≤ 55 years old,¹⁴ the return to fitness sports including lightweight training after TSA was 97.2%. In a study comprising only patients undergoing HA,¹³ the authors found a 69% (9/13) rate of return to fitness sports. The rates for male and female patients were 77.8% and 50%, and the rates for patients < 66 and ≥ 66 years old were 66.7% and 75%, respectively.

Wang et al⁴⁷ reported the rate of return to weight lifting as 37% (7/19) after TSA, 50% (1/2) after reverse TSA, and 59% (22/37) after HA. Mannava et al³³ cited combined rates of return to weight lifting and fitness as 90.9%, with 72.7% returning to the same level or higher.

Patient-Reported Outcome Measures

Patient-reported outcomes among competitive weight lifters in the current study were excellent, including results with the KJOC, which is specific to overhead activities in upper extremity athletes.² There is limited comparable literature on the topic. Specifically, prior arthroplasty outcome studies note that PROMs after return to weight lifting, regardless of amount of weight, typically include mixed sporting populations and do not cite PROMs designed to assess high-level shoulder function. Garcia et al¹²⁻¹⁵ found improved ASES scores after HA, TSA, and reverse TSA in different studies. Similarly, Wang et al⁴⁷ reported improved ASES and Single Assessment Numeric Evaluation (SANE) scores after TSA and HA, and Mannava et al³³ noted improved ASES, Disabilities of the Arm, Shoulder and Hand (shortened version), SANE, and 12-Item Short Form Health Survey PCS scores after TSA. In those studies, scores were reported for all patients and not specific for weight lifting. In addition, studies used the ASES score, which is a good measure for activities of daily living but does not tell us much about the function of patients. Our results were similar to those of Garcia et al¹²⁻¹⁵ and Mannava et al,³³ although they did not specify "elite." In our study, we also used the PSS with its subscale measuring function, which was improved at final follow-up.

Recentering of the Humeral Head

One of the major concerns about the management of type B glenoid is addressing the posterior glenoid wear. In this patient population, the combination of pre-existing posterior glenoid wear and resumption of weight lifting in the

⁸References 3, 8, 12-15, 18, 25, 26, 28, 31, 33, 35, 37, 40, 42, 47.

postoperative period doubled the challenge. The design of the inlay glenoid component and surgical technique aimed to maintain native glenoid version rather than change it. The fact that the humeral head recentered on the glenoid despite surgery not changing the version could be explained by either the mechanical effect resulting from the intraoperative soft tissue release or the removal of the ridge on the glenoid while reaming, which is the actual cause of the biconcavity. This theory is supported by the fact that the humeral head recenters immediately intraoperatively, which is evident even on the postoperative radiographs taken in the recovery room.

We do not anticipate that the recentering effect is caused by a dynamic factor. In the ream-and-run⁴³ technique, a center reaming is performed that creates an articulation between the humeral head and the glenoid, eliminating the posterior subluxation of the humeral head, which has been reported as an aftereffect. This technique is not identical but very similar to the ream-and-run but uses the addition of an inlay glenoid, so it is more of a ream-and-fill technique.

There are multiple limitations for this study. First, we included a highly specific patient population who underwent TSA by a single surgeon. The outcomes of this study may not be extrapolated for other athletes. However, weight lifters are one of the groups of athletes who exercise with high loads that place the glenohumeral joint under great stress. In terms of radiological outcomes, computed tomography would provide more precise measurements than anteroposterior and axillary radiographs. To control this limitation, we utilized standardized radiographs in all patients. We did not report the amount of pre- and postoperative weight lifted and relied on patient self-report. We were also not able to compare outcomes with other TSA implant designs or HA. A short follow-up period and a small sample size were other limitations. A longer time would be needed to evaluate the secondary posterior subluxation after TSA, and it should be noted that concerns with wear are greater with longer follow-up.

CONCLUSION

Glenohumeral arthritis in competitive weight lifters has been difficult to treat owing to (1) high rates of posterior eccentric glenoid wear and (2) significant concern in this population for further posterior subluxation and implant loosening as well as wear after TSA and return to weight lifting. However, in the current study, we demonstrate excellent early to midterm clinical and radiographic outcomes after TSA in competitive weight lifters using a nonspherical humeral head and inlay glenoid component. Rates of RTS and patient-reported shoulder function were excellent. Radiographically, the humeral head centralizes on the glenoid after surgery, and there is no evidence of instability or component loosening at a mean 38-month follow-up. Going forward, prospective studies with larger patient numbers and longer follow-up are necessary.

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