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The influence of preoperative external rotation weakness or stiffness on reverse total shoulder arthroplasty

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Background: Some reverse total shoulder arthroplasty (rTSA) patients may have limited preoperative external rotation (ER) because of stiffness or weakness. Currently it is not known if this affects their clinical outcome or if their ER will improve after surgery.

Methods: A multicenter shoulder arthroplasty database was queried to analyze patients undergoing a primary rTSA using a single prosthesis design featuring a medial glenoid–lateral humerus. Their pre- and postoperative range of motion was evaluated in addition to 5 outcome measures. Patients with limited preoperative ER due to weakness or stiffness were compared to patients with normal preoperative range of motion. The following questions were asked: (1) Does a preoperative ER deficit impact the postoperative outcome? (2) Do patients with preoperative ER deficits due to stiffness or weakness regain ER after rTSA? and (3) Does a preoperative ER lag sign predict a poor outcome?

Results: 608 patients were included in this study. Active external rotation (preoperative/postoperative) was as follows for the 3 patient groups: Normal patients (45°/44°), Stiff (−4°/30°), and Weak (16°/32°). Weak patients had a preoperative ER lag of 30°, which improved by 16° after surgery. The clinical outcome scores for all 3 groups improved after rTSA. Stiff patients had significantly greater improvement than Weak and Normal patients. Outcome scores were equivalent for Normal and Stiff patients. Weak patients tended to have slightly lower outcome scores.

Conclusions: Patients with limited preoperative ER can obtain a good clinical result with rTSA using a medial glenoid–lateral humerus prosthesis, ER range of motion can improve after rTSA, and stiff patients have a particularly good prognosis for recovery.

Some patients undergoing reverse total shoulder arthroplasty (rTSA) will present with limited preoperative external rotation (ER). This loss of motion may be caused by either stiffness or weakness. Stiffness results from mechanical factors such as osteophytes, capsular contractures, or impingement, whereas weakness is caused by dysfunction of the posterior rotator cuff. Loss of ER impairs a patient's function, as this motion is necessary for some activities of daily living, such as reaching the top or back of the head. Therefore, it would be helpful to know if a patient with limited ER will regain this motion after rTSA, and if the prognosis for recovery varies between patients who are ER limited by either stiffness or weakness. It would also be helpful to know if limited ER will impact rTSA clinical outcomes. Presently, these issues are not well addressed in the literature.

Some authors have reported that ER does not improve after rTSA.[3,27,28] However, in those studies, a Grammont rTSA prosthesis was used, which features an in-lay humerus (ie, a medialized humerus) and a glenosphere whose center of rotation is positioned on the face of the glenoid (ie, a medialized glenoid). Many newer rTSA prosthesis designs include an on-lay humerus (ie, a lateralized humerus) and/or a glenosphere whose center of rotation is positioned lateral to the face of the glenoid by up to 1 cm (ie, a lateralized glenoid).[11,19,22] Additional prosthetic lateralization relative to the Grammont prosthesis has been previously demonstrated to more effectively tension the posterior rotator cuff and posterior deltoid, and biomechanical tests have suggested that this may improve ER function and strength.[11-14,19-22] Recent outcome studies with lateralized rTSA prostheses have reported greater ER improvement,[4-7,16,17,25,26] but these studies have not attempted to analyze patients based on their preoperative ER deficiency, let alone stratified by ER stiffness or weakness.

Institutional Review Board approval was obtained for this clinical study (WIRB tracking no. 20091701; protocol no. CR09-005).

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Presently, the consensus in the literature is that severe ER deficiency predicts a poor outcome with rTSA.[1-3,8,9,27,28] Gerber et al[8,9] and Boileau et al[1,2] have each recommended that a combined tendon transfer with rTSA be performed in these patients. However, these studies focused on patients with the most severe ER deficits characterized by magnetic resonance imaging with documented atrophy of the infraspinatus and teres minor, as well as a positive horn blower's sign. There is a larger group of patients with significant ER weakness who do not fit these strict criteria; these patients will commonly present preoperatively with an ER lag sign. It would be helpful for the orthopedic surgeons to know how this broader group of ER deficit patients will respond to rTSA.

