J Shoulder Elbow Surg (2022) 31, e37–e47

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ONLINE ARTICLES

# Deltoid fatigue part 2: a longitudinal assessment of anatomic total shoulder arthroplasty over time

**Bradley S. Schoch, MD[a,*], Marie Vigan, PhD[b], Christopher P. Roche, MSE, MBA[c], Moby Parsons, MD[d], Thomas W. Wright, MD[e], Joseph J. King, MD[e], Jean David Werthel, MD[a,b]**

[a]*Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, FL, USA*
[b]*Department of Orthopedic Surgery, Hopital Ambroise Paré, Boulogne-Billancourt, France*
[c]*Exactech Inc., Gainesville, FL, USA*
[d]*The Knee, Hip and Shoulder Center, Portsmouth, NH, USA*
[e]*Department Orthopaedics and Rehabilitation, University of Florida, Gainesville, FL, USA*

**Background:** Gradual loss of overhead range of motion (ROM) has been observed after reverse shoulder arthroplasty (RSA). It remains unclear if this is caused by the effect of RSA design on muscle fiber lengthening or is part of the natural aging process of the shoulder musculature. Although studies have attempted to evaluate deltoid fatigue after RSA, there is a paucity of literature evaluating this effect after anatomic shoulder arthroplasty (aTSA), which would be expected to occur due to aging alone. The purpose of this study is to evaluate the effect of time on overhead ROM after aTSA and compare this with previous data on a similar cohort of RSAs. We hypothesized that overhead ROM would decrease gradually over time in both groups without differences between prosthesis types.
**Methods:** A retrospective review of 384 aTSAs without complications was performed over a 10-year period. All shoulders were treated for primary osteoarthritis using a single implant system. Patients were evaluated longitudinally at multiple postoperative time points. At least 1 follow-up visit was between 1 and 2 years postoperatively and another at least 5 years after surgery. ROM and patient reported outcome measures (PROMs) were evaluated using linear-mixed models for repeated measures. These results were compared with a previously evaluated cohort of 165 well-functioning RSAs analyzed using the same methodology.
**Results:** Primary aTSA shoulders were observed to lose 0.7° of abduction per year starting 1 year postoperatively ($P = .001$). Smaller losses were observed in external rotation (−0.3°/yr, $P = .06$) and internal rotation (−0.04/yr, $P < .001$). However, no significant losses were observed in forward elevation ($P = .8$). All PROMs diminished slowly over time, but these changes did not exceed the minimally clinically important difference when modeled over 10 years (Simple Shoulder Test −0.08/yr, $P < .001$; American Shoulder Elbow Surgeons −0.5/yr, $P < .001$; University of California Los Angeles Shoulder Score −0.2/yr, $P < .001$). When compared with a similarly analyzed cohort of RSAs, overhead ROM decreased at a slower rate in the aTSA cohort (abduction −0.7° vs. −0.8°/yr, $P = .9$; FE −0.06° vs. −0.8°/yr, $P = .05$).
**Discussion:** In the well-functioning aTSA, gradual loss of ROM occurs in all planes of motion except forward elevation. However, these losses are small and have little meaningful impact relative to minimally clinically important difference thresholds on PROMs. Progressive loss of abduction seen in both aTSA and RSA is likely secondary to aging of the periscapular and rotator cuff musculature.

Institutional review board approval was received for this study (WIRB 1300448).

*Reprint requests: Bradley S. Schoch, MD, Department Orthopedic Surgery and Rehabilitation, Mayo Clinic, 4500 San Pablo Rd, Jacksonville, FL 32224, USA.
E-mail address: Schoch.bradley@mayo.edu (B.S. Schoch).


https://doi.org/10.1016/j.jse.2021.07.019

When compared with RSA, loss of motion after aTSA was statistically similar, calling into question the belief that RSA-induced deltoid fatigue leads to loss of overhead motion over time.

**Level of evidence:** Level III; Retrospective Cohort Comparison; Treatment Study



**Keywords:** TSA; deltoid fatigue; loss of motion; decline; long-term; RSA; reverse

Loss of overhead range of motion (ROM) at mid-term follow-up after primary reverse shoulder arthroplasty (RSA) has been documented by multiple studies.[2,7,19] The authors have theorized that humeral distalization in RSA leads to lengthening of the deltoid, causing excessive strain on the deltoid muscle fibers. This change in resting length then manifests as deltoid fatigue resulting in loss of overhead motion beginning 6-8 years after surgery.[2,11] However, a more recent study designed to evaluate the effect of time on overhead ROM after an RSA cohort did not observe an abrupt loss of motion at mid-term follow-up.[16] Instead, the authors showed that overhead ROM progressively declined at a rate of 0.8°/yr beginning 1 year after surgery.

In the native nonpainful shoulder, progressive loss of overhead ROM has been observed as part of the normal aging process. Stathokostas et al[21] performed an observational study of 436 patients (aged 55-85 years) living independently in a single Canadian city. Men were noted to lose 5° of abduction per decade, compared with 6° per decade in women. Using piecewise linear regression, the observed rate of decline did accelerate in men after the age of 71 (0.8°/yr) and women after the age of 63 (0.74°/yr). Given the similarities in loss of motion in the native shoulder and after primary RSA, the independent impact of a nonanatomic arthroplasty configuration on longitudinal deltoid function and overhead motion remains unclear.

