Rate of improvement in shoulder strength after anatomic and reverse total shoulder arthroplasty

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A R T I C L E   I N F O

Background: The rate at which patients regain shoulder strength after anatomic and reverse total shoulder arthroplasty (TSA) is unknown. In this study, we aimed to quantify differences in the timeline during which patients gained shoulder strength after primary anatomic and reverse TSA.

Methods: We retrospectively reviewed prospectively collected data from 374 shoulders after primary anatomic TSA (aTSA) and 601 shoulders after primary reverse TSA (rTSA). Postoperative improvement in external rotation (ER) strength and forward elevation (FE) strength from baseline was assessed at 3 months, 6 months, 1 year, and 2 years. Percent change in mean shoulder strength between each time point was determined for anatomic and reverse groups separately. A handheld dynamometer was used to assess ER strength with the involved shoulder in 0° ER, 0° abduction, and the elbow in 90° flexion and FE strength with the involved shoulder in the scapular plane at 30° of flexion and 30° of abduction.

Results: Both aTSA and rTSA groups ceased to have statistically significant gains in FE strength after 1 year postoperatively. In contrast, patients continued to have statistically significant gains in ER strength between 1 year and 2 years postoperatively after rTSA ($P = .001$), but not after aTSA ($P = .476$). Both aTSA and rTSA groups saw improvement in strength in both ER (+32.1% and +51.4%, respectively) and FE (+38.3% and +90.3%, respectively) at 2-year follow-up. The aTSA group's ER and FE strength increased the most between 3 and 6 months (+16.2% and +35.7%, respectively). In contrast, the rTSA group gained the most ER strength between 6 months and 1 year (+14.8%) and the greatest FE strength between baseline and 3 months (+40.3%).

Conclusion: Patients gain ER strength earlier and FE strength later after aTSA compared with rTSA. Most gains in strength occurred in the first year. However, statistically significant gains in shoulder ER strength in the rTSA group continued between 1 year and 2 years postoperatively, suggesting that 2-year follow-up may be inadequate to capture the full benefits of rTSA on shoulder strength. The results of this study provide insight into the timeline of strength recovery after aTSA and rTSA that will help inform patient counseling and future study design.

Anatomic and reverse total shoulder arthroplasties (TSAs) are efficacious treatment modalities for restoring shoulder function and alleviating pain. Numerous outcome measures have been used to track postoperative patient outcomes, including outcome scores, shoulder range of motion (ROM), and shoulder strength. Of these, shoulder strength is seldom reported; yet, it is an important predictor of outcomes, as greater postoperative shoulder strength after TSA has been associated with greater participation in sports and recreation and improved daily function.[27]

The postoperative timeline during which patients gain shoulder strength after anatomic TSA (aTSA) and reverse TSA (rTSA) is unknown. A 2008 study by Sperling et al[24] assessed shoulder strength and ROM at baseline, 6 months, and 1 year in a 15-patient cohort undergoing aTSA, and although shoulder strength in extension, abduction, and external rotation (ER) significantly improved between 6-month and 1-year follow-up, minimal improvement in ROM was observed after 6 months. The continued improvement in shoulder strength after ROM plateaued in that study brings into

question at what time point postoperatively does shoulder strength no longer improve. Studies typically use a minimum 1-year[4,26] or 2-year[7,14,16,23] follow-up to report on shoulder strength after TSA despite the paucity of literature supporting an appropriate time point. The absence of knowledge regarding the timeline during which patients gain shoulder strength after TSA limits our ability to confidently assess improvement postoperatively and counsel patients on postoperative expectations.

The purpose of this study is to quantify improvement in shoulder strength from baseline at 3 months, 6 months, 1 year, and 2 years after primary aTSA and rTSA. By identifying the time point at which shoulder strength ceases to improve, surgeons will be better equipped to determine appropriate outcome measure time points and counsel patients with a more accurate strength recovery timeline.

Methods

A retrospective review of prospectively enrolled patients who underwent primary aTSA and rTSA was performed at our institution between November 2004 and November 2018. We initially identified 409 aTSAs and 683 rTSAs performed during the study period. Patients with an age between 40 and 90 years at the time of surgery with shoulder strength data available preoperatively and postoperatively were included. Patients were excluded if they had a previous arthroplasty on the involved shoulder, a preoperative diagnosis of infection, acute fracture, fracture sequelae, or an oncologic diagnosis. Patients were also excluded if they had intra-operative or postoperative complication or had an adverse event to eliminate potential confounders that would affect the expected recovery of strength postoperatively. All patients were included, regardless of follow-up, to produce a more robust model and evaluation of the effect of time on strength after TSA. Patients with bilateral shoulder arthroplasties were included, and each shoulder was analyzed independently.