To aid the orthopedic surgeon in counseling a patient with an ER deficit, an improved understanding is needed of how the ER deficit affects the recovery and the rTSA outcome and to determine if any additional procedure is required. Currently, there is little guidance in the literature on this topic,[1,2,8-10,18,23] particularly considering that most existing publications involved a Grammont prosthesis.[1,2,8,9,18] We therefore asked: (1) Does a preoperative ER deficit impact the outcome of a medial glenoid–lateral humerus rTSA prosthesis? (2) Do patients with preoperative ER deficits due to either stiffness or weakness regain ER after rTSA with a medial glenoid–lateral humerus rTSA prosthesis? and (3) Does a preoperative ER lag sign predict a poor outcome? We hypothesize that patients who have a preoperative ER deficit will have worse clinical outcomes. Furthermore, we hypothesize that patients with ER deficits due to stiffness will have better clinical outcomes than patients with ER deficits due to weakness and will also have a greater improvement in postoperative ER.

Methods

A multicenter international database of primary rTSA patients was analyzed for this clinical study. Clinical data were collected between April 2007 and January 2016 by 12 fellowship-trained orthopedic surgeons at different clinical sites, using a single platform shoulder system (Equinoxe; Exactech, Inc.; Gainesville, FL, USA). For each patient at each site, extensive data were collected related to demographics, diagnosis, range of motion, outcome measures, radiographic outcomes, and adverse events. Surgical information such as the implant types and sizes and additional procedures were also recorded.

Inclusion criteria for this study included primary rTSA performed for cuff tear arthropathy or a combination of osteoarthritis and rotator cuff insufficiency. Patients with fracture diagnoses and revision cases were excluded, as were patients with latissimus transfers. Because we were evaluating clinical improvement, patients without preoperative and latest follow-up measurements for both active and passive ER with the arm at the patient's side were also excluded. Finally, only patients with 2 years or more of clinical and radiographic follow-up were included.

After applying inclusion and exclusion criteria, patients were further analyzed to identify those with limited preoperative ER due to stiffness (Stiff) or weakness (Weak). A comparative group of patients (Normal) who did not have any preoperative ER limitation were also identified and used as a representative control. These 3 patient cohorts were defined by their preoperative passive ER and the difference between active ER and passive ER, which was defined as lag, and provided a measure of weakness. The specific preoperative criteria for each cohort was defined as follows: (1) Normal cohort = passive ER $\geq 30^\circ$ and a lag $<10^\circ$; (2) Stiff cohort = passive ER $\leq 20^\circ$ and a lag $\leq 10^\circ$; and (3) Weak cohort = passive ER $\geq 30^\circ$ and a lag $\geq 20^\circ$.

Each patient from each cohort was evaluated preoperatively and at latest follow-up using the Simple Shoulder Test, University of California Los Angeles Shoulder Score, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, Constant score, and Shoulder Pain and Disability Index outcome metrics. Active abduction, active forward flexion, and active and passive ER were also recorded. Active internal rotation was also measured by vertebral segments and was scored by the following discrete assignment: $0^\circ = 0$, hip = 1, buttocks = 2, sacrum = 3, L5-L4 = 4, L3-L1 = 5, Th12-Th8 = 6, and Th7 or higher = 7. Patient interrogation as well as range of motion and strength evaluation were performed by the procedural surgeon, a physical therapist, or research coordinator. Complications and adverse events were recorded as well. Radiographic analysis was conducted at latest follow-up using anteroposterior, axillary lateral, and scapular Y radiographs. Radiographs were evaluated for lucency around the humeral stem according to the Gruen classification adapted to the humerus[15] and scapular notching was evaluated according to the Nerot classification.[27] Finally, a 2-tailed, unpaired Student *t* test identified statistical differences between preoperative, postoperative, and pre- to postoperative improvement for all metrics between the 3 patient cohorts.

Results

At the time of this study, the shoulder arthroplasty database contained a total of 1051 rTSA patients, of which 608 primary rTSA patients met the inclusion and exclusion criteria for this study. A comparison of demographics and implant information for each cohort is presented in Table I. Only 2 significant differences were observed. First, the rate of subscapularis repair was significantly greater in Stiff patients than Normal patients ($P = .0056$) and also Weak patients ($P = .0238$). Additionally, both Stiff patients ($P = .0254$) and Weak patients ($P = .0276$) had a significantly greater use of augmented baseplates than Normal patients, suggesting they had greater glenoid wear.

