J Shoulder Elbow Surg (2020) 29, S126–S133

ELSEVIER

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

A 10-year experience with reverse shoulder arthroplasty: are we operating earlier?

R. Chris Reams, MD[a], Marie Vigan, PhD[b], Thomas W. Wright, MD[a], Joseph J. King, MD[a], Jean-David Werthel, MD[b], Bradley S. Schoch, MD[c,*]

[a]*Department of Orthopaedic Surgery and Rehabilitation, University of Florida, Gainesville, FL, USA*
[b]*Department of Orthopedic Surgery, Hôpital Ambroise Paré, Boulogne-Billancourt, France*
[c]*Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, FL, USA*

Introduction: As surgeons' confidence in reverse shoulder arthroplasty (RSA) increases, they may tend to offer RSA earlier in the course of glenohumeral joint disease. This study evaluates the changes in the "tipping point" for primary RSA over a 10-year period to evaluate changes in practice.

Methods: A total of 3975 primary RSAs performed over a 10-year period were retrospectively reviewed from a multi-institutional database. Of these, 3536 primary RSAs with preoperative diagnoses of osteoarthritis with rotator cuff deficiency (1626), irreparable rotator cuff tear (396), and rotator cuff tear arthropathy (1514) were included in the analysis. Preoperative range of motion (ROM) and patient-reported outcome measures (PROMs) were used to calculate tipping points for each subgroup on a yearly basis over a 10-year period, and assessed for changes over time.

Results: PROMs (American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, Simple Shoulder Test) and the Constant score remained similar over the 10-year study period, with all demonstrating slightly higher tipping points later in the study. ROM measures (forward elevation, abduction, and external rotation) all showed small increases over time, demonstrating better ROM before electing to undergo RSA in later years.

Conclusions: With the increasing use of RSA over the last decade, the ROM tipping point for patients electing to undergo surgery has increased, whereas the PROM tipping point has remained stable. This indicates that patients undergoing RSA in the present have greater ROM preoperatively compared with 10 years ago; however, their perceived disability remains similar. Surgeons and patients continue to pursue RSA at a similar preoperative morbidity over the last 10 years.

Level of evidence: Descriptive Epidemiology Study

Keywords: Tipping point; RSA; reverse shoulder; decision; indications; surgery

Reverse shoulder arthroplasty (RSA) has proven to be a valuable tool in the treatment of end-stage glenohumeral arthritis with concurrent rotator cuff disease and/or glenoid bone loss. In its infancy, indications were limited, with RSA used for rotator cuff tear arthropathy (RCA) in the elderly low-demand patient.[6] Many studies have shown historic complication rates with RSA ranging anywhere from 7%-68%.[3,5,7,13,17,19-22] However, many of these studies involve older designs that have been associated with higher complications.[9,12,16] With time, biomechanical knowledge and design alterations have made RSA a more reliable surgical option with decreasing complication rates.[8] Modern designs now consider lateralization of the center of rotation, humeral offset, humeral neck-shaft

Institutional review board approval has been received (WIRB study no. 1112376).

*Reprint requests: Bradley S. Schoch, MD, Department of Orthopedic Surgery, Mayo Clinic, 4500 San Pablo Road, Jacksonville, FL 32224, USA.

E-mail address: schoch.bradley@mayo.edu (B.S. Schoch).

1058-2746/$ - see front matter © 2020 Published by Elsevier Inc. on behalf of Journal of Shoulder and Elbow Surgery Board of Trustees.
https://doi.org/10.1016/j.jse.2020.04.040

angle, and improved deltoid and residual rotator cuff tensioning.[2,14] Despite competing designs, patients can now expect improved postoperative function and durable long-term implant survival.[1] With design improvements and decreasing complication rates, surgeons are becoming more confident in using RSA. Today, RSA is the most common configuration chosen when performing primary shoulder arthroplasty.[4]

As surgeon comfort and proficiency increase, it is plausible that RSA is being performed on patients earlier in the progression of shoulder disease. Although this is not inherently negative, orthopedic surgeons should continually explore the optimal timing for surgical intervention. Recently, the concept of the ''tipping point'' for shoulder arthroplasty was introduced. This term describes the point at which a patient's symptom severity leads to the decision to undergo elective shoulder arthroplasty.[18] Somerson et al[15] examined 931 patients who underwent ream-and-run, hemiarthroplasty, anatomic total shoulder arthroplasty, cuff tear arthropathy arthroplasty, or RSA from 2010 to 2017. They used preoperative Simple Shoulder Test (SST) scores for each diagnosis to develop a ''tipping point'' at which patients' self-assessment of disability led them to choose surgery. This has been useful with regard to counseling prospective surgical patients in how their SST scores compare to similar patients choosing to undergo primary shoulder arthroplasty.[15] However, it remains unclear whether the tipping point has changed over time with the evolution of the RSA. This study evaluates the change in tipping point for primary RSA over a 10-year period to evaluate for changes in practice. We hypothesized that the threshold to undergoing primary elective RSA (tipping point) would be higher (less preoperative impairment) as surgeons became more confident in the performance of RSA over the 10-year period.

