

Restoration of External Rotation Following Reverse Shoulder Arthroplasty without Latissimus Dorsi Transfer

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Background: Latissimus dorsi transfers have been considered necessary to restore active external rotation following reverse shoulder arthroplasty (RSA). The purpose of this study was to assess the effectiveness of an RSA system that lateralizes the center of rotation in restoring active external rotation without a latissimus dorsi transfer in patients with a preoperative external rotation deficit (external rotation of $<0^\circ$).

Methods: We retrospectively reviewed the records of patients who had undergone RSA with a lateralized center of rotation without a latissimus dorsi transfer. All patients had had a preoperative external rotation deficit (active external rotation of $<0^\circ$), and all were followed for a minimum of 2 years. Patients were stratified into 2 groups on the basis of the preoperative diagnosis: (1) those with a combined loss of active elevation and external rotation as a result of rotator cuff tear arthropathy (CLEER group) and (2) those with a combined loss of active elevation and external rotation as a result of other posttraumatic etiologies (non-CLEER group). The mean improvement of external rotation was analyzed. Subgroup analysis was performed on the basis of the Goutallier classification, glenosphere lateralization, and total prosthetic lateralization.

Results: Thirty-three patients (24 in the CLEER group and 9 in the non-CLEER group) met the inclusion criteria. The average follow-up was 43.4 months (range, 24 to 77 months). External rotation improved significantly in both the CLEER group (from -21° preoperatively to 28° postoperatively; $p < 0.001$) and the non-CLEER group (from -19° preoperatively to 26° postoperatively; $p = 0.001$). Goutallier classification, glenosphere lateralization, and total prosthetic lateralization were not correlated with the degree of improvement of external rotation in either group ($p > 0.05$ for all).

Conclusions: RSA with a lateralized center of rotation can effectively restore external rotation without the use of a latissimus dorsi transfer in patients with a preoperative external rotation deficit as a result of rotator cuff arthropathy or other posttraumatic etiologies.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Reverse total shoulder arthroplasty (RSA) has been shown to be a successful surgical option for patients with rotator cuff arthropathy, massive rotator cuff tear with pseudoparalysis, fracture of the proximal aspect of the humerus, and osteoarthritis in the setting of glenoid bone loss, among other indications^{1,2}. Although RSA provides reliable restoration of shoulder elevation, the ability to restore external rotation has been less predictable.

Early reports involving the original Grammont design for RSA did not show improvements in external rotation³⁻⁵. It

became apparent that preoperative atrophy of the teres minor significantly influenced the ability of the medialized Grammont-style RSA to restore external rotation⁶. Furthermore, patients with a combined loss of active elevation and external rotation as a result of rotator cuff arthropathy (CLEER) were often treated with a latissimus dorsi transfer together with a Grammont-style RSA in an effort to restore both forward elevation and external rotation^{5,7,8}. Studies have shown that RSA combined with latissimus dorsi transfer improves postoperative external rotation,

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TABLE | Patient Characteristics in the CLEER and Non-CLEER Groups*

Case	Diagnosis	Preop. Goutallier Classification		External Rotation Lag	Can You Place Your Hand Behind Your Head with the Elbow Straight Out to the Side?	
		Infraspinatus	Teres Minor		Preop. Answer	Answer at the Time of Final Follow-up
CLEER group						
1	CTA	4	4	Unknown	No	Yes
2	CTA with failed RCR	NA	NA	Yes	No	No
3	CTA	3	2	Yes	No	No
4	CTA	4	2	Yes	No	No
5	CTA	3	3	Yes	No	Yes
6	CTA	4	4	Yes	Unknown	Yes
7	CTA with locked anterior dislocation	NA	NA	Unknown	No	No
8	CTA	4	2	Yes	Unknown	Yes
9	CTA	4	1	Yes	No	Yes
10	CTA	4	4	Yes	No	No
11	CTA	2	2	Yes	Unknown	No
12	CTA	4	4	Yes	No	Yes
13	CTA	3	0	Yes	No	Yes
14	CTA	4	1	Yes	No	Yes
15	CTA	NA	NA	Yes	No	Yes
16	CTA with failed RCR	4	1	Yes	Unknown	No
17	CTA	3	0	Yes	No	Yes
18	CTA	4	2	Yes	No	Yes
19	CTA	4	3	Yes	No	Yes
20	CTA	4	3	Yes	No	Yes
21	CTA	4	4	Yes	No	No
22	CTA	4	2	Yes	No	Yes
23	CTA	2	0	Yes	No	Yes
24	CTA	4	3	Yes	No	No
Non-CLEER group						
25	Acute fracture-dislocation of the glenoid	2	1	Yes	No	Yes
26	Posttraumatic osteonecrosis	3	1	Yes	No	Yes
27	Proximal humeral malunion with degenerative joint disease	3	0	No	No	Yes
28	Greater tuberosity nonunion	4	0	Yes	No	Yes
29	Proximal humeral nonunion	0	0	Yes	No	No
30	Posttraumatic osteonecrosis/malunion	2	0	Unknown	No	Yes
31	Proximal humeral nonunion/malunion	4	3	Yes	No	No
32	Proximal humeral malunion	3	0	No	No	Yes
33	Osteonecrosis	2	0	Unknown	No	Yes