Table I
Demographic and implant comparison between patients with preoperative external rotation weakness, stiffness, or patients with normal preoperative external rotation

Cohort comparison	Normal cohort	Stiff cohort	Weak cohort
Cohort size (sex), n	125 (80 F/45 M)	98 (61 F/37 M)	89 (52 F/37 M)
Age, yr	72.1 ± 7.3	72.7 ± 7.2	72.6 ± 6.9
Height, in.	65.2 ± 4.3	65.1 ± 3.8	64.9 ± 4.3
Weight, lb	171.6 ± 39.6	177.9 ± 43.2	171.2 ± 40.4
BMI	28.2 ± 5.2	29.5 ± 7.0	28.5 ± 5.4
Subscapularis repair, %	41.3 ± 0.5	60.8 ± 0.5	43.9 ± 0.5
Follow-up, mo	40.0 ± 17.2	35.7 ± 15.4	36.9 ± 15.1
Glenosphere size, mm	39.5 ± 2.1	39.8 ± 2.1	39.9 ± 2.3
Augmented baseplates, %	7.3	18.6	17.7
Humeral liner and tray offset, mm	0.8 ± 1.7	1.0 ± 2.0	0.6 ± 1.6

BMI, body mass index; *F*, female; *M*, male.

Table II
Comparison of average preoperative measurements, rTSA outcomes: normal, stiff, and weak preoperative external rotation patients

Preoperative external rotation	Preoperative measurement										
	SST	UCLA	ASES	Constant	SPADI	Active abduction	Active forward flexion	Active IR score	Active external rotation	Passive external rotation	ER lag
Normal, mean ± SD	4.2 ± 2.9	14.4 ± 4.6	37.2 ± 16.5	41.0 ± 15.7	80.9 ± 25.7	92.6 ± 39.8	102.1 ± 42.0	4.0 ± 1.7	44.5 ± 14.8	46.0 ± 15.3	−1.5 ± 2.9
Stiff, mean ± SD	3.2 ± 2.3	12.8 ± 3.5	36.3 ± 14.1	32.4 ± 11.5	87.5 ± 19.0	64.7 ± 25.9	84.3 ± 30.3	2.6 ± 1.5	−4.3 ± 11.0	9.9 ± 9.3	−14.3 ± 6.9
Weak, mean ± SD	3.8 ± 2.8	12.9 ± 4.1	38.8 ± 15.1	37.1 ± 13.6	82.0 ± 22.8	72.3 ± 31.4	89.1 ± 41.4	4.1 ± 1.8	15.9 ± 16.2	46.4 ± 14.1	−30.4 ± 14.6
P value (normal vs stiff)	**.0066**	**.0048**	.6762	**<.0001**	**.0478**	**<.0001**	**.0005**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
P value (normal vs weak)	.3979	**.0240**	.5001	.1130	.7877	**.0001**	**.0298**	.6060	**<.0001**	.9237	**<.0001**
P value (stiff vs weak)	.0942	.7640	.2528	**.0158**	.0867	.0745	.3584	**<.0001**	**<.0001**	**<.0001**	**<.0001**

rTSA, reverse total shoulder arthroplasty; *SD*, standard deviation; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles Shoulder Score; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *SPADI*, Shoulder Pain and Disability Index; *IR*, internal rotation; *ER*, external rotation.
Boldface indicates statistical significance.

Analysis of the preoperative outcomes demonstrated a general trend that Normal patients had the best outcome metric scores, Stiff patients had the worst outcome metric scores, and Weak patients were in the middle (Table II). Specifically, Stiff patients were significantly worse off before surgery than Normal patients according to 4 of 5 outcome metrics and 6 of 6 ROM measurements. Weak patients were significantly worse off before surgery than Normal patients according to 1 of 5 outcome metrics and 4 of 6 ROM measurements. Additionally, Stiff patients had significantly lower Constant scores than Weak patients and had significantly less active and passive ER. Of the 3 groups, Stiff patients had the least active and passive ER prior to surgery, whereas Weak patients had the largest lag.

