J Shoulder Elbow Surg (2021) 30, 1375–1383

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Deltoid fatigue: a longitudinal assessment of reverse 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, Gainesville, FL, USA*
[d]*The Knee, Hip and Shoulder Center, Portsmouth, NH, USA*
[e]*Department Orthopaedic Surgery and Rehabilitation, University of Florida, Gainesville, FL, USA*

Background: Studies evaluating the mid-term performance of reverse shoulder arthroplasty (RSA) have identified a drop in the Constant-Murley score between 6 and 8 years after surgery, which is most affected by a loss of forward elevation and strength. Alterations of the deltoid length and moment arm after RSA lead to nonphysiological stress on the deltoid muscle. Concern has arisen that the long-term implications of increased deltoid work may be causing "deltoid fatigue." The purpose of this study was to evaluate the long-term effects of RSA on overhead range of motion (ROM) and validate the hypothesis of deltoid fatigue.
Methods: We performed a retrospective review of 165 RSAs over a 5-year period. Diagnoses were limited to cuff tear arthropathy, osteoarthritis with rotator cuff deficiency, and irreparable rotator cuff tear. All procedures were performed using a single implant system. Patients were evaluated longitudinally at multiple time points. They were required to undergo a minimum of 3 follow-up visits, with at least 1 visit at >5 years. ROM and patient-reported outcome measures were evaluated using linear mixed models for repeated measures to evaluate changes in outcome measures over time. A secondary analysis was performed to assess the influence of patient demographic factors on observed changes in ROM and patient-reported outcome measures.
Results: Primary RSA shoulders were observed to lose 0.8° of forward elevation and abduction per year starting at 1 year postoperatively ($P = .006$), without a significant drop at mid-term follow-up. No significant change in external or internal rotation was observed. Male patients and patients with a diagnosis of osteoarthritis with rotator cuff deficiency showed greater baseline overhead ROM at 1 year postoperatively, but the subsequent rates of functional decline were similar regardless of age, sex, or indication.
Discussion: This study challenges the previous theory of deltoid fatigue resulting in a significant loss of overhead ROM beginning 6-8 years after index arthroplasty. However, a slower progressive decline in overhead ROM in well-functioning RSA shoulders was observed, averaging 0.8° of overhead ROM per year. This progressive deterioration occurs at a slightly greater rate than that observed in the natural shoulder. The observed rate of functional decline was found to be independent of age, sex, and preoperative diagnosis.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Reverse shoulder arthroplasty; loss of motion; decline; long-term; overhead; elevation; progressive

Institutional review board approval was received (Western Institutional Review Board study no. 1112376).

*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).

1058-2746/$ - see front matter © 2020 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2020.08.038

Reverse shoulder arthroplasty (RSA) is one of the few operations in orthopedics in which surgeons do not attempt to re-create the normal anatomy. Following substantial disruption of the rotator cuff insertion, the vertical glenohumeral force couple between the deltoid and rotator cuff is lost and pain and/or weakness of the shoulder may develop in patients.[2,3] Three main biomechanical design characteristics allow the RSA to restore pain-free functional shoulder motion despite a deficient rotator cuff: (1) the medialization of the glenohumeral joint center of rotation, which increases the deltoid lever arm, thereby allowing it to power the shoulder and lift the arm; (2) the distalization of the humerus and more specifically of the humeral insertion of the deltoid, which leads to a pre-tensioning of the deltoid muscle fibers; and (3) the transformation of the unconstrained shoulder to a semi-constrained joint with a stable fulcrum.

Two years after primary RSA, electromyographic activity of the anterior and lateral heads of the deltoid is lower compared with the unaffected shoulder, suggesting that activation of the deltoid may slowly deteriorate over time.[15] Long-term clinical reports have shown loss of overhead range of motion (ROM) over time following RSA.[1,5,8,10,20] In 2006, Guery et al[10] reported on 80 RSAs, evaluating survivorship as defined by an absolute Constant score > 30. A notable decline in function was observed after 6 years and was found to be independent of patient age. Similar clinical deterioration has been identified in patient series reported at different points of follow-up. After comparing a cohort of 87 RSAs with a previously reported group of 191 RSAs,[25] Bacle et al[1] reported a decrease in the relative Constant score and forward elevation when comparing mid- and long-term follow-up. Loss of active forward elevation and strength had the greatest effect on decreased Constant scores between studies.[1,25] The authors hypothesized that ''impaired deltoid efficiency could be the result of muscle senescence coupled with non-physiological biomechanical requirements.''[1] Thus, there is concern among shoulder surgeons that in patients undergoing RSA, ''deltoid fatigue'' may develop over time. This concern is amplified by the fact that the indications for RSA are expanding, with the procedure being performed in younger patients with expected higher functional demand exceeding 6 years.