*CTA = cuff tear arthropathy, RCR = rotator cuff repair, and NA = no CT available.

with complication rates being similar to those associated with RSA alone⁸⁹.

RSA designs with a more lateralized center of rotation could potentially restore external rotation without the need

for a latissimus dorsi transfer. Several clinical studies and virtual shoulder models have indicated that such designs can improve external rotation by allowing greater impingement-free motion and by retensioning the remaining rotator cuff

TABLE I (continued)

Preop. Motion (°)				Motion at the Time of Latest Follow-up (°)		
Active External Rotation	Passive External Rotation	Forward Elevation	Abduction	External Rotation	Forward Elevation	Abduction
-30	Unknown	60	70	0	150	90
-20	40	40	30	30	65	40
-20	0	90	80	55	115	110
-20	0	100	85	-15	145	125
-20	60	55	45	40	130	85
-20	60	70	30	15	115	95
-30	Unknown	40	70	30	80	60
-10	60	90	70	30	135	100
-25	15	60	40	20	130	120
-30	45	65	60	20	55	35
-20	45	20	20	30	80	70
-20	30	90	85	40	135	110
-20	60	30	40	40	115	75
-20	0	70	65	20	135	120
-20	30	40	40	25	120	125
-20	60	40	30	45	50	30
-10	0	100	60	35	140	150
-30	30	140	70	20	90	70
-30	30	110	80	30	140	80
-20	30	30	35	45	150	120
-20	30	30	30	10	90	90
-25	20	75	50	30	125	100
-5	20	80	65	40	130	90
-20	50	65	80	30	50	50
-30	0	30	30	60	140	95
-10	10	95	70	60	150	100
-15	-15	75	40	25	120	80
-20	25	30	30	20	130	90
-10	0	60	60	20	90	60
-20	Unknown	75	60	-20	80	70
-30	0	50	30	0	50	50
-10	-10	30	30	25	60	60
-30	Unknown	60	55	40	120	90

and posterior aspect of the deltoid¹⁰⁻¹⁴. However, to our knowledge, no study to date has focused on the subset of patients with a preoperative external rotation deficit. The purposes of the present study were (1) to evaluate whether a preoperative deficit in external rotation is recovered postoperatively in patients with or without CLEER who are

managed with RSA involving a glenosphere with a lateralized center of rotation and without a latissimus dorsi transfer and (2) to determine if fatty infiltration of external rotator muscles, glenosphere lateralization, or total prosthetic lateralization impact the improvement of external rotation in these patients.

Materials and Methods

The present study involved a retrospective review of data that were collected from a Western Institutional Review Board (WIRB)-approved Levy Elbow and Shoulder Surgical Repository (WIRB Study #1138999; WIRB Protocol #20130731) and was granted an institutional review board exemption determination (Protocol #2016-012-EX) prior to the initiation of this research. All patients from whom data were collected provided informed consent to participate in the study.

