Infraspinatus or teres minor fatty infiltration does not influence patient outcomes after reverse shoulder arthroplasty with a lateralized glenoid

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A R T I C L E   I N F O

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Background: Previous studies show that reverse shoulder arthroplasty (RSA) may improve forward elevation (FE) but external rotation may remain impaired with substantial teres minor fatty infiltration. The purpose of this study was to examine the influence of fatty infiltration on postoperative range of motion (ROM) and patient-reported outcomes (PROs) after RSA with a more lateralized center of rotation.

Methods: About 69 patients (average age 69 years; 44 women, 25 men) with preoperative MRI, 1-year postoperative ROM, 2-year Veteran's Rand Survey, American Shoulder and Elbow Surgeons subjective form, and Single Alpha-Numeric Evaluation scores who underwent RSA with a lateralized glenoid component between 2010 and 2014 were identified. Patients with Fuchs stage 3 fatty degeneration were compared with patients with Fuchs stage ≤ 2 using a one-way ANOVA.

Results: Eleven patients had Fuchs stage 3 in the teres minor and 28 with stage 3 in the infraspinatus. Charlson comorbidity indices, Veteran's Rand Survey scores, age, and BMI were not different between groups. There were no differences after one year (follow-up = 15 ± 14 months) in FE (FE = 128 ± 29) or external rotation (33 ± 13) between groups. There were no differences in two-year minimum (follow-up = 42.9 ± 17.9 months) American Shoulder and Elbow Surgeons scores between degenerated teres minor (76.4 ± 20) or infraspinatus (69.1 ± 24) groups.

Conclusion: This is the first study to assess the influence of teres minor and infraspinatus fatty infiltration on the postoperative ROM and PROs with a more lateralized glenoid RSA implant. Our results show that in a more lateralized RSA, neither teres minor nor infraspinatus fatty infiltration appear to negatively influence ROM or PROs.

Reverse shoulder arthroplasty (RSA) is being used in increasing frequency for patients with cuff tear arthropathy. This procedure became commonly accepted with the introduction of the Grammont-style prosthesis in the late 1980s.[9] The native concave glenoid is replaced with a convex glenosphere, therefore medializing the center of the rotation of the glenohumeral articulation. Stability is partly achieved by lengthening the humerus, which increases deltoid tension and compensates for rotator cuff deficiency.[3,5]

Grammont-style RSA has been shown to significantly improve patient-reported outcomes (PROs) and improve shoulder elevation and function. However, improving external rotation (ER) can remain challenging. The ability to restore ER may rely on the condition of the infraspinatus and teres minor muscles. Increased fatty

infiltration of the infraspinatus and teres minor muscles has been shown to negatively impact ER.[5,11,29] As a result, concomitant latissimus dorsi tendon transfer has been suggested to improve ER when preoperative ER lag signs are present in patients undergoing RSA.[14]

In contrast to the Grammont-style RSA, there are multiple studies suggesting that when the center of rotation (COR) is less medialized, ER may improve through better tensioning of the posterior rotator cuff.[2,14,23] Despite this theoretic advantage, there is no study which investigates if the preoperative health of the posterior rotator cuff muscles can influence ER when using a more lateralized center of rotation.

The Goutallier grading system has become the gold standard for describing fatty infiltration of the rotator cuff. Goutallier developed this system based on axial CT images.[13] It was subsequently adapted to parasagittal MRI by Fuchs.[10] Schiefer et al found the application of Goutallier grading system to MRI resulted in highly significant interobserver and intraobserver agreement.[32]

The present study was designed to assess whether the preoperative Fuchs stage of the posterior rotator cuff musculature influences postoperative active ER after RSA with a more lateralized design. A secondary aim was to assess if the preoperative Fuchs stage affects functional outcomes of patients treated with lateralized RSA. We hypothesized that higher Fuchs stage would have a negative influence on ROM and functional outcomes with the use of a lateralized RSA design.