Although previous studies have theorized that deltoid fatigue may occur over time, these reports are limited to nonhomogeneous cohort averages compared at discrete time points. Additionally, no study has assessed for deltoid fatigue in a single cohort of patients followed up longitudinally over a period, leading to the possibility of bias introduced by arbitrarily choosing follow-up intervals. In contrast, statistical modeling evaluates covariates and allows for adjustments to explain data variability. This allows a better understanding of the effect of time as a continuum on the studied parameter.

The purpose of this study was to evaluate the theory of deltoid fatigue in a single cohort of patients followed up longitudinally by evaluating for loss of motion over time following RSA by use of linear mixed models. We hypothesized that patients undergoing primary RSA would show gradual loss of overhead ROM beginning 6 years after surgery.

Methods

Between September 2007 and April 2013, a multinational shoulder arthroplasty database was retrospectively reviewed for all primary RSAs performed for cuff tear arthropathy (CTA), osteoarthritis (OA) with rotator cuff deficiency, and irreparable rotator cuff tear (RCT). All operations were performed by high-volume shoulder surgeons using a single implant system (Equinoxe; Exactech, Gainesville, FL, USA) at 11 different clinical sites. This implant uses a medialized-glenoid, lateralized-humerus design.[17,26] Shoulders treated for acute fractures, post-traumatic arthritis, avascular necrosis, or oncologic purposes were excluded. Any shoulder sustaining a postoperative complication or undergoing revision surgery was also excluded to evaluate deltoid fatigue in well-functioning RSAs without a clinically identifiable cause of impairment. Notching was not considered a complication resulting in patient exclusion. To be eligible for inclusion, shoulders were required to undergo at least 3 yearly follow-up visits, with at least 1 visit at >5 years. After application of the inclusion and exclusion criteria, 165 shoulders were eligible for the study. Of the surgical procedures, 95% were performed through a deltopectoral approach.

Through the database, demographic information about each patient was collected, in addition to corticosteroid injection history and prior surgery. At each follow-up visit, shoulders were evaluated for both ROM and patient-reported outcome measures (PROMs). ROM was assessed by the performing surgeon or research assistant. Abduction, forward elevation, and external rotation were measured in degrees. Internal rotation was measured according the scale described by Flurin et al.[6] PROMs included the American Shoulder and Elbow Surgeons (ASES) score, Simple Shoulder Test (SST) score, and University of California, Los Angeles (UCLA) shoulder score. The Constant-Murley score, a combination of patient-reported and objective measures, was also assessed. In addition, those individual questions pertaining to overhead ROM were analyzed individually over time. Individual questions from the ASES score included the following: ''Is it difficult for you to reach a high shelf?'' and ''Is it difficult for you to lift 10 lb [4.5 kg]?'' Individual questions from the SST score included the following: ''Can you place a coin on a shelf at the level of your shoulder without bending your elbow?,'' ''Can you lift one pound (a full pint container) [0.45 kg] to the level of your shoulder without bending your elbow?," and "Can you lift eight pounds (a full gallon container) [3.6 kg] to the level of your shoulder without bending your elbow?" The presence of notching was assessed using the Sirveaux classification.[22]

Statistical analysis

The primary outcome measure evaluated was overhead ROM, as measured by forward elevation and abduction. The remaining ROM measures, the PROMs, and individual questions pertaining to overhead ROM were evaluated secondarily. Outcome measures were assessed 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 variation.

The influence of the following covariates on ROM and PROMs was assessed: age at surgery (<70 years, 70-75 years, or >75 years), sex, diagnosis (OA with rotator cuff deficiency, RCT, or CTA), body mass index (<25, 25-30, or >30), previous surgery, and use of injections. The impact of each covariate was tested in mixed models. Backward selection of the covariates entered into the model was applied to examine associations between ROM or PROMs and the different covariates. From the population parameters and the individual measurements, individual parameters were estimated. All statistical analyses were performed with the R package (R Foundation for Statistical Computing, Vienna, Austria). The significance level was set at $P < .05$.

Results

Cohort

A total of 165 patients undergoing primary RSA were evaluated at a median final follow-up of 7 years (range, 5-11 years). The mean age at surgery was 71 years (range, 53-84 years). Female patients represented 67.9% of the cohort. The most common diagnosis was CTA (58%), followed by OA with rotator cuff deficiency (29%) and RCT (13%). The median number of follow-up points for each patient was 5 (range, 3-11). Full demographic details are available in Table I. Postoperative radiographs were available for 163 shoulders. Notching occurred in 10% of shoulders. This included 12 patients (7%) with grade 1 notching, 2 (1%) with grade 2, and 4 (2%) with grade 3.