A retrospective query of the aforementioned shoulder and elbow surgery repository was performed for patients who had undergone RSA between 2007 and 2014 and had a minimum 2-year follow-up. As part of the standard registry protocol, the range of motion achieved with the best effort of the patient was recorded preoperatively and at each postoperative visit. Goniometer measurements were made by providers other than the senior author (J.C.L.). Active external rotation was measured with the patient's arm at the side. The presence of an external rotation deficit and external rotation lag sign prior to surgery were noted when documented in the clinical chart. To better assess the functional impact of the restoration of external rotation, the answer to the question "Can you place your hand behind your head with the elbow straight out to the side?" (from the Simple Shoulder Test) was recorded both preoperatively and at the time of the latest follow-up (Table I). Patients who had a preoperative external rotation deficit (defined as $<0^\circ$ of active external rotation) were included in the study. During the collection period, 5 patients were managed with a latissimus dorsi transfer, 2 patients with osteoarthritis required release of the rotator cuff for the treatment of severe contractures, and 3 patients (including 2 patients with rotator cuff tear arthropathy and 1 patient with greater tuberosity nonunion) were found to have a preoperative external rotation lag sign with recoil to the abdomen. Those 10 patients were excluded, as were 25 patients who had undergone a revision. Overall patient satisfaction with the outcome at the time of the most recent follow-up was reported as excellent, good, satisfactory, or unsatisfactory.

The degree of fatty infiltration of the rotator cuff muscles was assessed by 3 physicians with various levels of experience (1 research fellow, 1 clinical fellow, and 1 senior author) at 2 separate time points. A consensus ruling was made during the review of preoperative 2-dimensional sagittal reconstruction computed tomography (CT) images. Fatty infiltration of the infraspinatus and teres minor was graded with use of the classification system described by Goutallier et al.¹⁵

The 33 patients included in the study were stratified into 2 groups on the basis of the preoperative diagnosis: (1) those with a combined loss of active elevation and external rotation (specifically, external rotation of $<0^\circ$) as a result of rotator cuff tear arthropathy (CLEER group; 24 patients) and (2) those with a combined loss of active elevation and external rotation as a result of other posttraumatic etiologies (non-CLEER group; 9 patients) (Fig. 1) (Table I).

All surgical procedures were performed by the senior author (J.C.L.) using an identical deltopectoral approach

involving the same RSA system (Reverse Shoulder Prosthesis, DJO Surgical) that featured a humeral component with a 135° neck-shaft angle and a glenosphere with varying amounts of lateralization of the center of rotation (typically selected on the basis of glenoid size). All humeral stems were inserted in 30° of retroversion. The subscapularis was repaired without tension, with the arm in 40° of external rotation, in 29 of the 33 cases. Postoperatively, all patients were enrolled in an identical rehabilitation protocol. Patients were managed with a shoulder immobilizer for the initial 6-week period and performed pendulum exercises 3 times daily. At 6 weeks, patients initiated self-directed supine active-assisted exercises (e.g., forward elevation and external rotation) and were encouraged to use the