To date, there are limited data measuring the effect of time on loss of overhead function in anatomic shoulder arthroplasty (aTSA) patients. The purpose of this study is to evaluate the effect of time on changes in overhead ROM and patient-reported outcome measures (PROMs) in a cohort of well-functioning aTSAs. We further sought to compare these results with a similarly analyzed cohort of RSAs from a previously published study.[16] We hypothesized that patients undergoing primary aTSA would demonstrate gradual loss of overhead ROM at a similar rate as previously observed after primary RSA.[16]

## Methods

A retrospective review of all primary aTSAs performed for primary osteoarthritis between 2005 and 2014 was performed using a multinational shoulder arthroplasty database. All operations were performed using a single implant system (Equinoxe; Exactech Inc., Gainesville, FL, USA) by high-volume shoulder surgeons. Any shoulder sustaining a postoperative complication or undergoing revision surgery was excluded in order to evaluate the natural history of overhead ROM in the well-functioning aTSAs without a clinically identifiable cause for impairment. Furthermore, any shoulder with a documented glenoid lucency greater than a Lazarus grade 2 was also eliminated due to the effect of radiolucent lines on postoperative ROM.[10,17]

Patients enrolled in the multicenter database are followed at routine intervals after surgery. All available follow-up points after 1 year were used. To be included, shoulders were required to have a minimum of 3 separate follow-up points including 1 visit between 1 and 2 years after surgery, a second follow-up point at a minimum of 5 years after surgery, and the third follow-up point at any other yearly visit. These criteria resulted in 384 eligible patients. Implanted glenoid components included 190 all-polyethylene pegged, 78 all-polyethylene keeled, and 112 caged glenoid components. Four shoulders did not have adequate documentation in the database to discern which type of anatomic glenoid component was inserted.

Demographic information for each patient was collected along with information on prior corticosteroid injection and non-arthroplasty surgeries. Active ROM and PROMs were evaluated at each follow-up visit. Abduction, forward elevation, and external rotation (ER) were measured in degrees by the performing surgeon or research assistant. Internal rotation (IR) was measured according the scale described by Flurin et al.[5] PROMs included American Shoulder Elbow Surgeons (ASES) score, Simple Shoulder Test (SST), and the University of California Los Angeles Shoulder Score (UCLA). The Constant-Murley score, a combination of patient answered questions and physician measurements, was also assessed. ROM and PROMs were compared between aTSA and a previously published cohort of RSAs using similar selection criteria.[16] Glenoid component lucencies were evaluated by the treating surgeon according to the Lazarus score.[10]

### RSA comparison cohort

A cohort of 165 well-functioning RSAs was previously evaluated using the same methodology.[16] All shoulders had a diagnosis of cuff tear arthropathy, osteoarthritis with rotator cuff deficiency, or irreparable rotator cuff tear. Shoulders were all treated with the Equinoxe shoulder system (Exactech Inc.). RSAs performed for acute fractures, post-traumatic arthritis, avascular necrosis, or for oncologic purposes were excluded. Any shoulder sustaining a postoperative complication or undergoing revision surgery was also excluded in order to evaluate the effect of implant design in shoulders without another identifiable cause for poor motion. Patients were evaluated at the same time points as the aTSA cohort.

### Statistical analysis

Change in overhead ROM was evaluated as the primary outcome and measured by forward elevation and abduction. These measures were chosen, as they represented factors directly related to deltoid function. Secondary outcome measures included change in ER, IR, PROMs, and the Constant score. Statistical analyses were performed using linear-mixed models for repeated measures. This modeling is a generalization of a standard linear regression, which allows modeling of the parameter changes for each individual over time and takes into account the intrasubject association. This allows for a more accurate evaluation of the effect of time on outcome measures.

Secondary analyses were performed to evaluate the effect of covariates on changes in ROMs and PROMs using mixed modeling. Backward selection of the covariates was applied to evaluate associations between ROMs/PROMs and the different covariates. Using population parameters in addition to individual measurements, each parameter was estimated. Changes in ROMs and PROMs were then compared with a cohort of RSAs using linear-mixed models.

To account for differences in age between the aTSA and RSA groups and concern for the effect of age on ROM, the comparison between the aTSA and RSA groups was repeated using a linear-mixed model after matching for age (±5 years).[1,21] Each patient in the RSA group was matched by age, with 1 patient in the aTSA group. In doing so, the aTSA and RSA groups were again compared in regard to both baseline and change in ROM and PROM over time. All statistical analyses were performed with R (R Foundation for Statistical Computing, Vienna, Austria). The statistical significance level was set at $P < .05$.

## Results

### Cohort

Three-hundred and eight-four shoulders in 353 patients were evaluated at a median final follow-up of 6.5 years (range, 5-14 years) after undergoing primary aTSA. The mean age at surgery was 66 years (range, 32-86 years). A total of 195 shoulders in males and 189 shoulders in females were evaluated. The median number of qualifying follow-up visits for each patient was 5 (range, 3-12). Full demographic details are outlined in Table I. Postoperative radiographs were available for 375 shoulders. Glenoid component radiolucent lines at the latest follow-up were present in 26% of shoulders and graded as grade 1 (65, 17%) and grade 2 (33, 9%). The remaining 277 shoulders demonstrated no periglenoid lucencies.

Postoperative abduction declined at a rate of 0.7°/yr ($P < .001$). However, forward elevation was relatively maintained with an observed decline of −0.06°/yr ($P = .8$). Slow declines were also seen in both ER and IR over time (−0.3°/yr, $P = .06$; −0.04 levels/yr, $P < .001$); however, these changes were clinically very small despite loss of IR reaching statistical significance.

Small but statistically significant declines were also observed for all PROMs. Full details are provided in Table II. However, when evaluated as change per decade, none of these exceed the minimal clinically important difference as described by Simovitch et al.[18]

### Influence of covariates on ROM and PROM changes

Age at the time of aTSA surgery did not influence changes in overhead motion, ER, or IR over time. When analyzed as an entire cohort, a small loss of abduction was observed. The rate of abduction loss was significantly greater in patients with a body mass index (BMI) >30 ($P = .04$) and those patients with a history of prior corticosteroid injections ($P < .001$). Although forward elevation was maintained over time when analyzed as a group, patients with a history of diabetes showed more stable forward elevation, losing 1.5° less of forward elevation per year (0.2°/yr vs. −1.3°/yr, $P = .03$). Patients with a BMI >30 and those with a history of diabetes demonstrated lower observed IR at 1 year ($P < .001$, $P = .04$); however, change over time was similar regardless of BMI or diabetic status. These effects are illustrated in Fig. 1. Preoperative factors did not have an effect on ER at 1 year postoperatively nor changes over time. Full details are provided in Table III.