Overhead ROM and PROMs

Overhead ROM showed a slow and steady decline over time. On the basis of linear mixed models, forward elevation decreased significantly at a rate of 0.8°/yr ($P = .006$). The rate of abduction loss was equivalent to that of forward elevation, averaging 0.8°/yr ($P = .006$). No significant changes in external or internal rotation were seen over the study period.

Table I Demographic information

	n*	Data
Age at surgery, yr	165	71.4 (6.6)
Age category, n (%)		
<70 yr		55 (33.3)
70-75 yr		54 (32.7)
>75 yr		56 (33.9)
Male sex, n (%)		53 (32.1)
BMI, n (%)	165	
<25		43 (26.1)
25-30		62 (37.6)
>30		60 (36.4)
Previous surgery, n (%)	165	58 (35.2)
Diagnosis, n (%)	165	
OA		48 (29.1)
RCT		21 (12.7)
CTA		96 (58.2)
Diabetes, n (%)	128	7 (5.5)
Tobacco, n (%)	128	6 (4.7)
Use of injections, n (%)	162	42 (25.9)
Subscapularis repair, n (%)	143	80 (55.9)

BMI, body mass index; *OA*, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *CTA*, cuff tear arthropathy.
* Number of patients with available information.

Similarly to overhead ROM, significant decreases in function were observed as measured by the ASES and UCLA scores. However, despite statistical significance, these results were nominally quite small. No significant changes were observed in the SST or Constant score over time. Table II shows full details.

Given the small changes observed in PROMs, those questions specifically dealing with overhead ROM and strength were individually modeled for changes over time. All individual questions assessing strength with overhead motion failed to demonstrate any significant change over time. Similarly, when we evaluated the ability to place a coin on a shelf at shoulder level, no significant change was observed over time ($P = .6$). A small but significant loss of function was observed over time when patients were serially asked about their ability to reach a high shelf; however, the absolute rate of decline was very small (–0.003/year, $P < .001$).

Influence of covariates on ROM and PROM changes

A slow and steady, small deterioration in overhead ROM was observed over time in the study population. Both sex and preoperative diagnosis affected baseline overhead ROM at 1 year following RSA. Male patients demonstrated significantly greater forward elevation and abduction at 1 year postoperatively compared with female patients (Table III). However, the rate of subsequent decline was equivalent, with no differences between male and female patients.

Table II Changes in slopes of range of motion and patient-reported outcome measures

	Average at 1-2 yr	Average at final follow-up	Slope of variation	*P* value
Abduction, °	114.7 ± 23.6	109.6 ± 27.7	−0.8/yr	.006
Forward elevation, °	131.9 ± 26.9	128.2 ± 28.5	−0.8/yr	.006
External rotation, °	35.1 ± 19.6	32.9 ± 20.6	−0.05/yr	.8
Internal rotation	4.6 ± 1.8	4.6 ± 1.8	−0.003/yr	.9
SST score	9.7 ± 2.8	9.4 ± 2.9	−0.03/yr	.4
Constant score	64.9 ± 13.5	65.5 ± 14.7	−0.04/yr	.8
ASES score	81.5 ± 18.4	78.4 ± 20.8	−0.7/yr	.006
UCLA score	29.9 ± 4.7	29.1 ± 5.7	−0.2/yr	.006

SST, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles.
Slopes were estimated by linear mixed models.

Table III Impact of covariates on overhead range of motion and patient-reported outcome measures

Covariate	n	Value at 1 yr	*P* value for 1 year baseline	Slope	*P* value for rate of change
Abduction					
Male sex with OA	12	131°			
Male sex with RCT	10	122°			
Male sex with CTA	31	120°			
Female sex with OA	36	120°			
Female sex with RCT	11	111°			
Female sex with CTA	65	110°			
Effect of sex			.002		.5
Effect of diagnosis			.01		.5
Forward elevation					
Male sex with OA	12	148°			
Male sex with RCT	10	130°			
Male sex with CTA	31	140°			
Female sex with OA	36	138°			
Female sex with RCT	11	121°			
Female sex with CTA	65	130°			
Effect of sex			.04		.2
Effect of diagnosis			.02		.3
ASES score					
Male sex aged < 70 yr	21	84.2		0.03/yr	
Male sex aged 70-75 yr	16	93.1		−0.7/yr	
Male sex aged > 75 yr	16	91.7		−1.4/yr	
Female sex aged < 70 yr	34	74.4		0.03/yr	
Female sex aged 70-75 yr	38	83.9		−0.7/yr	
Female sex aged > 75 yr	40	82.4		−1.4/yr	
Effect of age			.08		.03
Effect of sex			.0002		.2
UCLA score					
Male sex aged < 70 yr	21	30.7			
Male sex aged 70-75 yr	16	32.6			
Male sex aged > 75 yr	16	32.0			
Female sex aged < 70 yr	34	28.4			
Female sex aged 70-75 yr	38	30.4			
Female sex aged > 75 yr	40	29.8			
Effect of age			.04		.4
Effect of sex			.0007		.3

OA, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *CTA*, cuff tear arthropathy; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California, Los Angeles.