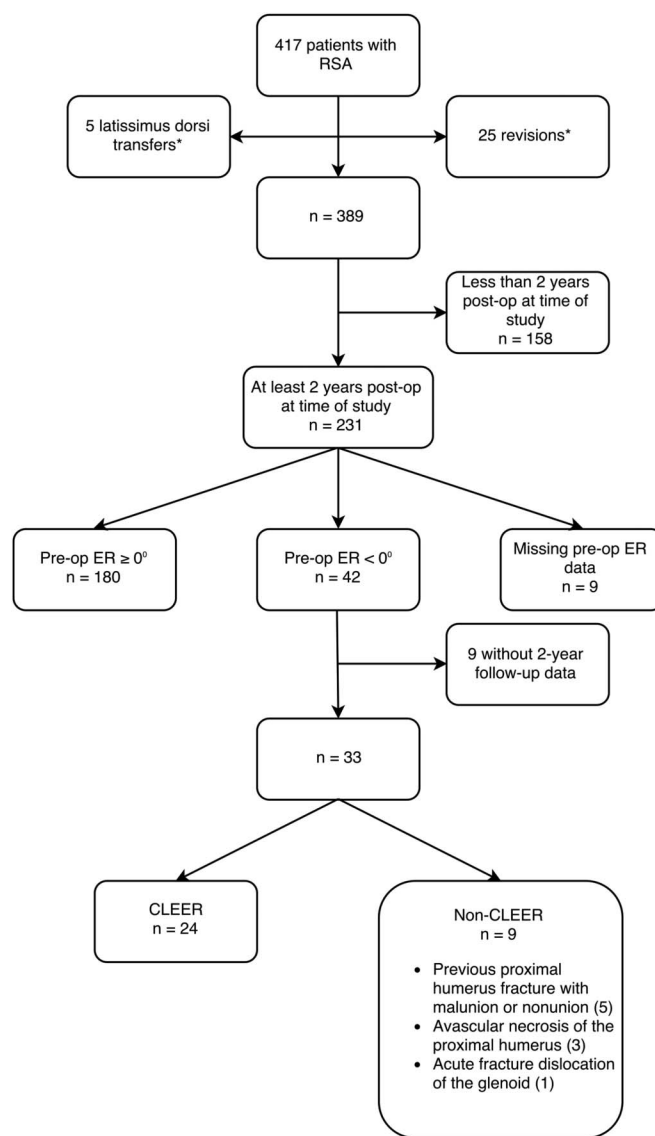


Fig. 1
Flow diagram showing the inclusion and exclusion criteria of the study population. ER = external rotation. * 2 patients underwent revision RSA and latissimus dorsi transfer.

TABLE II Goutallier Classification of Infraspinatus and Teres Minor in for CLEER and Non-CLEER Groups

Structure and Group	Goutallier Classification (no. of patients)					Mean Grade (and Std. Dev.)
	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4	
Infraspinatus						
CLEER group	0	0	2	4	15	3.6 ± 0.7
Non-CLEER group	1	0	3	3	2	2.6 ± 1.3
Teres minor						
CLEER group	3	3	6	4	5	2.2 ± 1.4
Non-CLEER group	6	2	0	1	0	0.6 ± 1.0

involved extremity for routine activities, with a 2-lb (0.9-kg) weight restriction. After 3 months, patients were encouraged to continue self-directed stretching and strengthening exercises and were allowed to return to full activity within their comfort level.

Humeral socket type (standard or semiconstrained), humeral augment (neutral, +4, or +8), and glenosphere size are recorded in our data repository. Lateralization of the center of rotation was determined on the basis of the prosthetic design, ranging in this group from 2 to 10 mm of glenosphere lateralization (32N, 10 mm; 32-4, 6 mm; 36N, 6 mm; 36-4, 2 mm)¹⁶. Total prosthetic lateralization was determined by combining the glenosphere lateralization, the humeral augment lateralization, and the variable thicknesses of the polyethylene components on the basis of the manufacturer's information.

Statistical Methods

Statistical analysis was conducted through paired and unpaired t tests and through linear regressions. Subgroup comparisons were made according to disease type (CLEER versus non-CLEER), glenosphere lateralization, total prosthetic lateralization, and Goutallier classification (for the infraspinatus and teres minor). A multivariate regression model was also created to determine the existence of predictors of postoperative external rotation. An alpha value of <0.05 was deemed significant. All statistical analyses were conducted with SPSS (version 20; IBM).

Results

Of the 42 patients with a preoperative external rotation deficit, 33 (79%) had complete 2-year follow-up data; this group included 20 female patients (61%) and 13 male patients (39%). The mean age (and standard deviation) was 74.6 ± 7.2 years at the time of the procedure, and the mean follow-up was 43.4 ± 15.5 months (range, 24 to 77 months). In the CLEER group, 20 patients had a preoperative external rotation lag sign and 2 did not have preoperative documentation regarding a lag sign (Table I). In the non-CLEER group, 5 patients had an external rotation lag sign, 2 did not have external rotation lag sign, and 2 did not have preoperative documentation regarding a lag sign (Table I).

Preoperative CT images were available for 30 patients (21 in the CLEER group and 9 in the non-CLEER group). In the CLEER group, 21 patients (100%) had at least grade-2

fatty infiltration of the infraspinatus and 15 (71%) had at least grade-2 fatty infiltration of the teres minor, with a mean Goutallier grade of 3.6 ± 0.7 for the infraspinatus and 2.2 ± 1.4 for the teres minor. In the non-CLEER group, 8 patients (89%) had at least grade-2 fatty infiltration of the infraspinatus and 1 patient (11%) had at least grade-2 fatty infiltration of the teres minor, with a mean Goutallier grade of 2.6 ± 1.3 for the infraspinatus and 0.6 ± 1.0 for the teres minor (Table II).