When evaluating patients based on age at the time of surgery, patients younger than 70 demonstrated significantly less decline in postoperative ASES, Constant, and UCLA scores over time. Figure 2 illustrates these associations with age. Males demonstrated higher baseline SST and Constant scores 1 year postoperatively, but gender had no effect on the rate of change in any PROM evaluated. A higher BMI was found to be associated with a greater rate of decline for SST, Constant, and ASES scores. Figure 2 illustrates these associations with BMI. However, BMI was not found to affect changes in the UCLA score over time.

### aTSA vs. RSA

When compared with the previously evaluated cohort of RSAs,[16] patients undergoing aTSA were significantly younger (66 vs. 71, $P < .001$) and more commonly male (51% vs. 32%, $P = .003$). The aTSA cohort was also less likely to have undergone prior surgery (14% vs. 35%, $P < .001$), but more likely to have had a prior corticosteroid injection (38% vs. 26%, $P = .006$). As expected, the distribution of diagnoses was significantly different given the most common use for each prosthesis type.

When comparing motion between groups, patients undergoing aTSA demonstrated significantly greater overhead ROM at 1 year after surgery (forward elevation, 147° vs. 134°; abduction, 132° vs. 116°; $P < .001$). However, when comparing the rate of change over time, both groups demonstrated similar rates of slow decline in overhead motion. Full details are outlined in Table IV and illustrated in Fig. 3. The similarity in rate of decline of overhead ROM was seen in all 3 age groups analyzed, regardless of prosthesis (Fig. 4).

Similar to overhead ROM, aTSA shoulders also demonstrated greater modeled ER and IR at 1 year

**Table I** Demographic information

| | aTSA No.* | Data | RSA No.* | Data | $P$ value |
|---|---|---|---|---|---|
| Age at surgery (years) | 384 | 66.9 (7.9) | 165 | 71.4 (6.6) | <.001 |
| <70 | | 247 (64.3%) | | 55 (33.3%) | <.001 |
| 70-75 | | 76 (19.8%) | | 54 (32.7%) | |
| >75 | | 61 (15.9%) | | 56 (33.9%) | |
| Male | 384 | 195 (50.9%) | 165 | 53 (32.1%) | .003 |
| BMI | 381 | 29.9 (6.5) | 165 | 28.5 (5.6) | .05 |
| <25 | | 86 (22.6%) | | 43 (26.1%) | .7 |
| 25-30 | | 139 (36.5%) | | 62 (37.6%) | |
| ≥30 | | 156 (40.9%) | | 60 (36.4%) | |
| Previous surgery | 383 | 52 (13.6%) | 165 | 58 (35.2%) | <.001 |
| Diagnosis | | | 165 | | |
| OA | 384 | 384 (100%) | | 48 (29.1%) | <.001 |
| RCT | | | | 21 (12.7%) | |
| CTA | | | | 96 (58.2%) | |
| Diabetes | 329 | 43 (13.1%) | 128 | 7 (5.5%) | .02 |
| Tobacco | 329 | 33 (10.0%) | 128 | 6 (4.7%) | .09 |
| Prior injections | 382 | 146 (38.2%) | 162 | 42 (25.9%) | .006 |

*BMI*, body mass index; *OA*, osteoarthritis, *RCT*, rotator cuff tear, *CTA*, cuff tear arthropathy; *aTSA*, anatomic shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty.

* No. represents the number of patients with available information.

**Table II** Changes of the slopes of ROMs and PROMs

| | Observed average at 1-2 yr | Observed average at final follow-up | Slope of variation | $P$ value |
|---|---|---|---|---|
| Abduction (degree) | 129.9 ± 27.6 | 126 ± 31.7 | −0.7/year | .001 |
| Forward elevation (degree) | 145.3 ± 24.9 | 147.6 ± 27.2 | −0.06/year | .8 |
| External rotation (degree) | 50.5 ± 18.3 | 49.5 ± 18.4 | −0.3/year | .06 |
| Internal rotation | 5.2 ± 1.3 | 5 ± 1.4 | −0.04/year | <.001 |
| SST score | 10.9 ± 1.6 | 10.5 ± 2.2 | −0.08/year | <.001 |
| Constant score | 72.5 ± 11.6 | 72.7 ± 12.5 | −0.2/year | .1 |
| ASES score | 87.9 ± 13.9 | 85.7 ± 17.2 | −0.5/year | <.001 |
| UCLA score | 31.8 ± 3.3 | 31.1 ± 4.8 | −0.2/year | <.001 |

*ROM*, range of motion; *PROM*, patient reported outcome measure; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles.

Slopes were estimated by linear-mixed models.

postoperatively. One year postoperative SST, Constant score, and ASES were all higher in patients undergoing aTSA; however, there were no significant differences in the rate of change of any PROM over time between prosthesis types.

After multivariate analysis, no significant differences were noted between aTSA and RSA in regard to 1-year postoperative ROM, change in motion over time, 1-year PROM, or change in PROM scores over time. This similarity demonstrates that in a well-functioning shoulder arthroplasty without an identifiable cause for a poor outcome, both aTSA and RSA perform in a comparable fashion over time in regard to changes in motion and function.