Figure 1 graphically demonstrates the longitudinal effect of the covariates on overhead ROM.

Similarly, baseline overhead ROM at 1 year postoperatively was significantly greater in shoulders with a diagnosis of OA with rotator cuff deficiency, with no differences in the rate of motion loss after RSA. Age at arthroplasty did not affect overhead ROM at 1 year or the subsequent rates of decline over time.

Both age and sex had significant effects on baseline ASES and UCLA scores at 1 year postoperatively. Female patients and patients aged < 70 years at the time of surgery demonstrated lower ASES scores at 1 year postoperatively. However, only age was predictive of a more rapid decline in ASES scores over time, with worsening occurring at a faster rate in patients aged > 75 years than in patients aged between 70-75 years at the time of surgery. It is interesting to note that patients aged < 70 years at the time of surgery demonstrated no decline in ASES scores over time. UCLA scores showed similar differences in baseline function at 1 year postoperatively, with female patients and patients aged < 70 years having worse scores. The rate of decline in UCLA scores over time was independent of both age and sex. Further details are provided in Table III and Figure 2.

Discussion

Prior studies have suggested a loss of overhead ROM in patients undergoing primary RSA at mid- to long-term follow-up.[1,5,8,10] The theory of deltoid fatigue suggests that over time, after RSA, the demands on the deltoid may lead to longer-term loss of overhead ROM. In this study of a closed population of shoulders followed up longitudinally at multiple time points, a small but progressive loss of forward elevation and abduction averaging 0.8°/yr was observed. Although this decline was statistically significant, the slow progressive loss of motion was quite small and did not demonstrate an abrupt loss of overhead ROM 6-8 years following index surgery as has been suggested by previous studies.

Early cohort studies comparing shoulders with different lengths of follow-up have correlated longer-term follow-up with loss of motion and decreased function after primary RSA.[5,20] In a study of 484 RSAs with a minimum follow-up period of 2 years, Favard et al[5] demonstrated poorer overhead ROM in patients with longer follow-up (130° at < 5 years vs. 125° > 7 years); however, these small differences did not reach statistical significance. When evaluating function, the same study showed lower relative Constant scores in patients with longer follow-up. With a follow-up period < 5 years, the relative Constant score averaged 88.5, compared with 88.2 after 7-year follow-up and 78.0 after 9-year follow-up. On the basis of their results, Favard et al concluded that functional deterioration occurred after 8 years. This study is similar to other studies that have shown a progressive decrease in the magnitude of overhead motion improvements in patients with longer clinical follow-up.[20] However, these studies are limited by the fact that the shoulders were evaluated as a large cohort and individuals were not followed up longitudinally and compared with themselves over time. One possible cause of the clinical deterioration in the study of Favard et al may have been related to complications, which occurred in 18% of patients and can affect clinical outcomes.[4] Additionally, 49% of shoulders in their study had a grade 3 or 4 notch after 9 years of follow-up, which has previously been shown to have a detrimental effect on both overhead motion and PROMs.[21] This finding differs from the results of our series, in which notching was significantly less common (11%) and less severe (grade 3 notching in 2%). Additionally, shoulders with complications were excluded. The lower rates of notching in this series may be a result of the exclusion of patients undergoing reoperations and having complications. However, the implant studied, which uses a humeral component with a 145° neck-shaft angle, has been shown to have a lower rate of scapular notching.[11,12,14,16,26] In addition, surgical techniques have advanced, with surgeons now routinely placing the glenoid component low on the glenoid face in an effort to decrease notching.[13,16] Despite newer techniques and the exclusion of patients with documented complications, a progressive loss in overhead motion was still observed.

Longer-term cohort studies have also been performed, comparing means of a population at early follow-up with available patients from the same cohort at longer-term follow-up. In a study of 87 RSA patients treated with a Grammont-style RSA and followed up for ≥10 years, Bacle et al[1] observed a significant decrease in forward elevation and the relative Constant score compared with 191 RSAs performed over the same period with a minimum 2-year follow-up.[25] This study design is different from ours: In our study, each patient was followed up longitudinally at multiple time points with no patient dropout. Thus, this study would not be subject to selection bias from patients dropping out when changes are compared over time. When examining patients based on preoperative diagnosis, Bacle et al found that a preoperative diagnosis of a failed arthroplasty or a massive irreparable RCT was associated with worse motion. Shoulders with CTA and primary OA were not found to have a loss of motion over time. In our study, in which shoulders undergoing revision to RSA were not included, we also found an effect of the preoperative diagnosis on loss of motion over time. Shoulders with an irreparable RCT had lower forward elevation and external rotation at 1 year postoperatively, but their rate of motion loss after RSA was similar to that of all other evaluated diagnoses. Additionally, the Constant score in this study remained unaffected over time, without a significant deterioration.