Materials and methods

A retrospective review of all reverse shoulder arthroplasty surgeries performed at a single institution from 2007 to 2014 was done using an IRB-approved outcomes database. Inclusion criteria included: preoperative diagnosis of cuff tear arthropathy, implantation of lateralized glenoid system (DJO, Austin, TX, USA), adequate preoperative MRI, minimum of two-year follow-up, postoperative ROM measurements, and subjective outcome scores. The Pennsylvania Shoulder Score (PENN), American Shoulder and Elbow Surgeons (ASES), Veteran's Rand Survey (VR12), and Single Alpha-Numeric Evaluation (SANE) subjective forms were used. Revision procedures and RSA performed for fractures were excluded. Of 166 initially identified, 69 patients met the inclusion and exclusion criteria. The patients had an average age of 69.9 years (range 52 − 87 years). There were 44 women and 25 men.

All procedures were performed by one of four fellowship-trained shoulder surgeons using a standard deltopectoral approach. A reverse shoulder arthroplasty prosthesis was implanted using a more lateralized center of rotation (DJO, Austin, TX). The decision to repair the subscapularis was made by the treating physician on a case-by-case basis. Postoperatively, patients who did not undergo subscapularis repair were initially immobilized in a sling for comfort, with progression to passive and active range of motion as tolerated under the direction of formal physical therapy. Patients who underwent subscapularis repair were restricted to passive external rotation to neutral for six weeks, with progression of active and passive range of motion as tolerated thereafter. Both groups were permitted to return to full activity without restriction at three months.

Two fellowship-trained shoulder surgeons independently evaluated preoperative MRIs and graded the infraspinatus and teres minor muscle bellies using the Fuchs classification for fatty infiltration (Table I). The sagittal T1 images at the level of the scapula were used and a grade of zero to four was assigned. Both surgeons independently evaluated each patient's MRI twice separated by a seven day "washout" period between viewing to eliminate recall bias.

Table I
Goutallier classification of fatty degeneration of rotator cuff muscles

Grade 0	No fatty infiltration
Grade 1	Fatty streaking
Grade 2	Less than 50% fatty infiltration
Grade 3	50% fatty infiltration
Grade 4	Greater than 50% fatty infiltration

Each patient completed subjective outcomes at regular follow-up appointments. This included the PENN, ASES score, VR12, and the SANE. PENN is a 100-point scale with three sections consisting of pain, satisfaction, and function. Each answer is based on 10-point numeric scale. ASES is also a 100-point subjective scale that analyzes pain and ten activities of daily living. The VR12 is a twelve-item self-evaluating form. SANE is a single question evaluation of current health status. These data were extracted from patient charts and used for data analysis. Of the 69-patient cohort, 59 patients had ER recorded, and 65 patients had FE recorded. The postoperative ROM at the last follow-up visit was used for data analysis. The presence of a preoperative and postoperative lag sign was also recorded.

All statistical analyses were performed using SPSS version 26.0 (IBM, Armonk, NY, USA). Descriptives statistics, including comparative analyses of Fuchs scores (2 or less vs. 3), for both infraspinatus and teres minor were performed. Variables included age, sex, race, diagnosis type, body mass index, preoperative shoulder elevation, preoperative ER, number of comorbidities, diabetes, smoking history, and preoperative or postoperative injections.

Postoperative FE, ER, ASES, SANE, and PENN scores were comparatively analyzed for Fuchs scores of 2 or less vs. 3. Comparative analyses were completed for both Fuchs scores for infraspinatus and Fuchs scores for teres minor. For all analyses, a Mann-Whitney U was used because the continuous variables were not normally distributed. For all analyses, a P-value of $<.05$ was considered statistically significant.

Results

Intraobserver and interobserver reliability of Fuchs grading was assessed with Kappa value and ranged 0.41 to 0.46. As per the Landis and Kochs-Kappa benchmarking scale, this correlates with moderate agreement.[22] The Fuchs grades for the infraspinatus are listed in Table II. Twenty-eight patients had grade 3 (group 1A), and 41 patients had grade 2 or less (group 1B). There were no statistically significant differences between Fuchs groups for postoperative FE, ER, ASES, SANE, or PENN scores.