Postoperatively, Stiff patients had significantly better outcome scores than Weak patients, and these differences were statistically significant for 3 of 5 outcome metrics (Table III). The outcome metric scores for Stiff patients were statistically indistinguishable from those of Normal patients. Weak patients tended to have lower outcome scores than Normal patients although this reached statistical significance only for SPADI. Postoperative active forward elevation was similar for all 3 groups and averaged ≥135°. Active ER for Weak and Stiff patients was >30° for both groups but was still significantly less than the 44° active ER observed in Normal patients. Weak patients had a postoperative lag of 16°, which was significantly more than both Stiff patients who had a lag of 12° and Normal patients who had a lag of 7°.

When evaluating pre- to postoperative improvement (Table IV), all 3 groups experienced significant improvement after rTSA. Stiff patients experienced the greatest amount of clinical improvement: they had significantly more improvement in 3 of 5 outcome metrics and 6 of 6 ROM measurements relative to Normal patients and significantly more improvement in 5 of 5 outcome metrics and 5 of 6 ROM measurements relative to Weak patients. Of particular interest, Stiff patients averaged 35° improvement in active ER, which was significantly more than both Weak and Normal patients. By comparison, Weak patients averaged 16° improvement in active ER and 14° improvement in lag, which was approximately half of their preoperative lag. Weak patients had significantly greater improvement in active ER than Normal patients and also significantly more improvement in lag than both Normal and Stiff patients.

Finally, no differences were observed in the humeral radiolucent line rates (Weak = 5.2%, Stiff = 7.9%, and Normal = 8.2%), the scapular notching rates (Weak = 6.5%, Stiff = 5.7%, and Normal = 5.2%), scapular notching grades (Weak = 3 grade 1 and 2 grade 2; Stiff = 3 grade 1 and 2 grade 2; Normal = 4 grade 1 and 1 grade 2), or complication rates (Weak = 10.1%, Stiff = 11.2%, and Normal = 8.0%) between the 3 cohorts. Please refer to Table V for a detailed description of complications and adverse events between the 3 cohorts.

Discussion

This study analyzed the results of rTSA using a medial glenoid–lateral humerus prosthesis and compared outcomes of patients with limited preoperative ER due to stiffness or weakness relative to patients with normal preoperative ER. We observed that patients with ER deficiencies experienced clinical outcomes that were similar to those of patients with a normal preoperative range of motion, regardless if the patients were ER deficient because of

Table III
Comparison of average postoperative measurements, rTSA outcomes: normal, stiff, and weak preoperative external rotation patients

Preoperative external rotation	Postoperative measurement										
	SST	UCLA	ASES	Constant	SPADI	Active abduction	Active forward flexion	Active IR score	Active external rotation	Passive external rotation	ER lag
Normal, mean ± SD	10.0 ± 2.7	29.9 ± 5.6	82.3 ± 20.4	69.6 ± 13.0	20.3 ± 23.3	127.2 ± 32.8	138.7 ± 28.2	4.6 ± 1.5	43.5 ± 17.8	50.4 ± 18.2	−6.9 ± 10.7
Stiff, mean ± SD	10.1 ± 2.4	30.0 ± 4.8	82.1 ± 17.8	69.8 ± 12.3	23.3 ± 21.6	111.7 ± 26.3	142.1 ± 21.3	4.4 ± 1.7	30.3 ± 16.6	42.2 ± 13.6	−11.9 ± 12.8
Weak, mean ± SD	9.3 ± 2.9	28.2 ± 6.7	77.2 ± 20.4	65.5 ± 15.9	28.0 ± 28.3	109.7 ± 26.2	135.0 ± 28.8	4.8 ± 1.7	31.6 ± 19.5	47.9 ± 17.1	−16.3 ± 16.2
P value (normal vs stiff)	.7932	.8456	.9434	.9005	.3495	**.0002**	.3289	.6109	**<.0001**	**.0003**	**.0460**
P value (normal vs weak)	.0706	.0564	.0897	.0762	**.0437**	**.0001**	.3364	.3554	**<.0001**	.3208	**<.0001**
P value (stiff vs weak)	**.0368**	**.0346**	.0821	**.0431**	.2050	.5922	.0556	.2247	.6340	**.0127**	**.0401**

rTSA, reverse total shoulder arthroplasty; *SD*, standard deviation; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles Shoulder Score; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *SPADI*, Shoulder Pain and Disability Index; *IR*, internal rotation; *ER*, external rotation.
Boldface indicates statistical significance.