All shoulder arthroplasties were performed through a delto-pectoral approach using the Equinoxe shoulder system (Exactech, Gainesville, FL, USA). Postoperatively, all patients (including aTSA and rTSA) completed a similar rehabilitation protocol consisting of a physical therapist–directed home exercise program which was taught at postoperative office visits. The program began with pendulum exercises with motion limited to passive forward flexion and ER to neutral at 3 weeks postoperatively. Sling use was subsequently discontinued, and active ROM was initiated without limitations at 6 weeks postoperatively. Strengthening exercises were initiated 12 weeks postoperatively with gradual return to activities.

Patient data were prospectively collected preoperatively and then at 3 months, 6 months, 1 year, and 2 years postoperatively. Changes in strength at postoperative time points were calculated using mixed-effect models so that preoperative strength values accounted for differences in baseline strength and patient follow-up variability (see details in the Statistics section). ER strength was measured with the involved shoulder in 0° ER, 0° abduction, and the elbow in 90° flexion (Fig. 1, A). Forward elevation (FE) strength was measured with the involved shoulder in the scapular plane at 30° of flexion and 30° of abduction (Fig. 1, B). Both measures of shoulder strength were assessed using a handheld dynamometer (Lafayette Instrument Company, Lafayette, Indiana) using maximal patient effort coached by the research coordinator/athletic trainer or physical therapist.

Included shoulders were split into aTSA and rTSA groups. Demographics, availability of strength data at each follow-up time point, and mean shoulder strength at each time point were compared between groups. Percent increase in mean improvement

between baseline (preoperative measurement) and 2-year follow-up and between intermediate follow-up time points was expressed by calculating the percent change. Statistically significant differences in mean shoulder strength between time points were identified for each group to elucidate the time point postoperatively at which shoulder strength improvement plateaued. Follow-up was limited to 2 years postoperatively to mitigate the potential confounding effects of aging on shoulder strength.[9,15]

Differences in demographic characteristics between aTSA and rTSA groups were quantified using a two-tailed unpaired t-test and Pearson chi-squared tests. In the analysis of longitudinal strength data, repeated measures from the same individuals are correlated. Furthermore, the absence of complete follow-up data for all patients necessitated the use of a statistical method that would allow for comparison of all available data at each time point with incorporation of interpatient variability. Therefore, we implemented mixed-effect models using patients as random effects to assess whether ER strength and FE strength in each group improved significantly between time points. Tukey correction was used to correct for pairwise comparisons. By utilizing a mixed-effect model, we reduced the probability of type I error and accommodated for missing data and addressed the time dependency of strength recovery after shoulder arthroplasty.[6] All statistical analyses were performed with R software (version 3.6.3; R Core Team, Vienna, Austria) with a defined α = 0.05.

Results

A total of 374 aTSAs and 601 rTSAs were evaluated (Table I). rTSA shoulders were significantly older at surgery (70.7 ± 7.5 vs. 65.8 ± 8.5, P < .001), were more commonly female (52.2% vs. 44.9%, P = .031), and had increased comorbidities (hypertension, heart disease, and diabetes mellitus). Groups were comparable in body mass index, dominant arm operation, tobacco use, and availability of follow-up data at each time point.

ER strength

aTSA demonstrated significantly greater ER strength than rTSA at each time point (P < .001) (Table II). Mean ER strength improved between each time point for the reverse group, but not the anatomic group (Fig. 2 and Table II). Although ER strength improved significantly between 1-year and 2-year follow-up in the rTSA group, there was not a significant improvement in the aTSA group (P = .001 and P = .476, respectively). Both groups showed significant improvement in ER strength from baseline to 2-year follow-up; however, rTSA shoulders had a greater increase in mean ER strength (+51.4% vs. +32.1%). The greatest increase in ER strength occurred between 3-month and 6-month follow-up in the aTSA group (+16.2%) and between 6-month and 1-year follow-up in the rTSA group (+14.8%).