Our results are similar to those reported by Gerber et al,[8] who showed no significant deterioration in the mean relative Constant score over a 15-year period in a cohort of 20

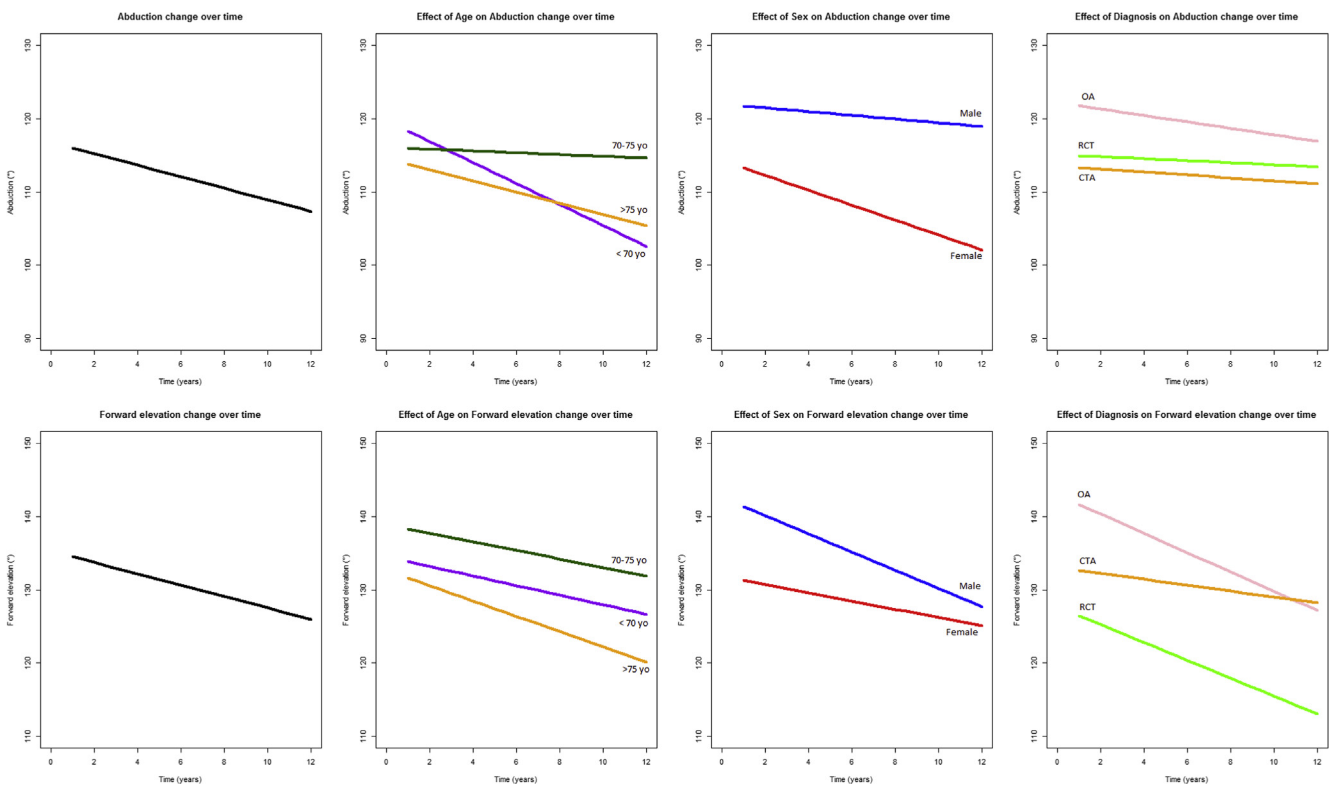

Figure 1 Effect of covariates on overhead range of motion. *yo*, years old; *OA*, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *CTA*, cuff tear arthropathy.

shoulders. In their longitudinal cohort study, they did show a significant loss of mean abduction over time (34°, $P = .018$), which averaged 2.4°/yr. This change was noted to occur abruptly at about 9 years after primary RSA. A loss of forward elevation (20°, averaging 1.4°/yr) was also observed but did not reach statistical significance ($P = .207$). Similarly to other studies, their methods are insufficient to effectively evaluate the theory of deltoid fatigue. First, not all patients were evaluated at each studied interval. Second, time-period groupings were set arbitrarily, and statistical analyses were performed to evaluate differences between groups. These methods are inadequate to assess the effect of time on overhead ROM, allowing only for the comparison between groupings. Furthermore, 59% of shoulders sustained a complication, with 55% requiring a reoperation. Only shoulders that underwent prosthesis explantation were removed from clinical analysis (27%). Therefore, shoulders undergoing reoperation continued to be evaluated and assessed clinically over time, which likely affected the functional results. Although the authors theorized that loss of abduction could be the result of nonphysiological muscle fiber recruitment, it does not explain why forward elevation was not similarly affected.