The center of rotation was lateralized through the glenosphere by 10 mm for 4 patients with a 32N glenosphere, 6 mm for 28 patients (12 with a 32-4 glenosphere and 16 with a 36N glenosphere), and 2 mm for 1 patient with a 36-4 glenosphere. A standard humeral polyethylene component was used in 25 patients (including 19 who received a standard neutral component, 5 who received a standard +4-mm component, and 1 who received a standard +8-mm component) and a semiconstrained humeral polyethylene component was used in 8 patients (2 who received a semiconstrained neutral component and 6 who received a semiconstrained +4-mm component).

Overall, the mean active external rotation improved from $-21^\circ \pm 7^\circ$ preoperatively to $27^\circ \pm 18^\circ$ postoperatively ($p < 0.001$), with a mean improvement of $48^\circ \pm 18^\circ$ (range, 0° to 90°) (Fig. 2). Thirty-two patients (97%) showed overall improvement in external rotation, and only 2 patients (6%) had an external rotation deficit (external rotation of $<0^\circ$) postoperatively. The rate of patient satisfaction with the overall outcome was 93.9% at the time of the most recent follow-up, with the remaining patients rating the outcome as unsatisfactory.

Significant improvement was observed in external rotation for both the CLEER group (from -21° to 28° ; $p < 0.001$) and the non-CLEER group (from -19° to 26° ; $p = 0.001$). There was no difference between the 2 groups in terms of the mean preoperative ($p = 0.570$) or postoperative ($p = 0.769$) external rotation measurements or in the mean improvement of external rotation ($p = 0.702$) (Fig. 2).

Preoperatively, all 29 patients who had completed a preoperative Simple Shoulder Test answered "No" to the question: "Can you place your hand behind your head with the elbow straight out to the side?". Postoperatively, 22 (67%) of the 33 patients reported that they were able to perform the task (Table I). Nine of the 11 patients who reported an inability to perform this task did not recover forward elevation of $>90^\circ$.

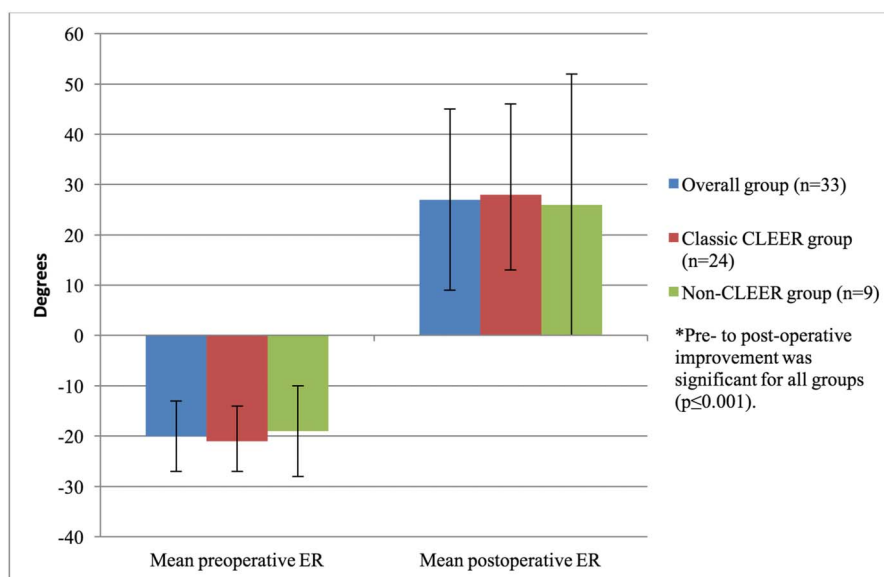


Fig. 2

Graph showing the improvement in external rotation (ER) following RSA without a latissimus dorsi transfer. Mean preoperative and postoperative active external rotation with standard deviation is shown for overall, classic CLEER, and non-CLEER groups.