Given the significant age differences between the aTSA and RSA groups, these groups were reanalyzed after case matching aTSA patients with the 165 RSA patients based on age at the time of surgery. After matching the aTSA and RSA groups for age ($P = .4$), the mixed analysis for paired data demonstrated that aTSA patients continued to demonstrate higher 1-year ROM and PROMs than RSA patients. Similarly, the rate of change in ROM and PROM after surgery remained similar even after controlling for age. Specifically, for forward elevation, the rate of change no longer trended toward significance when comparing matched aTSAs and RSAs (−0.4°/yr vs. −0.8°/yr, $P = .3$) with the entire cohorts (−0.06°/yr vs. −0.8°/yr, $P = .05$). See Table V for full details.

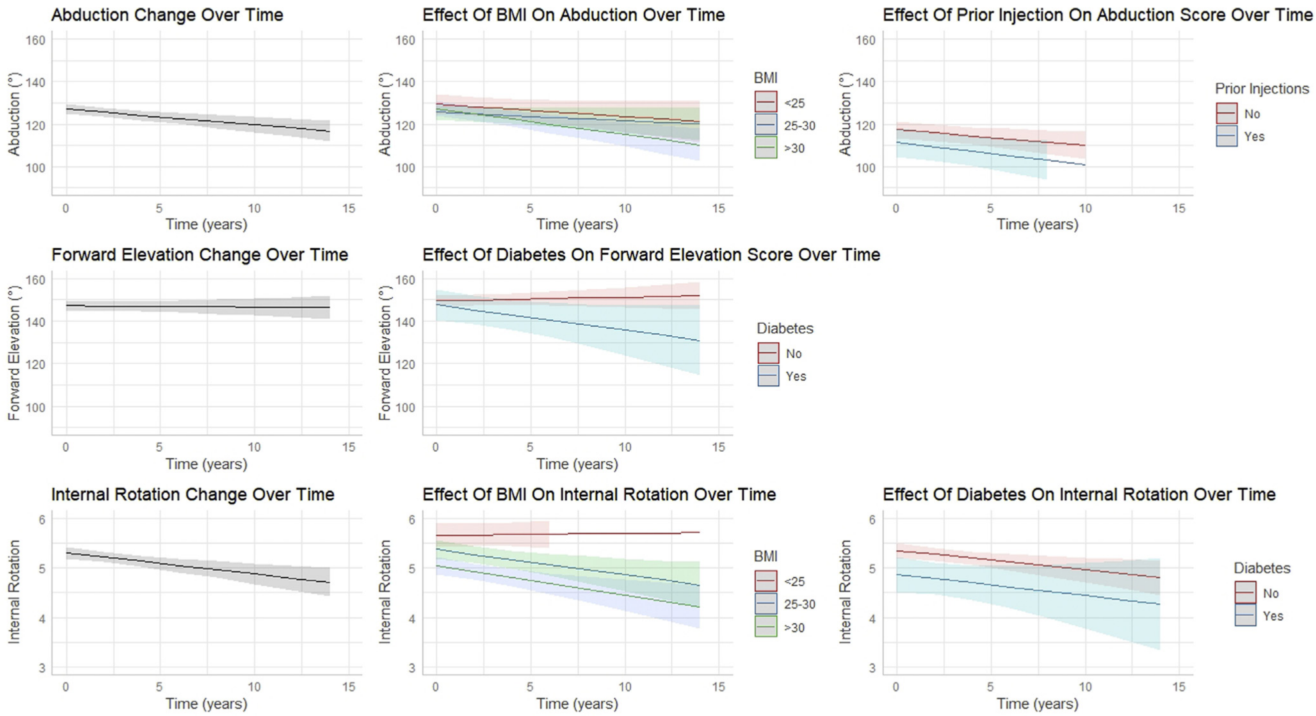


**Figure 1** Effect of covariates on range of motion. *BMI*, body mass index.

## Discussion

Previous reports have suggested that patients undergoing RSA develop deltoid fatigue with a resultant loss of overhead motion at midterm follow-up.[2,7,19] However, these studies failed to directly quantify individual patient changes in ROM over time because their study design evaluated nonhomogeneous groups of patients at different time points. The belief of deltoid fatigue was recently challenged by Schoch et al,[16] who demonstrated a slow steady decline in overhead ROM after primary RSA in a closed cohort of patients followed over time at multiple time points without an identifiable cause for loss of function followed over time. In order to further evaluate the effect of anatomic alterations on overhead ROM after RSA, this current study was designed to longitudinally assess differences in overhead motion between aTSA and RSA patients. Abduction and elevation are largely the result of deltoid muscle activation after RSA in comparison with aTSA where the rotator cuff remains the critical component to generate overhead motion. In contrast, ER and IR remain a function of the intact rotator cuff or subscapularis repair after RSA and are likely less subject to isolated deltoid changes.[6,23] When evaluating patients treated with aTSA, which does not induce the same structural changes on the deltoid muscle as RSA, shoulders were shown to slowly lose abduction but maintain forward elevation over time. However, when compared directly with the RSA cohort, both aTSA and RSA demonstrated statistically similar rates of overhead motion decline over time. This direct comparison challenges the belief of deltoid fatigue by demonstrating no differences in the rates of postoperative overhead ROM change when comparing RSA and aTSA through midterm follow-up.