FE strength

Shoulders treated with aTSA demonstrated significantly greater FE strength than rTSA shoulders at baseline, 6 months, 1 year, and 2 years (Table III). The rTSA group had slightly greater FE strength only at the 3-month follow-up point (8.7 ± 5.0 vs. 8.4 ± 4.7), but this difference was not statistically significant (P = .441). Mean FE strength improved between each time point for the rTSA group; however, similar to ER strength, recovery of FE strength after aTSA did not begin until after the 3-month follow-up visit, at which time the strength was lower than preoperative measurements (Fig. 3 and Table III). FE strength did not significantly improve between 1-year and 2-year follow-up in either group. Although both the aTSA and
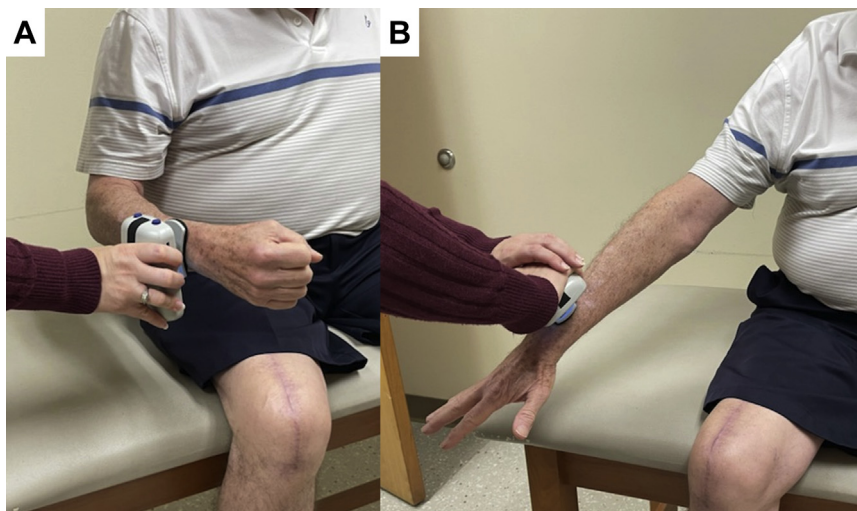
Figure 1 Maximal voluntary strength in (**A**) external rotation and (**B**) forward elevation was assessed preoperatively and at postoperative follow-up visits by a research coordinator.

Table I
Demographics of included shoulders.

Characteristic	aTSA	rTSA	*P* value
Number of shoulders	374	601	
Age at surgery, y	65.8 ± 8.5	70.7 ± 7.5	**<.001**
Sex: female	44.9% (168)	52.2% (314)	**.031**
BMI, kg/m²	30.7 ± 7.5	30.2 ± 6.6	.290
Dominant arm operation	54.0% (202)	56.9% (342)	.413
Comorbidities			
Hypertension	53.5% (200)	64.4% (387)	**<.001**
Heart disease	12.8% (48)	20.1% (121)	**.005**
Diabetes mellitus	14.4% (54)	21.6% (130)	**.007**
Tobacco use	8.6% (32)	7.2% (43)	.500
Available follow-up			
Pre-Op	100% (374)	100% (601)	-
3 mo	92.0% (344)	94.8% (570)	.753
6 mo	77.5% (290)	81.7% (491)	.633
1 y	76.5% (286)	76.4% (459)	1
2 y	60.2% (225)	61.2% (368)	.912

aTSA, anatomic total shoulder arthroplasty; *BMI*, body mass index; *rTSA*, reverse total shoulder arthroplasty.
Values are presented as mean ± SD or % (N).
Bold values indicate statistical significance.

Table II
Temporal improvement in external rotation strength.

Measure	aTSA		rTSA		*P* value[*]
Strength[†] (lbs.)					
Baseline	10.9 ± 6.1		7.4 ± 4.5		**<.001**
3 mo	10.5 ± 5.2		7.8 ± 4.5		**<.001**
6 mo	12.2 ± 5.5		8.8 ± 4.7		**<.001**
1 y	13.6 ± 6.3		10.1 ± 5.1		**<.001**
2 y	14.4 ± 6.4		11.2 ± 5.8		**<.001**
Temporal improvement[‡]					
Overall	+32.1%	**<.001**	+51.4%	**<.001**	
Baseline vs. 3 mo	−3.8%	.144	+5.4%	.825	
3 mo vs. 6 mo	+16.2%	**<.001**	+12.8%	**<.001**	
6 mo vs. 1 y	+11.5%	**.002**	+14.8%	**<.001**	
1 y vs. 2 y	+5.9%	.476	+10.9%	**.001**	

aTSA, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty.
Bold values indicate statistical significance.
   [*]Comparisons between each group for a given time point were based on Welch's two-sided t-test.
   [†]The mean and standard deviation are provided for each group and time point.
   [‡]*P* values delineate comparisons of external rotation strength within each group over time and are based on longitudinal analysis using a mixed-effect model with Tukey correction for pairwise comparisons.

rTSA had significant improvement in FE strength from baseline to 2-year follow-up, rTSA shoulders had a substantially greater increase in mean FE strength (+90.3% vs. +38.3%). The greatest increase in FE strength occurred between baseline and 3-month follow-up with rTSA (+40.3%) and between 3-month and 6-month follow-up after aTSA (35.7%).