In our study, loss of overhead ROM was noted to begin 1 year after surgery, which is earlier than in the study of Gerber et al,[8] in which abrupt changes were noted approximately 9 years after index surgery. The noted steady decline is different from the more abrupt drop-off noted by Simovitch et al,[20] which occurred at 72 months after RSA. The differences in these results may be due to the fact that their study was designed to require only 2 follow-up points, with 1 required to be beyond 2 years. Additionally, Simovitch et al did not exclude patients undergoing revision, so it is possible that the loss of motion was due to a complication with clinical evaluation occurring before revision surgery. This may explain why their study population also experienced a marked decrease in external rotation in around the same follow-up period of 72 months. This finding is in contrast to the results of our study, in which no loss in external rotation was found over time. Given the function of the deltoid with RSA, it would be expected that overhead motion would be more affected than external rotation. Thus, the study by Simovitch et al makes it difficult to evaluate the role of deltoid fatigue independent of the effects of complications and revision surgery.

Multiple studies have suggested that older patients are at greater risk of losing ROM over time following RSA, with Gerber et al[8] considering this a possible cause of deltoid fatigue.[7] In our study, loss of motion after RSA was found to occur at the same rate regardless of patient age. By use of linear matrix modeling, the rate of loss of overhead motion occurred at approximately 0.8°/yr. This is not dissimilar to changes in overhead ROM that occur in the native shoulder as we age.[23] In a study of 441 individuals (aged 55-85 years) from London, Ontario, Canada, Stathokostas et al[23] showed a slow decline in active shoulder abduction with increasing age. The rate of decline averaged 5°/decade in male patients and 6°/decade in female patients. This compares with the rate of 8°/decade observed in this study. Thus, it could be considered that deltoid fatigue is simply due to increasing age rather than an effect of altered deltoid tensioning.[26] Using a piecewise linear regression analysis, Stathokostas et al noted that the rate of decline increased in men aged > 71 years and women aged > 63 years. This finding is in contrast to the results of our study, in which no acceleration in the rate of decline was observed after RSA based on age. Further observational studies on the natural history of overhead ROM are needed to confirm that the loss of motion after RSA is related only to age.

In addition to gradual deterioration of overhead motion, a slow progressive decline in the ASES score was observed. The rate of decline was greatest in patients aged > 75 years. This finding is in contrast to the results of the Constant score, which was stable over time. One possible explanation for this observation is the intrinsic differences between these scores. The ASES score is a PROM that does not include any physical examination parameters. Instead, patients only reply to questions designed to evaluate functional limitations. In contrast, the Constant score involves 8 questions, 6 of which are objective measures. Furthermore, forward flexion and abduction are scored in 30° intervals. Thus, the small changes over time observed in this study would not have been enough to change the Constant score, as was observed in previous studies evaluating Grammont-style prostheses with greater loss of overhead motion.[1,5] Furthermore, the absolute change in the mean ASES score remained quite small and below the minimal clinically important difference (10.3).[19]

This study is the first study to evaluate a single closed population of RSA patients with multiple longitudinal follow-up points to assess for changes in ROM over time. The use of linear mixed modeling allows ROM to be