Table IV
Comparison of average improvement, rTSA outcomes: normal, stiff, and weak preoperative external rotation patients

Preoperative external rotation	Improvement										
	SST	UCLA	ASES	Constant	SPADI	Active abduction	Active forward flexion	Active IR score	Active external rotation	Passive external rotation	ER lag
Normal, mean ± SD	5.6 ± 3.4	15.5 ± 6.5	44.4 ± 23.6	27.8 ± 16.3	60.7 ± 28.1	34.6 ± 42.0	36.7 ± 44.1	0.6 ± 1.9	−1.0 ± 19.1	4.5 ± 20.0	−5.4 ± 10.0
Stiff, mean ± SD	6.9 ± 3.0	17.3 ± 5.5	46.2 ± 20.0	37.4 ± 14.1	63.5 ± 25.5	47.0 ± 36.0	57.8 ± 33.8	1.9 ± 2.0	34.7 ± 16.3	32.3 ± 16.3	2.4 ± 13.6
Weak, mean ± SD	5.4 ± 3.5	15.3 ± 6.8	38.4 ± 22.6	28.3 ± 17.2	54.1 ± 31.4	37.4 ± 38.5	45.9 ± 43.2	0.6 ± 2.0	15.7 ± 22.1	1.6 ± 18.4	14.1 ± 18.7
P value (normal vs stiff)	**.0500**	**.0357**	.5652	**.0001**	.4866	**.0207**	**.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
P value (normal vs weak)	.6215	.8375	.1013	.8760	.1735	.6319	.1454	.8753	**<.0001**	.3236	**<.0001**
P value (stiff vs weak)	**.0019**	**.0348**	**.0164**	**.0003**	**.0342**	.0802	**.0355**	**<.0001**	**<.0001**	**<.0001**	**<.0001**

rTSA, reverse total shoulder arthroplasty; *SD*, standard deviation; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles Shoulder Score; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *SPADI*, Shoulder Pain and Disability Index; *IR*, internal rotation; *ER*, external rotation.
Boldface indicates statistical significance.

weakness or stiffness. Furthermore, we observed that active ER was significantly improved by rTSA, where both Stiff and Weak patients had an average postoperative active ER >30°. Although this range of motion was significantly less than the 44° average postoperative ER of Normal patients, it was still within an acceptable range.

We found that the cause of the deficit (stiffness vs. weakness) affected the magnitude of improvement and recovery. Stiff patients did particularly well after rTSA; in fact, they experienced the largest improvement in clinical outcome measures. Postoperatively, the outcome scores of Stiff patients were statistically indistinguishable from those of Normal patients, despite the fact that Stiff patients were significantly worse preoperatively. Stiff patients experienced an impressive improvement in active ER of 35°. Alleviating mechanical restrictions to motion such as osteophytes, capsular contractures, and impingement was most likely responsible for this magnitude of improvement. Based on these results, surgeons can have confidence that patients with limited ER due to stiffness will regain a functional range of motion and experience a good clinical result following rTSA. Weak ER patients also improved following rTSA but not to the same degree as the Stiff patients. By comparison, Weak patients experienced the same amount of improvement as Normal patients undergoing rTSA but their postoperative outcome scores tended to be lower than the other 2 patient cohorts, though the magnitude of these differences were small and did not exceed the minimal clinically important difference thresholds associated with each outcome metric, as was previously defined by Simovitch et al.[24] Active ER improved by 16° for Weak patients and their lag improved by 14° (from a preoperative average of 30°-16° at latest follow-up). This reduction in lag suggests that ER improved for Weak patients but did not normalize, as it was significantly larger than both Stiff and Normal patients.