Discussion

The postoperative timeline during which patients undergoing aTSA and rTSA regain shoulder strength is not well documented. Lack of this knowledge poses a barrier on surgeons' ability to counsel patients on postoperative strength recovery expectations. In addition, the absence of evidence supporting an appropriate measurement endpoint for shoulder strength after TSA limits experimental design. Therefore, we assessed two measures of shoulder strength (ER and FE) at five time points (baseline, 3 months, 6 months, 1 year, and 2 years) in patients undergoing primary aTSA and rTSA. We found that all patients see improvement in both ER and FE strength through the first year. In addition, we found that patients who underwent rTSA, but not patients who

underwent aTSA, continued to have statistically significant gains in ER strength between 1 year and 2 years postoperatively. Furthermore, the postoperative period during which patients gained the most strength differed based on procedure (aTSA vs. rTSA) and shoulder strength measure (ER vs. FE).

In the present study, ER strength continued to improve significantly between 1 year and 2 years postoperatively after rTSA. In contrast, ER strength remained relatively stable 1 year after aTSA. This observation may be explained by the profound biomechanical changes after rTSA, designed with a medialized center of rotation and constraint to allow the deltoid (a muscle capable of generating greater contractile force than rotator cuff muscles) to elevate the shoulder in the absence of a functioning posterosuperior rotator cuff. With the change in biomechanics, the deltoid coordination and activation may continue to improve over time, possibly explaining the continued strength improvement out to 2 years seen in this study. Regarding FE strength, neither group experienced significant improvement beyond 1 year postoperatively. In isolation, these findings support the use of 2-year minimum follow-up when evaluating strength outcomes after aTSA, but not
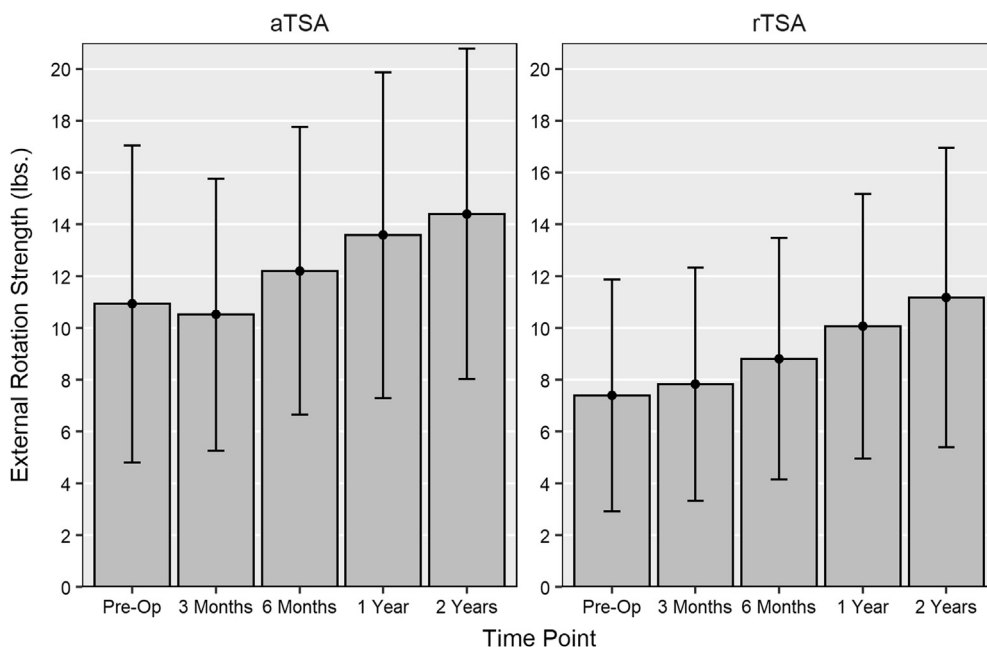
Figure 2 Mean (± SD) external rotation strength at each time point after aTSA and rTSA. *aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty; *SD*, standard deviation.