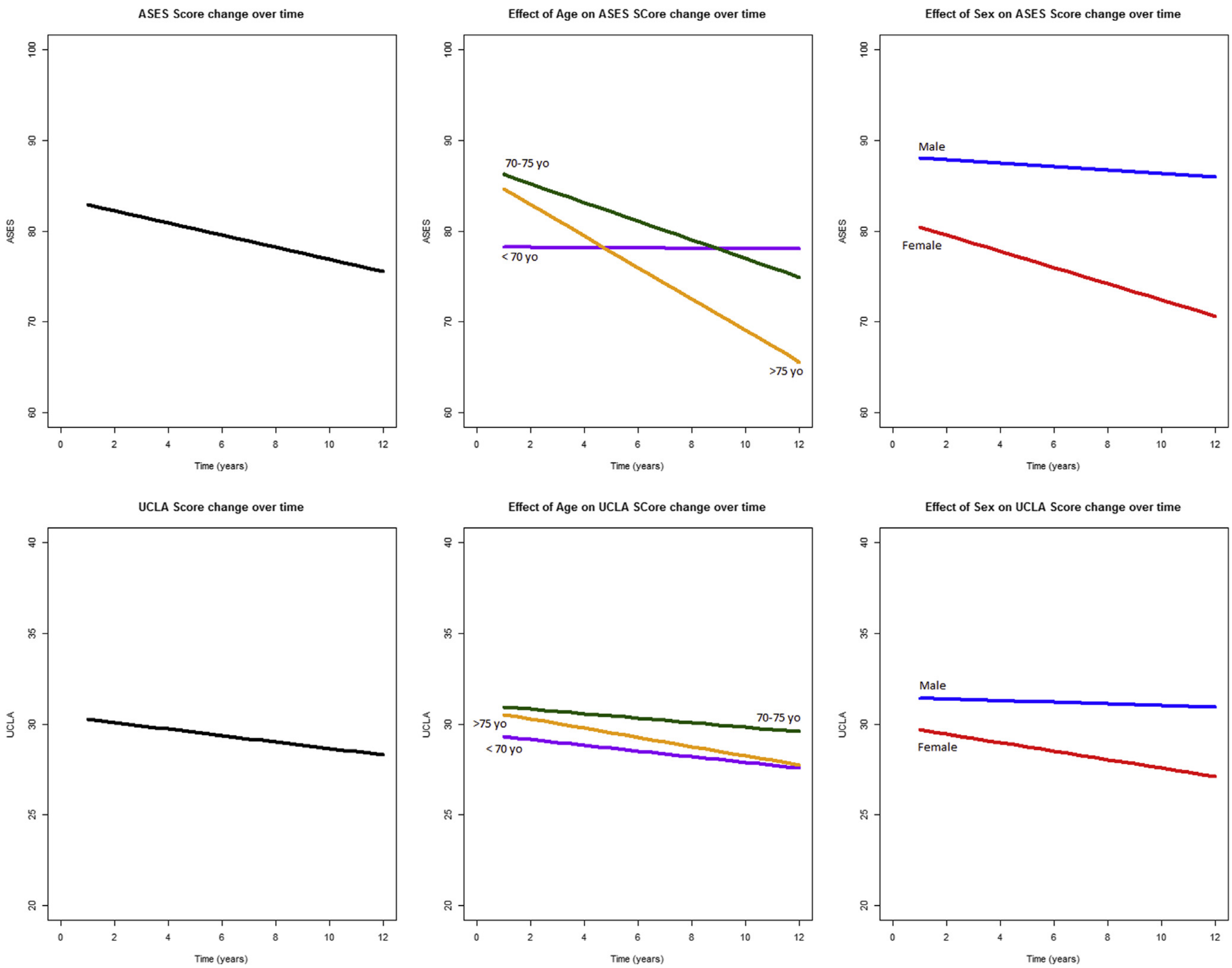

Figure 2 Effect of covariates on patient-reported outcome measures. *ASES*, American Shoulder and Elbow Surgeons; *yo*, years old; *UCLA*, University of California, Los Angeles.

evaluated over time with assessment of the influence of covariates to properly analyze the theory of deltoid fatigue. Additionally, the use of a single system allows for control of system lateralization and distalization, which may affect deltoid tensioning and the deltoid moment arm differently than other RSA designs.[24,26]

This study remains limited by its retrospective nature. Operations were performed by 11 surgeons from multiple institutions. No attempt was made to standardize patient selection, operative techniques, or rehabilitation protocols, which may have affected the observed results. However, we did attempt to control for any poorly performing shoulders by excluding any patient who sustained a complication or underwent a reoperation in an attempt to evaluate the theory of deltoid fatigue in well-functioning RSAs. Additionally, the techniques for ROM measurements were not standardized across sites. Although some sites are known to use goniometric measurements for all visits, we cannot guarantee that evaluation was performed using this technique at each site and each visit. In the case of visual estimation, the mean error for forward elevation is $5.3° \pm 4.1°$ compared with $4.0° \pm 3.9°$ with a goniometer.[18] With the small differences noted over time (0.8°/yr), it remains possible that some of this modeled difference may be caused by measurement error. Finally, the status of the rotator cuff, which can affect deltoid loading, was not assessed as a variable.[9]

Conclusion

Deltoid fatigue is a theoretical observation seen in shoulders undergoing RSA that exhibit loss of overhead ROM over time 6-8 years after index surgery. This study challenges the previous theory of deltoid fatigue as no dramatic loss of overhead ROM was observed at mid-term follow-up. A slow progressive loss of overhead ROM was observed following RSA measuring approximately 0.8°/yr, which is only slightly greater than the rate observed in the healthy shoulder. However, minimal clinically significant effects were observed for PROMs over time.