Previous reports have indicated that rTSA does not improve active ER range of motion.[3,27,28] Our study contradicts those findings as it relates to Stiff and Weak ER patients, but not for Normal patients. We believe that this discrepancy is primarily related to prosthesis design. A Grammont rTSA prosthesis was used in those studies that reported no improvements in ER,[3,27,28] whereas our series used a medial glenoid–lateral humerus rTSA prosthesis. As previously described, lateralization of the humerus better tensions the posterior deltoid and the remaining posterior rotator cuff as compared to both medial glenoid–medial humerus and lateral glenoid–medial humerus rTSA prosthesis designs.[11,20-22] Regardless of the medial or lateral rTSA prosthesis design, it should be noted that all rTSA prostheses medialize the humerus relative to the native anatomic position of the humerus.[11,20-22] This relative medialization is associated with posterior rotator cuff shortening and is likely responsible for an upper threshold of active ER achievable with rTSA, which is less than that achieved by a healthy, nonpathologic patient. In addition to mechanical impingement, this posterior rotator cuff shortening is also likely why Normal patients were not observed in our study to experience any active ER improvement, as their preoperative active ER was 45°, near the upper threshold of active ER achievable with rTSA.

Selecting the best treatment option for patients with preoperative ER deficiency can be a challenge for the orthopedic surgeon. In some situations, a tendon transfer procedure may be needed to supplement the rTSA to restore rotational motion and strength. Our study provides some information that may be helpful when evaluating such options. First, we found that a medial glenoid–lateral humerus rTSA prosthesis is associated with restoration of a modest amount of active ER. On average, we observed an improvement of 16° in Weak patients and 35° in Stiff patients, both of which were sufficient to obtain >30° postoperative ER for each cohort. Nevertheless, this magnitude of improvement may not be sufficient for all individuals, particularly those with the most severe deficits; these patients may benefit from a combined tendon transfer. Publications examining combined tendon transfers with rTSA have reported ER improvement in the range of 30°,[1,2,8-10,18,23] which was greater than what we observed in our study for the Weak patient cohort, in which no one received any muscle transfers.

Finally, we found that the presence of an ER lag sign alone does not predict a poor outcome with a medial glenoid–lateral humerus rTSA prosthesis. When surgeons are evaluating patients to

Table V
Comparison of complications/adverse events between the 3 patient cohorts

Complications	Normal cohort, n (%)	Stiff cohort, n (%)	Weak cohort, n (%)	All cohorts/ rate, n (%)
Acromion and scapular fractures	2 (1.6)	1 (1.0)	4 (4.5)	7 (2.2)
Persistent pain	2 (1.6)	2 (2.0)	2 (2.2)	6 (1.9)
Infection	1 (0.8)	3 (3.1)	1 (1.1)	5 (1.6)
Dislocations	2 (1.6)	0	2 (2.2)	4 (1.3)
Aseptic glenoid loosening	1 (0.8)	1 (1.0)	0	2(0.6)
Humeral fractures	0	2 (2.0)	0	2 (0.6)
Broken glenoid baseplate screw	1 (0.8)	0	0	1 (0.3)
Edema	0	1 (1.0)	0	1 (0.3)
Cerebrovascular accident	1 (0.8)	0	0	1 (0.3)
Pulmonary embolism	0	1 (1.0)	0	1 (0.3)

determine if a combined tendon transfer rTSA is required, they should not base their decision solely on that observation. Other clinical findings that may be taken into consideration and were not evaluated in this study include a positive hornblower's sign and the inability to actively externally rotate the arm to neutral. Also, atrophy of both the infraspinatus and teres minor on magnetic resonance imaging might also be an indication for poor postoperative function. Future studies are needed to more specifically analyze these variables and evaluate their relationship to postoperative function with different rTSA prosthesis designs.

This study has several limitations. It uses a multicenter international database to retrospectively report on the short-term clinical outcomes of a single platform reverse shoulder system. Although we have done our best to standardize the practices of each data collection site and facilitated the use of standardized data collection forms to quantify outcomes using various scoring metrics, each site collects its own data, and their inherent differences may influence the results. Also, at the time of this analysis, we did not collect data that would allow us to evaluate subsets of patients with ER weakness as defined by a hornblower's sign or magnetic resonance imaging–documented atrophy of the infraspinatus and teres minor, but we will address it in future work. Finally, in our study we only assessed lag with the arm at the side, as opposed to when the arm is abducted as did Shi et al[23]; future work should assess the improvement of lag for Weak and Stiff patients when the arm is elevated.