Table III reflects the Fuchs comparative analyses for teres minor. There was less fatty infiltration of the teres minor overall. Eleven patients had stage 3 (group 2A); whereas, 58 patients had stage 2 or less (group 2B) fatty infiltration. As with the infraspinatus findings,

Table II
Comparative outcomes for Goutallier grades of <3 and >3 for the infraspinatus

Variable	Goutallier grade infraspinatus		P value
	<3	>3	
Post-op forward elevation	127.9 (30.8)	128.1 (27.1)	.86
Post-op external rotation	32.8 (11.8)	33.1 (14.1)	.91
ASES	72.8 (21.5)	69.1 (24.5)	.55
SANE	73.7 (27.6)	56.3 (29.2)	.23
PENN	72.1 (23.8)	64.6 (25.2)	.18

ASES, American Shoulder and Elbow Surgeons; *SANE*, Single Alpha-Numeric Evaluation; *PENN*, Pennsylvania Shoulder Score.

Table III
Comparative outcomes for Goutallier grades of <3 and >3 for the teres minor

Variable	Goutallier grade infraspinatus		P value
	<3	>3	
Post-op forward elevation	127.3 (29.4)	131.8 (28.6)	.60
Post-op external rotation	31.9 (11.8)	38.0 (16.4)	.28
ASES	70.4 (22.9)	76.4 (20.9)	.37
SANE	69.3 (29.1)	75.1 (25.1)	.49
PENN	68.1 (25.1)	73.7 (21.6)	.46

ASES, American Shoulder and Elbow Surgeons; *SANE*, Single Alpha-Numeric Evaluation; *PENN*, Pennsylvania Shoulder Score.

there were no statistically significant differences between Fuchs groups for postoperative FE, ER, ASES, SANE, or PENN scores.

The average final follow-up for ROM measurements was 15 months. External rotation active ROM data were available for 59 patients; whereas, active FE data were available for 65 patients. The average postoperative active ER for the entire cohort was 33° (±13). There was no statistically significant difference in ER between infraspinatus groups (33.1° ± 14° in group 1A vs. 32.8° ± 11° in group 1B, P = .9). Similarly, there was no statistically significant difference between teres minor groups (P = .28). Group 2A had 31.9° ± 11° of ER whereas group 2B had 38° ± 16° of ER. There were eight patients who had a preoperative ER lag sign. Six of these eight patients (75%) had correction of the lag sign postoperatively, with an average ER of 15 degrees postoperatively.

The average active FE for the entire cohort was 128 ± 29°. For patients with fatty degeneration of the infraspinatus (grade 3 or 4), postoperative FE was 128.1 ± 27°. For patients with less fatty degeneration (grade 2 or less) of the infraspinatus, postoperative FE was 127.9 ± 30°. The difference in FE did not reach statistical significance, P = .86. The average FE for patients with fatty degeneration of the teres minor (grade 3 or 4), postoperative FE was 131.8 ± 28°; whereas, the average FE for patients with grade 2 or less of the teres minor was 127.3 ± 29°. This difference was also not statistically significant, P = .60. Furthermore, there was no difference in the average postoperative ER among patients with preoperative pseudoparalysis and those without, 25° vs. 31°, respectively, P = .167.

The average follow-up for patients' reported outcomes was 41.1 ± 17.9 months. Charlson comorbidity indices, VR12 scores, age, and BMI were not different between groups. Overall ASES score was on average 71.3 (SD23.1) and mean PENN score was 69 points. There were no significant differences in the ASES and PENN scores between the fatty infiltrated and noninfiltrated teres minor groups. Average ASES score for the fatty infiltrated teres minor group was 76.4 (±20.9) vs. 70.4 (±22.9) for noninfiltrated teres minor group, P = .28. The ASES scores for the fatty infiltrated infraspinatus group were 69.1 (±24.5) vs. 72.8 (±21.5) for noninfiltrated infraspinatus group. This was not statistically significant, P = .55.