Disclaimer

Exactech provided funding for maintenance of the database. No direct funding was provided for this project. Bradley S. Schoch is a paid consultant for Exactech and receives royalties from Exactech.

Christopher Roche is a paid employee of Exactech.

Moby Parsons is a paid consultant for Exactech.

Thomas W. Wright receives royalties from Exactech and Wolters Kluwer Health–Lippincott Williams & Wilkins and is a paid consultant for Exactech.

Joseph J. King owns stock in Pacira Pharmaceuticals and is a paid consultant for Exactech.

Jean David Werthel receives royalties from FH Orthopedics.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. 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
2. Burkhart SS. A stepwise approach to arthroscopic rotator cuff repair based on biomechanical principles. Arthroscopy 2000;16:82-90.
3. Burkhart SS. Partial repair of massive rotator cuff tears: the evolution of a concept. Orthop Clin North Am 1997;28:125-32.
4. Ernstbrunner L, Suter A, Catanzaro S, Rahm S, Gerber C. Reverse total shoulder arthroplasty for massive, irreparable rotator cuff tears before the age of 60 years: long-term results. J Bone Joint Surg Am 2017;99:1721-9. https://doi.org/10.2106/JBJS.17.00095
5. Favard L, Levigne C, Nerot C, Gerber C, De Wilde L, Mole D. Reverse prostheses in arthropathies with cuff tear: are survivorship and function maintained over time? Clin Orthop Relat Res 2011;469:2469-75. https://doi.org/10.1007/s11999-011-1833-y
6. 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.
7. Friedman RJ, Eichinger J, Schoch B, Wright T, Zuckerman J, Flurin P-H, et al. Preoperative parameters that predict postoperative patient-reported outcome measures and range of motion with anatomic and reverse total shoulder arthroplasty. JSES Open Access 2019;3:266-72. https://doi.org/10.1016/j.jses.2019.09.010
8. 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
9. Giles JW, Langohr GDG, Johnson JA, Athwal GS. The rotator cuff muscles are antagonists after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2016;25:1592-600. https://doi.org/10.1016/j.jse.2016.02.028
10. 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
11. Hettrich CM, Permeswaran VN, Goetz JE, Anderson DD. Mechanical tradeoffs associated with glenosphere lateralization in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1774-81. https://doi.org/10.1016/j.jse.2015.06.011
12. Langohr GDG, Willing R, Medley JB, Athwal GS, Johnson JA. Contact mechanics of reverse total shoulder arthroplasty during abduction: the effect of neck-shaft angle, humeral cup depth, and glenosphere diameter. J Shoulder Elbow Surg 2016;25:589-97. https://doi.org/10.1016/j.jse.2015.09.024
13. Li X, Dines JS, Warren RF, Craig EV, Dines DM. Inferior glenosphere placement reduces scapular notching in reverse total shoulder arthroplasty. Orthopedics 2015;38:e88-93. https://doi.org/10.3928/01477447-20150204-54

14. Oh JH, Shin S-J, McGarry MH, Scott JH, Heckmann N, Lee TQ. Biomechanical effects of humeral neck-shaft angle and subscapularis integrity in reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1091-8. https://doi.org/10.1016/j.jse.2013.11.003
15. 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
16. Roche CP, Marczuk Y, Wright TW, Flurin P-H, Grey S, Jones R, et al. Scapular notching and osteophyte formation after reverse shoulder replacement: radiological analysis of implant position in male and female patients. Bone Jt J 2013;95-B:530-5. https://doi.org/10.1302/0301-620X.95B4.30442
17. Routman HD, Flurin P-H, 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.
18. 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
19. 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
20. 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
21. Simovitch RW, Zuckerman JD, Wright TW, Flurin P-H, Roche C. Impact of scapular notching on reverse total shoulder arthroplasty outcomes—5 year minimum follow-up. J Shoulder Elbow Surg 2019; 28:e204-5. https://doi.org/10.1016/j.jse.2018.11.014
22. 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.
23. 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
24. Walker DR, Struk AM, Matsuki K, Wright TW, Banks SA. How do deltoid muscle moment arms change after reverse total shoulder arthroplasty? J Shoulder Elbow Surg 2016;25:581-8. https://doi.org/10.1016/j.jse.2015.09.015
25. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am 2007;89:1476-85. https://doi.org/10.2106/JBJS.F.00666
26. Werthel J-D, Walch G, Vegehan E, Deransart P, Sanchez-Sotelo J, Valenti P. Lateralization in reverse shoulder arthroplasty: a descriptive analysis of different implants in current practice. Int Orthop 2019;43:2349-60. https://doi.org/10.1007/s00264-019-04365-3