In a study of 21 aTSAs evaluated at a mean follow-up of 13 years, Sowa et al compared ROM with a previously reported cohort of 24 patients evaluated at 7 years.[12,20] The authors noted a small loss of forward elevation (125.5° at 7 years vs. 118.4° at 13 years) that did not reach statistical significance ($P = .3$).[20] These results are in contrast to a closed cohort of 45 aTSAs reported by Raiss et al.[13] These authors evaluated patients at multiple time points (1, 2, 3-4, 5-8, 9-14, and 15+ years) and reported both a loss of forward elevation and a lower Constant score beginning 8 years postoperatively.[13] However, these differences were only statistically significant when comparing the 6-month follow-up with the 15+-year follow-up time points. At all other time points, forward elevation was found to be similar. The small amount of observed loss of forward elevation found in the Raiss et al study may be related to their inclusion of patients with glenoid loosening, which reached 73% at the final follow-up.[13,17] Another possible explanation of the decline noted in the Raiss et al study is the inclusion of shoulders undergoing revision (31%), which has previously been shown to have poorer functional outcomes.[4] Furthermore, patients were evaluated at discrete time points. In the current study, linear regression modeling was used, which is better able to evaluate changes in ROM

**Table III** Impact of covariates on overhead ROM and PROM

| | Covariate | Observed average 1 yr | *P* value for baseline | Slope | *P* value for rate of change |
|---|---|---|---|---|---|
| Abduction | BMI and Prior injection | | | | |
| | <25 and no injection | | | 0.2°/years | |
| | 25-30 and no injection | | | 0.2°/years | |
| | >30 and no injection | | | −1.1°/years | |
| | <25 and prior injection | | | −0.7°/yr | |
| | 25-30 and prior injection | | | −0.7°/years | |
| | >30 and prior injection | | | −2.0°/years | |
| | *Effect of BMI* | | | | <.001 |
| | *Effect of prior injections* | | | | .04 |
| Forward elevation | Diabetes | | | | |
| | Yes | | | 0.2°/years | |
| | No | | | −1.3°/years | |
| | *Effect of diabetes* | | | | .03 |
| Internal rotation | BMI and Diabetes | | | | |
| | <25 and nondiabetic | 5.8 | | | |
| | 25-30 and nondiabetic | 5.4 | | | |
| | >30 and nondiabetic | 5.0 | | | |
| | <25 and diabetic | 5.5 | | | |
| | 25-30 and diabetic | 5.0 | | | |
| | >30 and diabetic | 4.7 | | | |
| | Hypertension | | | | |
| | Yes | | | −0.009°/years | |
| | No | | | −0.3°/years | |
| | *Effect of BMI* | | <.001 | | |
| | *Effect of diabetes* | | .04 | | |
| | *Effect of hypertension* | | | | <.001 |
| SST | Sex | | | | |
| | Male | 11.3 | | | |
| | Female | 10.6 | | | |
| | BMI | | | | |
| | <25 | | | −0.001/years | |
| | 25-30 | | | −0.04/years | |
| | >30 | | | −0.1/years | |
| | *Effect of sex* | | <.0001 | | |
| | *Effect of BMI* | | | | <.0001 |
| Constant | Sex | | | | |
| | Male | 75.6 | | | |
| | Female | 71.3 | | | |
| | BMI; Age | | | | |
| | <25; <70 | | | 0.7/years | |
| | 25-30; <70 | | | 0.2/years | |
| | >30; <70 | | | −0.3/years | |
| | <25; 70-75 | | | 0.05/years | |
| | 25-30; 70-75 | | | −0.4/years | |
| | >30; 70-75 | | | −1.0/years | |
| | <25; >75 | | | −0.3/years | |
| | 25-30; >75 | | | −0.8/years | |
| | >30; >75 | | | −1.3/years | |
| | *Effect of sex* | | .0001 | | |
| | *Effect of BMI* | | | | .002 |
| | *Effect of age* | | | | .0001 |
| ASES | BMI; Age | | | | |
| | <25; <70 | | | 0.3/years | |
| | 25-30; <70 | | | −0.1/years | |
| | >30; <70 | | | −0.9/years | |

(*continued on next page*)

**Table III** Impact of covariates on overhead ROM and PROM (*continued*)

| | Covariate | Observed average 1 yr | *P* value for baseline | Slope | *P* value for rate of change |
|---|---|---|---|---|---|
| | <25; 70-75 | | | −0.4/years | |
| | 25-30; 70-75 | | | −0.8/yr | |
| | >30; 70-75 | | | −1.6/years | |
| | <25; >75 | | | −0.02/years | |
| | 25-30; >75 | | | −0.4/years | |
| | >30; >75 | | | −1.2/years | |
| | *Effect of BMI* | | | | <.001 |
| | *Effect of age* | | | | <.001 |
| UCLA | Age and Diabetes | | | | |
| | <70 and nondiabetic | | | 0.04/years | |
| | 70-75 and nondiabetic | | | −0.4/years | |
| | >75 and nondiabetic | | | −0.1/years | |
| | <70 and diabetic | | | −0.4/years | |
| | 70-75 and diabetic | | | −0.7/years | |
| | >75 and diabetic | | | −0.5/years | |
| | *Effect of age* | | | | .0001 |
| | *Effect of diabetes* | | | | .006 |

*ROM*, range of motion; *PROM*, patient reported outcome measure; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles; *BMI*, body mass index.


**Figure 2** Effect of covariates on patient reported outcome measure. *ASES*, American Shoulder Elbow Surgeons; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles Shoulder Score; *BMI*, body mass index.