Figure 3 Mean (± SD) forward elevation strength at each time point after aTSA and rTSA. *aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty; *SD*, standard deviation.
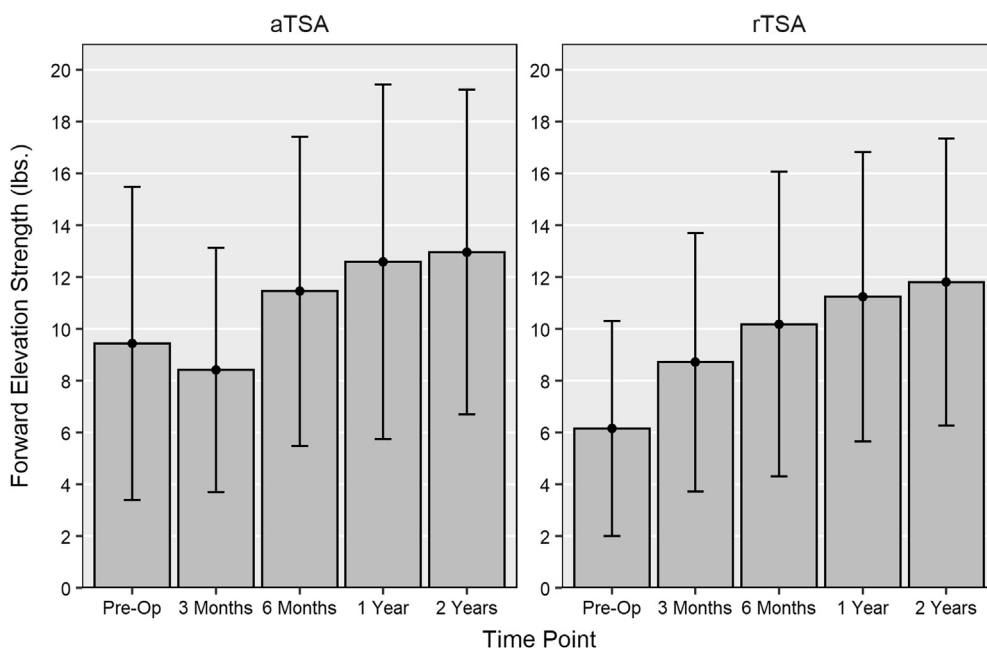
necessarily rTSA. However, taken together with prior work examining the rate of improvement in ROM and patient-reported outcome scores,[20,23] the use of 2-year minimum follow-up likely captures most of the improvement in functional outcomes after both aTSA and rTSA.

Although these findings suggest that a later postoperative time point may provide a more accurate evaluation of ER strength in patients who underwent rTSA, statistically significant differences in shoulder strength may not be clinically significant. Notably, Simovitch et al found that despite worsening ROM 72 months

postoperatively after aTSA and rTSA, patient-reported outcome scores remained stable.[23] Changing patient expectations with aging, rather than objective function assessed by ROM and strength, may be more important clinically. Although the minimal clinically important difference has been quantified for various shoulder outcome scores[2,3,21,22,25,28] and shoulder ROM[21,22] after TSA, it has not been reported for objective measures of shoulder strength. Future studies are needed to determine whether the statistically significant improvements identified in the present study are clinically significant.

Table III
Temporal improvement in forward elevation strength.

Measure	aTSA	rTSA		P value[*]	
Strength[†] (lbs.)					
Baseline	9.4 ± 6.0	6.2 ± 4.2		**<.001**	
3 mo	8.4 ± 4.7	8.7 ± 5.0		.441	
6 mo	11.4 ± 6.0	10.2 ± 5.9		**.007**	
1 y	12.6 ± 6.9	11.2 ± 5.6		**.011**	
2 y	13.0 ± 6.3	11.8 ± 5.5		**.036**	
Temporal improvement[‡]					
Overall	+38.3%	**<.001**	+90.3%	**<.001**	
Baseline vs. 3 mo	−10.6%	**.007**	+40.3%	**<.001**	
3 mo vs. 6 mo	+35.7%	**<.001**	+17.2%	**<.001**	
6 mo vs. 1 y	+10.5%	**.012**	+9.8%	**<.001**	
1 y vs. 2 y	+3.2%	.963	+5.4%	.568	

aTSA, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty.
Bold values indicate statistical significance.

[*]Comparisons between each group for a given time point were based on Welch's two-sided t-test.

[†]The mean and standard deviation are provided for each group and time point.