Subgroup analysis showed no significant correlation between the preoperative Goutallier classification and the improvement of external rotation in either the CLEER group ($p = 0.938$ for the infraspinatus and $p = 0.891$ for the teres minor) or the non-CLEER group ($p = 0.823$ for the infraspinatus and $p = 0.593$ for the teres minor). Additionally, there was no correlation between glenosphere lateralization ($p = 0.800$ for CLEER group and $p = 0.074$ for the non-CLEER group) or total prosthetic lateralization ($p = 0.380$ for the CLEER group and $p = 0.191$ for the non-CLEER group) and improvement of external rotation for either group (Table III).

Multivariate regression analysis of age, preoperative external rotation, infraspinatus Goutallier grade, teres minor Goutallier grade, glenosphere lateralization, and total prosthetic lateralization showed no significant predictors of improvement of external rotation in patients in the CLEER group ($p = 0.963$) or the non-CLEER group ($p = 0.753$).

Discussion

The present study demonstrated that significant improvements in external rotation can be achieved by means of RSA with a more lateralized center of rotation, without the need for a latissimus dorsi tendon transfer, in patients who present with an external rotation deficit. It was previously believed that restoring active external rotation in this population was difficult without a tendon transfer because the non-functional infraspinatus and teres minor muscles would supply insufficient force for external rotation motion and functional tasks⁸. In the current study, significant improvements in external rotation were seen for both the CLEER group (from -21° to 28°) and the non-CLEER group (from -19° to 26°). These improvements were consistent with, if not slightly better than, those observed in studies involving a latissimus dorsi transfer^{7-9,17}. Furthermore, when forward elevation of $>90^\circ$ was restored, all but 2 patients had a restored ability to perform a functional external rotation task.

The use of a latissimus dorsi transfer to treat massive irreparable rotator cuff tears was popularized by Gerber et al. in the late 1980s¹⁸. Several studies have since evaluated the use of a latissimus dorsi transfer in combination with RSA for the restoration of external rotation in patients with CLEER as a result of deficiencies of the key external rotators. In a study of 12 patients who underwent RSA and a latissimus dorsi transfer, Gerber et al. showed functional

TABLE III Correlation of Goutallier Classification, Glenosphere Lateralization, and Total Prosthetic Lateralization with External Rotation Improvement in CLEER and Non-CLEER Groups

Variable	R	P Value
Goutallier classification for infraspinatus		
CLEER group	0.018	0.938
Non-CLEER group	-0.087	0.823
Goutallier classification for teres minor		
CLEER group	0.032	0.891
Non-CLEER group	-0.207	0.593
Glenosphere lateralization		
CLEER group	-0.055	0.800
Non-CLEER group	0.621	0.074
Total prosthetic lateralization		
CLEER group	-0.188	0.380
Non-CLEER group	0.480	0.191

improvement in external rotation as evaluated with use of the Constant score⁵. However, the measured active external rotation was not significantly improved. In a similar study involving 17 patients with CLEER, Boileau et al. reported significantly improved active external rotation following RSA with latissimus dorsi and teres major transfers with use of a modified L'Episcopo technique⁸.

RSA involving the use of a glenosphere with a more lateralized center of rotation has been shown to improve external rotation¹⁰. Although some have theorized that a glenosphere with a more medialized center of rotation can recruit more deltoid fibers for elevation or abduction³, these fibers may not function well for external rotation. In contrast, a glenosphere with a more lateralized design has the potential to recruit the posterior aspect of the deltoid and residual functional rotator cuff external rotators. Frankle et al., in a study of 60 shoulders, reported significant improvements in external rotation following RSA with a lateralized center of rotation¹⁰. However, patients with a preoperative external rotation deficit were not a focus of that study; the preoperative external rotation ranged from -15° to 45° , and only 16 patients had preoperative measurements. Similarly, Valenti et al. evaluated 76 patients with a massive rotator cuff tear and $<60^{\circ}$ of active elevation who underwent RSA with a lateralized center of rotation¹¹. The authors reported a mean increase of 15° in external rotation; however, none of the patients had a preoperative external rotation deficit (range, 11° to 18°) and therefore a direct comparison with the current study may not be reasonable.