**Table IV** Modeled predictions of aTSA and RSA motion over time, entire cohort

| | 1-yr model prediction | | | Slope of variation | | |
|---|---|---|---|---|---|---|
| | aTSA | RSA | *P* value | aTSA | RSA | *P* value |
| Number of patients | 384 | 165 | | 384 | 165 | |
| Abduction (degree) | 132 (1.3) | 116 (2.0) | <.001 | −0.7/yr (0.2/yr) | −0.8/yr (0.2/yr) | .9 |
| Forward elevation (degree) | 147 (1.3) | 134 (2.0) | <.001 | −0.06/yr (0.2/yr) | −0.8/yr (0.3/yr) | .05 |
| External rotation (degree) | 52.1 (0.9) | 34.1 (1.4) | <.001 | −0.3/yr (0.2/yr) | −0.07/yr (0.2/yr) | .5 |
| Internal rotation | 5.3 (0.07) | 4.7 (0.1) | <.001 | −0.04/yr (0.01/yr) | −0.003/yr (0.02/yr) | .09 |
| SST | 11.0 (0.1) | 9.7 (0.2) | <.001 | −0.08/yr (0.02/yr) | −0.03/yr (0.02/yr) | .3 |
| Constant | 73.5 (0.7) | 65.9 (1.0) | <.001 | −0.2/yr (0.1/yr) | −0.04/yr (0.1/yr) | .5 |
| ASES | 89.1 (0.8) | 82.9 (1.2) | <.001 | −0.5/yr (0.1/yr) | −0.7/yr (0.2/yr) | .6 |
| UCLA | 32.1 (0.2) | 30.2 (0.3) | <.001 | −0.2/yr (0.04/yr) | −0.2/yr (0.05/yr) | .8 |

*aTSA*, anatomic shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles.

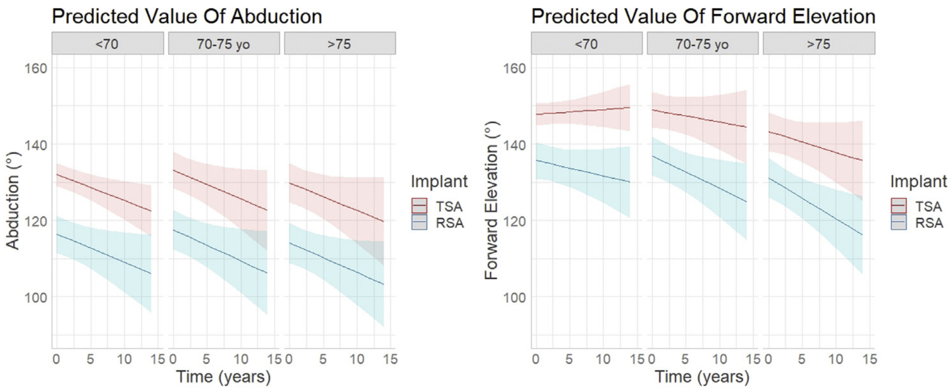


**Figure 3** Comparison of postoperative range of motion between aTSA and RSA over time. *aTSA*, anatomic shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty.

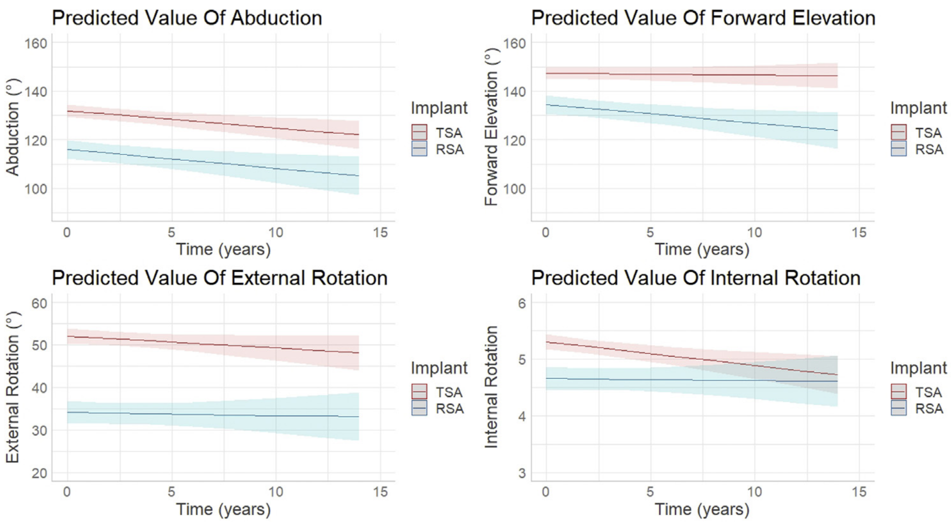


**Figure 4** Comparison of postoperative overhead range of motion between aTSA and RSA by age. *aTSA*, anatomic shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty.

**Table V** Mixed model for paired patient analysis of aTSA and RSA

| | 1-yr model prediction | | | Slope of variation | | |
|---|---|---|---|---|---|---|
| | aTSA | RSA | *P* value | aTSA | RSA | *P* value |
| Number of patients | 165 | 165 | | 165 | 165 | |
| Abduction (degree) | 132 (1.9) | 116 (2.7) | <.0001 | −0.7 (0.3) | −0.8 (0.4) | .9 |
| Forward elevation (degree) | 147 (2.0) | 134 (2.8) | <.0001 | −0.4 (0.3) | −0.8 (0.4) | .3 |
| External rotation (degree) | 52.9 (1.4) | 34.1 (1.9) | <.0001 | −0.5 (0.2) | −0.06 (0.3) | .2 |
| Internal rotation | 5.2 (0.1) | 4.7 (0.03) | .002 | −0.05 (0.02) | −0.003 (0.03) | .1 |
| SST | 11.0 (0.2) | 9.7 (0.3) | <.0001 | −0.1 (0.03) | −0.03 (0.05) | .1 |
| Constant | 72.3 (1.1) | 65.9 (1.4) | <.0001 | −0.3 (0.2) | −0.04 (0.2) | .2 |
| ASES | 89.1 (1.2) | 82.9 (1.6) | <.0001 | −0.7 (0.2) | −0.7 (0.3) | 1 |
| UCLA | 32.1 (0.3) | 30.2 (0.4) | <.0001 | −0.2 (0.07) | −0.3 (0.09) | .5 |

*aTSA*, anatomic shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles.

over time. When evaluated using these techniques, the current study demonstrated that aTSA can be expected to maintain stable forward elevation through midterm follow-up in shoulders without a known cause for loss of motion.