[‡]P values delineate comparisons of forward elevation strength within each group over time and are based on longitudinal analysis using a mixed-effect model with Tukey correction for pairwise comparisons.

The greatest gains in ER strength occurred between 3 and 6 months in the aTSA group and between 6 months and 1 year in the rTSA group (+16.2% and +14.8%, respectively) (Table II). Although Sperling et al[24] did not assess outcomes at 3 months postoperatively, they identified a greater gain in ER strength after aTSA between baseline and 6 months than between 6-month and 1-year follow-up (+41.9% vs. +14.8%) in a small cohort of patients. When grouping the data in a similar fashion, the present study similarly found that patients gained greater ER strength between baseline and 6 months than between 6-month and 1-year follow-up for both aTSA (+11.9% vs. +11.5%) and rTSA (+18.9% vs. +14.8%). Although the mean preoperative ER strength was greater in the study by Sperling et al than that in the present study (13.6 lbs. vs. 10.9 lbs.), this was likely due to differences in measurement methods; both patients undergoing aTSA in the study by Sperling et al and patients in the present study had a mean age of 66 years at the time of surgery.

For FE strength, the greatest gains occurred between 3 and 6 months in the aTSA group and between baseline and 3 months in the rTSA group (+35.7% and +40.3%, respectively) (Table III). The immediate large improvements in FE strength after rTSA likely derive from the design of the implant, allowing the deltoid to facilitate FE in the absence of a functioning posterosuperior rotator cuff. In addition, rapid improvement in the mean FE strength may be driven by patients in our study with rotator cuff arthropathy, some of which have concomitant pseudoparalysis, thereby lowering the mean baseline strength but resolving soon after surgery. Conversely, shoulder function after aTSA is still reliant on the rotator cuff postoperatively, and given the significant surgical insult to the rotator cuff tendons and muscles, it may take patients longer to recover. Later FE strength recovery may also be explained by greater limitations on rehabilitation in the immediate weeks after aTSA in an effort to protect the subscapularis repair.[5,10] Furthermore, the reliance on a healing subscapularis for shoulder stability after aTSA may result in pain that limits strength, whereas stability in rTSA is dependent on the deltoid.[10-12,18] These differences in the biomechanics, postoperative rehabilitation, and stability likely also explain the early loss of both ER and FE strength between baseline and 3 months after aTSA but not after rTSA (Figs. 1 and 2).

A unique strength of our study is the implementation of mixed-effect models to assess for statistically significant differences

between shoulder strength at different time points. Prior studies of TSA outcomes that compare shoulder strength between successive follow-up time points are limited by correlation between repeated measures of the same individuals, thus predisposing to type I error. By utilizing a mixed-effect model with patients as random effects, our study minimizes the potential for type I error, properly accommodates for missing data, and addresses the time-dependent nature of strength improvement.[6] Similar analyses have been performed to report on the return of subscapularis strength after aTSA.[13,14] However, prior studies assessing the return of ER and FE strength after aTSA or rTSA have not used this analysis.[1,7,14,16,17,23] In addition, all patients underwent aTSA or rTSA using the same shoulder system at a single institution, thus providing homogeneity within our study population.

The findings of this study should be interpreted with consideration of its limitations. We identified statistical differences in shoulder strength between follow-up time points; however, this does not equate to clinical significance. To the best of our knowledge, the minimal clinically important difference for shoulder strength after TSA has only been reported as part of the Constant score.[26] Although the use of a handheld dynamometer provides convenient and reliable assessments of shoulder strength,[8,19] the use of a stationary isokinetic dynamometer would have provided greater accuracy and precision. Furthermore, strength was assessed in 30 degrees of abduction and FE. This may not accurately represent strength with the arm at or above the level of the shoulder, which is common for daily activities. Finally, although an analysis of the rate of improvement of internal rotation strength would have provided an additional benefit to the shoulder arthroplasty literature, internal rotation strength is not routinely quantified during follow-up visits at our institution. Despite these limitations, the results of this study provide clinically and experimentally relevant insights into the recovery timeline for patients undergoing primary aTSA and rTSA.

Conclusion

Restoration of FE strength after shoulder arthroplasty largely occurs during the first year after surgery, with patients who underwent rTSA making the greater gains within the first 3 months. In contrast, ER strength recovers within one year after aTSA, but continues to improve after rTSA to at least the 2-year postoperative time point. These findings provide surgeons with an empiric characterization of temporal trends in shoulder strength after anatomic and rTSA, thus facilitating more accurate patient counseling.

Disclaimers:

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