Biomechanical studies involving computer models and simulated bone models have evaluated the effect of changing the center of rotation for RSA. Although medializing the center of rotation theoretically can increase the deltoid moment arm and limit the lever-arm forces directed at the glenoid-bone interface^{12,19,20}, shoulders with a lateralized center of rotation have been found to have increased joint stability^{21,22}, decreased scapular notching²³, and increased impingement-free range of motion^{12,24}. In a study involving Sawbones (Pacific Research) scapular models, Gutiérrez et al. determined that increasing the center-of-rotation offset (lateralization) had the largest impact among tested variables on the improvement of the total abduction range of motion²⁵. In a study involving the use of a virtual shoulder model to test the impacts of different combinations of humeral and glenosphere sizes and placements for RSA, Virani et al. concluded that lateralization of the glenosphere center of rotation led to greater motion in all planes¹².

Several clinical studies have compared the differences in outcomes among RSA designs with different centers of rotation. Streit et al. compared the outcomes for 9 patients who received a medialized, Grammont-style prosthesis with those for 9 patients who were treated with a prosthesis with a lateralized center of rotation¹⁴. Postoperative external rotation was shown to be greater in the lateralized group (35°) than in the medialized group (28°), although the difference was not significant ($p = 0.07$), possibly because of

the small number of patients in the study. Greiner et al. compared the results for 17 patients who underwent RSA with a "bony increased offset" lateralized Grammont RSA design with those for 17 patients who received a standard design¹³. The lateralization group had significantly greater improvement in external rotation, but only if patients with degenerative changes of the teres minor were excluded from the analysis.

Several previous studies have suggested that fatty infiltration of the teres minor has a negative influence on the restoration of external rotation. In a study of 42 patients with pseudoparesis who underwent a medialized center-of-rotation RSA, Simovitch et al. determined that a Goutallier grade-3 or 4 fatty infiltration of the teres minor was associated with decreased postoperative external rotation⁶. Costouros et al. reported similar results in a cohort of 22 patients with irreparable rotator cuff tears who underwent latissimus dorsi transfer alone²⁶. In contrast, the current study demonstrated no significant relationship between teres minor atrophy and the restoration of external rotation in patients undergoing RSA with a lateralized center of rotation. The Goutallier classification of the teres minor or infraspinatus did not correlate with the improvement of external rotation. Both the CLEER group and the non-CLEER group showed significant improvement, despite having different rates of teres minor atrophy.

To our knowledge, the present study is the first to show that RSA with a lateralized center of rotation can effectively restore external rotation without the use of latissimus dorsi transfers in patients with a preoperative external rotation deficit. Although the addition of a latissimus dorsi transfer is an effective treatment option for patients with CLEER and has not been shown to have outcomes inferior to RSA alone⁹, the increased operative time required to perform a tendon transfer along with the increased dissection may theoretically increase the risk of infection and other complications.

The present study had several limitations. To our knowledge, there is no degree of active external rotation that is universally considered satisfactory. Namdari et al. evaluated the range of motion that was required to perform various functional tasks and determined that an external rotation of $59^{\circ} \pm 10^{\circ}$ was required to perform the tasks with the arm abducted 90° ²⁷. Although external rotation at 90° of abduction was not measured in the present study, all but 2 patients who regained forward elevation of $>90^{\circ}$ also regained the ability to place their hand behind their head with the elbow straight out to the side. Another limitation is that the study group was not compared directly with patients who underwent RSA with a medialized center of rotation, with or without a latissimus dorsi transfer. Additionally, the strength of external rotation was not assessed, and it is possible that the improvement in external rotation strength in patients without latissimus dorsi transfers is inferior to that in patients with latissimus dorsi transfers. Finally, a larger cohort of patients with preoperative external rotation deficits in the non-CLEER group might have helped to identify further differences in external rotation and/or

correlations with prosthetic lateralization, which were both prone to beta-type error due to the low sample size. Furthermore, significant differences in external rotation improvement associated with fatty infiltration, glenosphere lateralization, or total prosthetic lateralization might have been detected with a larger overall cohort. Nonetheless, this series represents one of the larger series of patients with external rotation deficits treated with RSA.

In conclusion, RSA with a lateralized center of rotation can effectively restore external rotation without the use of latissimus dorsi transfers in patients with a preoperative deficit of both active elevation and external rotation as a result of rotator cuff tear arthropathy or other etiologies, and the overall rate of patient satisfaction with this procedure is high. ■

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