Discussion

We found that patients treated with lateralized RSA systems achieved on average 33° of ER despite varying degrees of posterior rotator cuff degeneration and tearing. The grade of Goutallier fatty infiltration of either the infraspinatus or teres minor did not seem to influence postoperative active ER. Six of eight patients with a preoperative ER lag sign were able to actively maintain ER at the latest follow-up. These findings are in contrast to those of Boileau et al, who warned that active ER may not be restored with reverse arthroplasty.[5] Boileau et al reported that patients with degenerated teres minor muscle achieved significantly worse ROM than others in a Grammont-style prosthetic design with more medialized

center of rotation. They found these patients had no active ER, whereas patients with preserved teres minor had 15° of ER.[5] These findings were confirmed by Simovitch et al, who divided their patients into two groups: group 1 had teres minor Goutallier grade 1 and 2 and group 2 had grade 3 and 4 changes. They found that patients in group 2 had 9° of postoperative ER compared with 19° of postoperative ER in group 1 patients.[33] In our study, we found that patients with advanced teres minor fatty infiltration, defined as Fuchs stage 3, can achieve similar postoperative ER as patients without fatty infiltration when a lateralized RSA construct is used.

Both the Grammont-style prosthesis as well as the lateralized prosthesis medialize the COR when compared with the native shoulder.[19] Both implant designs also lengthen the humerus, so it is the combination and magnitude of these changes that produce varying ROM and outcomes. Inferiorization of the glenoid component with resultant lengthening of the humerus is thought to increase the deltoid moment arm and thus provide a mechanical advantage.[37] Medialization of the glenoid can increase the deltoid's moment arm. However, medialization decreases deltoid muscle tension and reduces its muscle wrapping effect. Lateralized glenoid designs have been found to increase deltoid force and increase joint reaction force.[12,14] Lateralization can also be accomplished through the humeral component. This improves the deltoid wrapping effect around the greater tuberosity, resulting in more compressively directed joint load without adding force into the joint.[6,12]

Gutierrez et al determined that lateralization of the center of rotation was the most important factor in maximizing the overall arc of motion.[15,16] Li et al demonstrated that inferiorization or lateralization produced positive effects on IR and ER in RSA.[24] Loui et al designed a biomechanical comparison of three different types of RSA: glenoid lateralized design, humeral lateralized design, and Grammont style. In agreement with previous literature, they found that all three designs resulted in medialization of the COR as well as lengthening of the humerus compared with the anatomic shoulder.[25] In addition, all three designs increased deltoid efficiency and decreased joint reaction forces. Grammont designs resulted in the most beneficial joint reactive force profile, whereas lateral designs resulted in better compressive forces. As a trend, the lateral designs increased muscle forces in the anterior, middle, and posterior deltoid as well as rotator cuff muscles when compared with Grammont designs, which supports the improved ROM seen in our patients. Hamilton et al showed that the COR relative to the glenoid strongly influences the deltoid abduction moment arm in a biomechanical study.[17] The lateral offset of the humerus strongly influenced the ER moment arm of the posterior deltoid.[17]

Although COR is often discussed, many other factors contribute to the ultimate performance of RSA. Biomechanical studies have evaluated COR, humeral neck-shaft angle, humeral offset, humeral version, glenosphere diameter, superior-inferior glenosphere positioning, implant tilt, as well as soft tissue repair of the rotator cuff.[1,8,16,18–21,30,34,35] All these factors must be considered when evaluating implant design and implantation techniques.

The subscapularis may not be as easily repaired in a lateralized implant compared with the Grammont-style implant. A subscapularis under excessive tension or repair of a diseased, noncompliant subscapularis may antagonize ER.[28] Historically, the subscapularis tendon was repaired, when possible, for reverse shoulder replacements due to the concern of instability. Edwards et al and others reported a higher rate of instability in cases in which the subscapularis tendon could not be repaired in Grammont style implants, 9% vs. 0%.[7] These authors advocated attempted repair in all cases. Roberson et al compared outcomes, ROM, and dislocation rates in a cohort of patients treated with or without subscapularis repair in a lateralized RSA. They found no difference in outcomes, ROM, dislocation rate, or overall complication rate.[30]

Overall in the literature, there appears to be a lower dislocation rate for lateralized desgins (average of 3%, range 0%-4.2%) compared with medialized designs (average of 5%, range 0%-8.6%).[30] Thus, a lateralized implant may provide the same stability of a Grammont-style implant without the dependency on subscapularis repair. This may negate the need for altered therapy protocols to allow tendon healing and therefore affect postoperative ROM.[36]