Similar to the smaller cohort series on aTSA, Simovitch et al[19] evaluated 505 aTSAs at multiple time points (mean, 42.0 ± 22.1 months). The authors noted a progressive decrease in abduction and forward flexion in aTSAs and RSA occurring approximately 6 years after index surgery. This decline in overhead motion was not observed in our cohort of well-functioning aTSAs at midterm follow-up. These differences can likely be explained by the development of rotator cuff disease or progressive glenoid component loosening, both of which can affect postoperative ROM and function.[9,17] In the current study, shoulders with a documented rotator cuff tear or glenoid component lucency above a Lazarus grade 2 were eliminated. In addition, shoulders undergoing revision surgery were also eliminated, whereas Simovitch et al's study included patients who ultimately underwent revision surgery. In addition, the Simovitch et al study had a very limited proportion of their sample size with a follow-up beyond 72 months, stating as a limitation that only 6% of their dataset consisted of data 5 years or more after surgery. Therefore, their findings at longer follow-up time points were likely underpowered. These differences may explain the loss of overhead motion observed at 6 years in the Simovitch et al study.

When compared with RSA, patients treated with aTSA have been reported to have greater postoperative ROM.[3,15,22] However, these differences largely remain limited to ROM with the shoulder below the shoulder level. In a study of 19 patients with aTSA on one side and RSA on the contralateral shoulder, Cox et al[3] showed a significantly greater IR on the aTSA side (L1 vs. L3, $P = .044$). This is in contrast to a study comparing aTSA and RSA at midterm follow-up where Schoch et al[15] showed no difference in IR at midterm follow-up, with both groups demonstrating IR to L4/5. These 2 studies[3,15] also report dissimilar results in regard to postoperative ER, with Schoch et al showing a significant difference favoring aTSA (42° vs. 28°, $P < .001$) and Cox et al reporting no significant difference (36° vs. 32°, $P = .4$). Similar to these prior cohort studies, aTSA in this study demonstrated significantly greater ROM in both ER and IR at 1 year postoperatively compared with RSA. The differences observed across these studies may be partially explained by the presence and quality of the rotator cuff musculature after RSA, the status of the subscapularis, and potentially the prosthetic design.[6] However, none of these variables were evaluated in any of these studies.[3,15]

Based on this study, aTSAs lose approximately 2° of forward elevation per decade. In terms of abduction, aTSAs lose 7° per decade, which is slightly more than what is seen in the native aging shoulder (5°-6° per decade).[21] However, the clinical significance of this decline is questionable. Furthermore, the small differences fall within the expected error range of both visual estimation and goniometric measurements for shoulder ROM.[14] When compared with a previous report on RSA analyzed using the same methods,[16] aTSA appears to show a slower decline in FE (−0.06°/yr vs. −0.8°/yr, $P = .05$). However, when these models were directly compared controlling for age, the differences were not statistically significant (−0.4°/yr vs. −0.8°/yr, $P = .07$). Similar to forward elevation, abduction was lost at a similar rate in well-functioning aTSA and RSAs (−0.7° vs. −0.8°/yr, $P = .9$). Together, these results indicate that both aTSA and RSA can be expected to maintain overhead ROM at a similar rate in the absence of other known factors for loss of motion. This direct comparison calls into question the belief that the deltoid fatigues over time after RSA, suggesting that elongation of the deltoid muscle after RSA leads to fatigue-induced loss of overhead motion at midterm follow-up.[2,8] Rather, it suggests that the observed gradual loss of motion results from the natural aging process, occurring at a similar rate for both aTSA and RSA.

This study represents the first evaluation of a single closed cohort of aTSA shoulders followed longitudinally at multiple times points to quantify and compare ROM and functional changes from short-term to long-term relative to a cohort of RSA patients analyzed by the same method. In comparison with previous comparative cohort studies,[2,7,19] this evaluation used linear-mixed models for repeated measures, which allows for a more accurate evaluation of changes over time and accounts for intrasubject variation in outcome measures. The study remains limited by its retrospective nature and the use of a large multinational database. Indications for aTSA were not standardized, nor were postoperative rehabilitation protocols. However, we did attempt to control for some of this variability by evaluating a single implant design and eliminating shoulders with an identifiable cause for poor motion or function. Second, we did not evaluate or control for rotator cuff status in patients treated with RTSA. It is possible that changes in ER and IR may have been affected over time by the quality and integrity of the rotator cuff musculature. Third, postoperative evaluations were standardized in terms of data points collected. However, we cannot be certain that ROM was assessed in a similar fashion across all sites, so it is possible that some of the small measures of loss of motion could be partially related to measurement error.[14] Lastly, postoperative radiographs were not evaluated. Therefore, we are unable to evaluate the effect of deltoid lengthening after shoulder arthroplasty on changes in ROM over time.

## Conclusion

In the well-functioning aTSA, gradual loss of ROM can be expected in all planes of motion except forward elevation. However, these changes are exceedingly small, are less than minimal clinically important difference thresholds, and also have little meaningful impact on PROMs into long-term follow-up. These findings are similar to those seen in well-functioning RSA shoulders and likely represent the functional changes of the shoulder in the natural aging process.

## Disclaimer

Bradley S. Schoch is a paid consultant for Exactech, Inc. He receives royalties from Exactech, Innomed, and Responsive Arthroscopy.

Chris Roche is a paid employee at Exactech.

Moby Parsons is a paid consultant for Exactech.

Thomas W. Wright receives royalties from Exactech, Inc. and Wolters Kluwer Health—Lippincott Williams & Wilkins. He is also a paid consultant with Exactech, Inc.