Conclusions

The results of this study demonstrate that good clinical outcomes can be achieved in patients with preoperative ER deficits when a medial glenoid–lateral humerus rTSA prosthesis is used, and that active ER range of motion improves after surgery regardless of the cause of the deficit (stiffness vs. weakness). Although both Stiff and Weak patients achieved good outcomes, we observed that Stiff patients had a greater prognosis for clinical improvement. This stratified observation is helpful to the orthopedic surgeon when counseling patients on expected outcomes and also for segmenting patient populations in future clinical outcomes research. Weak patients experienced the same amount of clinical improvement as Normal patients, but their final outcome scores tended to be slightly lower. Furthermore, Weak patients experienced ER improvement after rTSA, but this did not normalize relative to that of Stiff or Normal patients. Future research is needed to evaluate subsets of patients and identify additional contributing factors so that we can better predict ER improvement after rTSA.

Disclaimer

Brad Carofino is a consultant for Exactech, Inc., but receives no royalties from it.

Howard Routman is a consultant for Exactech, Inc., and receives royalties from it.

Chris Roche is an employee of Exactech, Inc.

References

1. Boileau P, Chuinard C, Roussanne Y, Neyton L, Trojani C. Modified latissimus dorsi and teres major transfer through a single delto-pectoral approach for external rotation deficit of the shoulder: as an isolated procedure or with a reverse arthroplasty. J Shoulder Elbow Surg 2007;16:671–82. https://doi.org/10.1016/j.jse.2007.02.127.
2. Boileau P, Chuinard C, Roussanne Y, Bicknell RT, Rochet N, Trojani C. Reverse shoulder arthroplasty combined with a modified latissimus dorsi and teres major tendon transfer for shoulder pseudoparalysis associated with dropping arm. Clin Orthop Relat Res 2008;466:584–93. https://doi.org/10.1007/s11999-008-0114-x.
3. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14(Suppl S): 147S–61S. https://doi.org/10.1016/j.jse.2004.10.006.
4. Frankle M, Levy JC, Pupello D, Siegal S, Saleem A, Mighell M, et al. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. a minimum two-year follow-up study of sixty patients surgical technique. J Bone Joint Surg Am 2006;88(Suppl 1 Pt 2):178–90. https://doi.org/10.2106/JBJS.F.00123.
5. Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients. J Bone Joint Surg Am 2005;87:1697–705. https://doi.org/10.2106/JBJS.D.02813.
6. Friedman RJ, Cheung EV, Flurin PH, Wright T, Simovitch RW, Bolch C, et al. Are age and patient gender associated with different rates and magnitudes of clinical improvement after reverse shoulder arthroplasty? Clin Orthop Relat Res 2018;476:1264–73. https://doi.org/10.1007/s11999.0000000000000270.
7. Friedman RJ, Flurin PH, Wright TW, Zuckerman JD, Roche CP. Comparison of reverse total shoulder arthroplasty outcomes with and without subscapularis repair. J Shoulder Elbow Surg 2017;26:662–8. https://doi.org/10.1016/j.jse.2016.09.027.
8. Gerber C, Pennington SD, Lingenfelter EJ, Sukthankar A. Reverse Delta-III total shoulder replacement combined with latissimus dorsi transfer. A preliminary report. J Bone Joint Surg Am 2007;89:940–7. https://doi.org/10.2106/JBJS.F.00955.
9. Gerber C, Maquieira G, Espinosa N. Latissimus dorsi transfer for the treatment of irreparable rotator cuff tears. J Bone Joint Surg Am 2006;88:113–20. https://doi.org/10.2106/JBJS.E.00282.
10. Grey SG. Combined latissimus dorsi and teres major tendon transfers for external rotation deficiency in reverse shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):82–7.
11. Hamilton MA, Diep P, Roche C, Flurin PH, Wright TW, Zuckerman JD, et al. Effect of reverse shoulder design philosophy on muscle moment arms. J Orthop Res 2015;33:605–13. https://doi.org/10.1002/jor.22803.
12. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ. Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:1128–35. https://doi.org/10.1016/j.jse.2011.07.034.
13. Herrmann S, König C, Heller M, Perka C, Greiner S. Reverse shoulder arthroplasty leads to significant biomechanical changes in the remaining rotator cuff. J Orthop Surg Res 2011;6:42. https://doi.org/10.1186/1749-799X-6-42.
14. Langohr GD, Giles JW, Athwal GS, Johnson JA. The effect of glenosphere diameter in reverse shoulder arthroplasty on muscle force, joint load, and range of motion. J Shoulder Elbow Surg 2015;24:972–9. https://doi.org/10.1016/j.jse.2014.10.018.
15. Melis B, DeFranco M, Lädermann A, Molé D, Favard L, Nérot C, et al. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. J Bone Joint Surg Br 2011;93: 1240–6. https://doi.org/10.1302/0301-620X.93B9.25926.
16. Mollon B, Mahure SA, Roche CP, Zuckerman JD. Impact of glenosphere size on clinical outcomes after reverse total shoulder arthroplasty: an analysis of 297 shoulders. J Shoulder Elbow Surg 2016;25:763–71. https://doi.org/10.1016/j.jse.2015.10.027.
17. Mollon B, Mahure SA, Roche CP, Zuckerman JD. Impact of scapular notching on clinical outcomes after reverse total shoulder arthroplasty: an analysis of 476 shoulders. J Shoulder Elbow Surg 2017;26:1253–61. https://doi.org/10.1016/j.jse.2016.11.043.
18. Puskas GJ, Catanzaro S, Gerber C. Clinical outcome of reverse total shoulder arthroplasty combined with latissimus dorsi transfer for the treatment of chronic combined pseudoparesis of elevation and external rotation of the shoulder. J Shoulder Elbow Surg 2014;23:49–57. https://doi.org/10.1016/j.jse.2013.04.008 [Erratum: J Shoulder Elbow Surg 2017;26:1692].
19. Roche C, Crosby L. Kinematics and biomechanics of reverse total shoulder arthroplasty. In: Nicholson GP, editor. AAOS orthopaedic knowledge update: shoulder and elbow 4. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2013. 45–54.
20. Roche CP, Diep P, Hamilton M, Crosby LA, Flurin PH, Wright TW, et al. Impact of inferior glenoid tilt, humeral retroversion, bone grafting, and design parameters on muscle length and deltoid wrapping in reverse shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71:284–93.
21. Roche C, Flurin PH, Wright T, Crosby LA, Mauldin M, Zuckerman JD. An evaluation of the relationships between reverse shoulder design parameters and range of motion, impingement, and stability. J Shoulder Elbow Surg 2009;18: 734–41. https://doi.org/10.1016/j.jse.2008.12.008.
22. Routman HD, Flurin PH, Wright TW, Zuckerman JD, Hamilton MA, Roche CP. Reverse shoulder arthroplasty prosthesis design classification system. Bull Hosp Jt Dis (2013) 2015;73(Suppl 1):S5–14.
23. Shi LL, Cahill KE, Ek ET, Tompson JD, Higgins LD, Warner JJ. Latissimus dorsi and teres major transfer with reverse shoulder arthroplasty restores active motion and reduces pain for posterosuperior cuff dysfunction. Clin Orthop Relat Res 2015;473:3212–7. https://doi.org/10.1007/s11999-015-4433-4.
24. Simovitch R, Flurin PH, Wright T, Zuckerman JD, Roche CP. Quantifying success after total shoulder arthroplasty: the minimal clinically important difference. J Shoulder Elbow Surg 2018;27:298–305. https://doi.org/10.1016/j.jse.2017.09.013.

25. Simovitch RW, Friedman RJ, Cheung EV, Flurin PH, Wright T, Zuckerman JD, et al. Rate of improvement in clinical outcomes with anatomic and reverse total shoulder arthroplasty. J Bone Joint Surg Am 2017;99:1801–11. https://doi.org/10.2106/JBJS.16.01387.
26. Simovitch RW, Gerard BK, Brees JA, Fullick R, Kearse JC. Outcomes of reverse total shoulder arthroplasty in a senior athletic population. J Shoulder Elbow Surg 2015;24:1481–5. https://doi.org/10.1016/j.jse.2015.03.011.
27. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388–95. https://doi.org/10.1302/0301-620X.86B3.14024.
28. Werner CM, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476–86. https://doi.org/10.2106/JBJS.D.02342.