A biomechanical study by Onstot et al showed the antagonistic effect of subscapularis repair on ER in the setting of a lateralized RSA. They found a subscapualris repair required a 262%-460% increase in force to maintain ER with an abducted arm.[28] To further highlight the potential antagonistic effects of subscapularis repair, the subscapularis acts as an adductor and may work against the deltoid.[12,28,30,31] Routman et al showed the deltoid required a 132% increase in force to abduct the arm when the subscapularis was repaired.[31] Giles et al supported this showing rotator cuff repair with RSA increases the work of the deltoid for elevation, and this is exacerbated as the glenosphere is lateralized.[12]

Another disadvantage to rotator cuff tendon repair in a lateralized RSA is the increase in joint reaction forces.[12,31] The long-term consequences of increasing the joint reactive forces are unknown at this time, but could potentially lead to increased polyethylene wear and impact implant longevity.[12,30] Giles et al showed that repairing the rotator cuff resulted in 12% body weight increase in joint load, and glenosphere lateralization also increased the joint load by 13% body weight.[12] If the rotator cuff was repaired and the glenosphere lateralized, the forces increased to approximately 29% of body weight.[12] The authors recommended cautiously combining glenosphere lateralization with rotator cuff repair.

We did not find any differences in PROs between those with and without fatty infiltration of the teres minor or infraspinatus with a lateralized implant design. The ASES and PENN scores were similar between groups. By contrast, Simovitch et al reported that relative Constant scores differed significantly between patients who had rotator cuff fatty infiltration than those with less degeneration of the muscles, 83% vs 61%, respectively, $P < .01$.[33] Significantly lower Constant and ASES scores in patients with degenerated teres minor muscles who underwent RSA were also reported by Boileau et al.[5] Both authors agreed that Grammont RSA implantation does not adequately restore active ER, and tendons transfers should be considered in such a setting.[5,33] Boileau et al suggested that latissimus dorsi tendon transfer should be the preferred method to improve ER with Grammont-style RSA when there is severe teres minor fatty infiltration.[5] Gerber reported short-term success of RSA with latissimus dorsi transfer (LDT) in 12 patients with excellent outcome scores.[11] Puskas et al confirmed these results with excellent clinical outcomes at five-year follow-up in a cohort of forty patients with pseudoparesis of FE and ER treated with LDT and RSA.[29] Active ER improved from a mean of 4° to 27°, and ER lag sign was corrected in 25 of 32 patients available for follow-up. Although a small cohort, we found a similar reversal of external lag without the addition of LDT using a more lateralized design, as 6 of 8 patients improved from negative ER to greater than 15 degrees ER at final follow-up. Avoiding the addition of LDT may have clinical advantages, as Puskas et al reported a 17% overall orthopedic complication rate when combining LDT and RSA (4.8% of those neurological, 4.8% early infection, 4.8% instability, and 2.4% aseptic loosening).[29]

The present study had several limitations. Although a lateralizing glenosphere was used in all patients, surgeon preference based on patient size determined the specific glenosphere size. The amount of lateralization was either 6mm or 10mm depending on the glenosphere selected. Therefore, a specific recommendation cannot be made regarding the optimal amount of glenoid-sided lateralization for improving ER based on our findings. A comparison group with a Grammont-style prosthesis would also be helpful. As in all studies, the interrater reliability of the Fuchs staging system was an inherent weakness, as suggested by the kappa value.[10,26,27] The findings are dependent on the subjective interpretation of the MRIs, and imperfect classification can skew the results and interpretations. External rotation was routinely tested in adduction. Testing ER in abduction would have better tested the teres minor. Similarly, although commonly used, the outcome scores selected for this study may not sufficiently address activities of daily living that require combined elevation and external rotation. A more specific score, such as the ADLER score, could better account for this in future studies.[4] Finally, it is a relatively small cohort, which deserves prospective study in larger numbers.

Conclusion

Overall, the results of the present study indicate that ER is reliably restored with a "lateralized" RSA regardless of the preoperative condition of the rotator cuff. The increased efficiency of the deltoid was maintained regardless of the preoperative status of the rotator cuff. This is in contrast to Grammont style RSA in which tendon transfers may be required for patients with severe teres minor and infraspinatus infiltration to restore ER. Further prospective controlled studies with a larger number of patients are needed.

Disclaimer

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