Joseph J. King owns stock in Pacira Pharmaceuticals and is a paid consultant with Exactech, Inc.

Jean David Werthel receives royalties from FH Orthopedics.

Marie Vigan, her immediate family, and any research foundations with which she is affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

## References

1. Allen WE, Lin JJ, Barfield WB, Friedman RJ, Eichinger JK. Shoulder motion decreases as body mass increases in patients with asymptomatic shoulders. JSES Int 2020;4:438-42. https://doi.org/10.1016/j.jseint.2020.04.004
2. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: a follow-up of a previous study. J Bone Joint Surg Am 2017;99:454-61. https://doi.org/10.2106/JBJS.16.00223
3. Cox RM, Padegimas EM, Abboud JA, Getz CL, Lazarus MD, Ramsey ML, et al. Outcomes of an anatomic total shoulder arthroplasty with a contralateral reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:998-1003. https://doi.org/10.1016/j.jse.2017.12.005
4. Denard PJ, Raiss P, Sowa B, Walch G. Mid- to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. J Shoulder Elbow Surg 2013;22:894-900. https://doi.org/10.1016/j.jse.2012.09.016
5. Flurin P-H, Marczuk Y, Janout M, Wright TW, Zuckerman J, Roche CP. Comparison of outcomes using anatomic and reverse total shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):101-7.
6. Friedman RJ, Flurin P-H, 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
7. Gerber C, Canonica S, Catanzaro S, Ernstbrunner L. Longitudinal observational study of reverse total shoulder arthroplasty for irreparable rotator cuff dysfunction: results after 15 years. J Shoulder Elbow Surg 2018;27:831-8. https://doi.org/10.1016/j.jse.2017.10.037
8. Guery J, Favard L, Sirveaux F, Oudet D, Mole D, Walch G. Reverse total shoulder arthroplasty. Survivorship analysis of eighty replacements followed for five to ten years. J Bone Joint Surg Am 2006;88:1742-7. https://doi.org/10.2106/JBJS.E.00851
9. Hattrup SJ, Cofield RH, Cha SS. Rotator cuff repair after shoulder replacement. J Shoulder Elbow Surg 2006;15:78-83. https://doi.org/10.1016/j.jse.2005.06.002
10. Lazarus MD, Jensen KL, Southworth C, Matsen FA. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am 2002;84-A:1174-82.
11. Pegreffi F, Pellegrini A, Paladini P, Merolla G, Belli G, Velarde PU, et al. Deltoid muscle activity in patients with reverse shoulder prosthesis at 2-year follow-up. Musculoskelet Surg 2017;101(Suppl 2):129-35. https://doi.org/10.1007/s12306-017-0516-6
12. Raiss P, Aldinger PR, Kasten P, Rickert M, Loew M. Total shoulder replacement in young and middle-aged patients with glenohumeral

osteoarthritis. J Bone Joint Surg Br 2008;90:764-9. https://doi.org/10.1302/0301-620X.90B6.20387
13. Raiss P, Bruckner T, Rickert M, Walch G. Longitudinal observational study of total shoulder replacements with cement: fifteen to twenty-year follow-up. J Bone Joint Surg Am 2014;96:198-205. https://doi.org/10.2106/JBJS.M.00079
14. Russo RR, Burn MB, Ismaily SK, Gerrie BJ, Han S, Alexander J, et al. How does level and type of experience affect measurement of joint range of motion? J Surg Educ 2018;75:739-48. https://doi.org/10.1016/j.jsurg.2017.09.009
15. Schoch BS, King JJ, Zuckerman J, Wright TW, Roche C, Flurin P-H. Anatomic versus reverse shoulder arthroplasty: a mid-term follow-up comparison [Epub ahead of print]. Shoulder Elbow. https://doi.org/10.1177/1758573220921150
16. Schoch BS, Vigan M, Roche C, Parsons M, Wright TW, King JJ, et al. Deltoid fatigue: a longitudinal assessment of reverse shoulder arthroplasty over time. J Shoulder Elbow Surg 2021;30:1375-83. https://doi.org/10.1016/j.jse.2020.08.038
17. Schoch BS, Wright TW, Zuckerman JD, Bolch C, Flurin P-H, Roche C, et al. Glenoid component lucencies are associated with poorer patient-reported outcomes following anatomic shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:1956-63. https://doi.org/10.1016/j.jse.2019.03.011
18. Simovitch R, Flurin P-H, 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
19. Simovitch RW, Friedman RJ, Cheung EV, Flurin P-H, 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
20. Sowa B, Bochenek M, Bülhoff M, Zeifang F, Loew M, Bruckner T, et al. The medium- and long-term outcome of total shoulder arthroplasty for primary glenohumeral osteoarthritis in middle-aged patients. Bone Joint J 2017;99-B:939-43. https://doi.org/10.1302/0301-620X.99B7.BJJ-2016-1365.R1
21. Stathokostas L, McDonald MW, Little RMD, Paterson DH. Flexibility of older adults aged 55-86 years and the influence of physical activity. J Aging Res 2013;2013:743843. https://doi.org/10.1155/2013/743843
22. Wright MA, Keener JD, Chamberlain AM. Comparison of clinical outcomes after anatomic total shoulder arthroplasty and reverse shoulder arthroplasty in patients 70 years and older with glenohumeral osteoarthritis and an intact rotator cuff. J Am Acad Orthop Surg 2020;28:e222-9. https://doi.org/10.5435/JAAOS-D-19-00166
23. Young BL, Connor PM, Schiffern SC, Roberts KM, Hamid N. Reverse shoulder arthroplasty with and without latissimus and teres major transfer for patients with combined loss of elevation and external rotation: a prospective, randomized investigation. J Shoulder Elbow Surg 2020;29:874-81. https://doi.org/10.1016/j.jse.2019.12.024