Methods

Following institutional review board approval, a retrospective review of all primary RSAs between 2009 and 2018 was performed. All shoulders were prospectively enrolled in a multinational joint registry, spanning 26 institutions with standardized data collection. A total of 3975 unique RSAs were identified, all using a single implant system (Exactech Equinoxe, Gainesville, FL, USA). Shoulders with a preoperative diagnosis of osteonecrosis (41), rheumatoid arthritis (105), post-traumatic arthritis (130), and fracture (148) and those without a diagnosis (15) were excluded. This left 3536 primary RSAs for evaluation. The preoperative diagnoses for the study group included osteoarthritis with rotator cuff deficiency (OA) (n = 1626), irreparable rotator cuff tear (RCT) (n = 396), and RCA (n = 1514). The decision to undergo surgery was made between the performing surgeon and patient after failing conservative measures. Surgical indications were not standardized across institutions or surgeons.

Patient demographic information, prior surgeries, and previous injections were recorded. Before undergoing primary arthroplasty, all patients were evaluated using a standardized registry protocol. All patients were examined before surgery by the performing surgeon or by clinical research assistants. All examination results were recorded in the database. Preoperative active range motion (ROM) measurements included forward elevation (degrees), abduction (degrees), and external rotation (ER) with the elbow at the side (degrees). Patient-reported outcome measures (PROMs) obtained included American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES) score and the SST. The Constant score, a combined patient-reported and physician input outcome score, was also evaluated. The tipping points for each shoulder undergoing primary RSA were then evaluated according to diagnosis (OA, RCT, or RCA) and the year of surgery to assess for changes over time.

Statistical analysis

Mean, standard deviation, and 95% confidence interval for means were calculated for PROMs and ROM measures. Differences between means for diagnosis and year were studied with analysis of variance, employing Tukey honestly significant difference test for post hoc analysis. Significant results were displayed as difference and 95% confidence interval. A linear regression was performed to examine the trend of PROMs and ROM measures over time. Figures represent mean, its 95% confidence interval, and the regression line. All P values were 2-sided, and statistical significance was determined using $P < .05$. All calculations were undertaken using R statistical software package V3.2.5 (R Foundation for Statistical Computing, Vienna, Austria).

Results

A total of 3536 shoulders were evaluated before undergoing primary RSA. Mean age overall was 72 years, with 1277 male and 2259 female patients. Sex distribution as well as mean height, weight, and BMI for the different groups was similar over the 10-year period, with no significant differences based on year or diagnosis (Table I). Average age at surgery was significantly lower in shoulders with a preoperative diagnosis of RCT compared with those with OA and RCA ($P = .009$) (Fig. 1). However, within each group, age remained stable over the study period ($P = .7$ for OA, .3 for RCT, and .7 for RCA).

Before analyzing the tipping point, groups were analyzed based on the preoperative diagnosis. For all PROMs and the Constant score, preoperative scores were similar regardless of diagnosis (ASES, $P = .4$; SST, $P = .5$; Constant, $P = .5$). Therefore, all patients were combined for subsequent analyses of outcome scores. ASES scores demonstrated small year-to-year differences ($P = .03$); however, on post hoc analysis, no significant difference remained, with all years demonstrating statistically similar tipping points before RSA (Fig. 2). Both the SST and Constant scores showed significant year-to-year differences within the study period ($P < .001$). For both scores, these

Table I Patient demographic information

	Overall population (N = 3536)	OA (n = 1626)	RCT (n = 396)	RCA (n = 1514)	*P* value*
Age	72.7 ± 7.4	72.8 ± 7.6	71.7 ± 7.5	72.9 ± 7.1	.009
Male, n (%)	1277 (36.5)	582 (36.2)	135 (34.5)	560 (37.3)	.6
Height	65.3 ± 4.0	65.3 ± 4.1	65.3 ± 3.7	65.2 ± 4.0	.4
Weight	173.3 ± 41.5	177.0 ± 42.4	171.1 ± 36.0	169.9 ± 41.5	<.001
BMI	28.5 ± 5.9	29.1 ± 6.2	28.1 ± 5.4	27.9 ± 5.7	<.001

BMI, body mass index; *OA*, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *RCA*, rotator cuff tear arthropathy.
Values are mean ± standard deviation unless otherwise noted.
* Test of Kruskall-Wallis for continuous variables and χ^2 for qualitative variable.

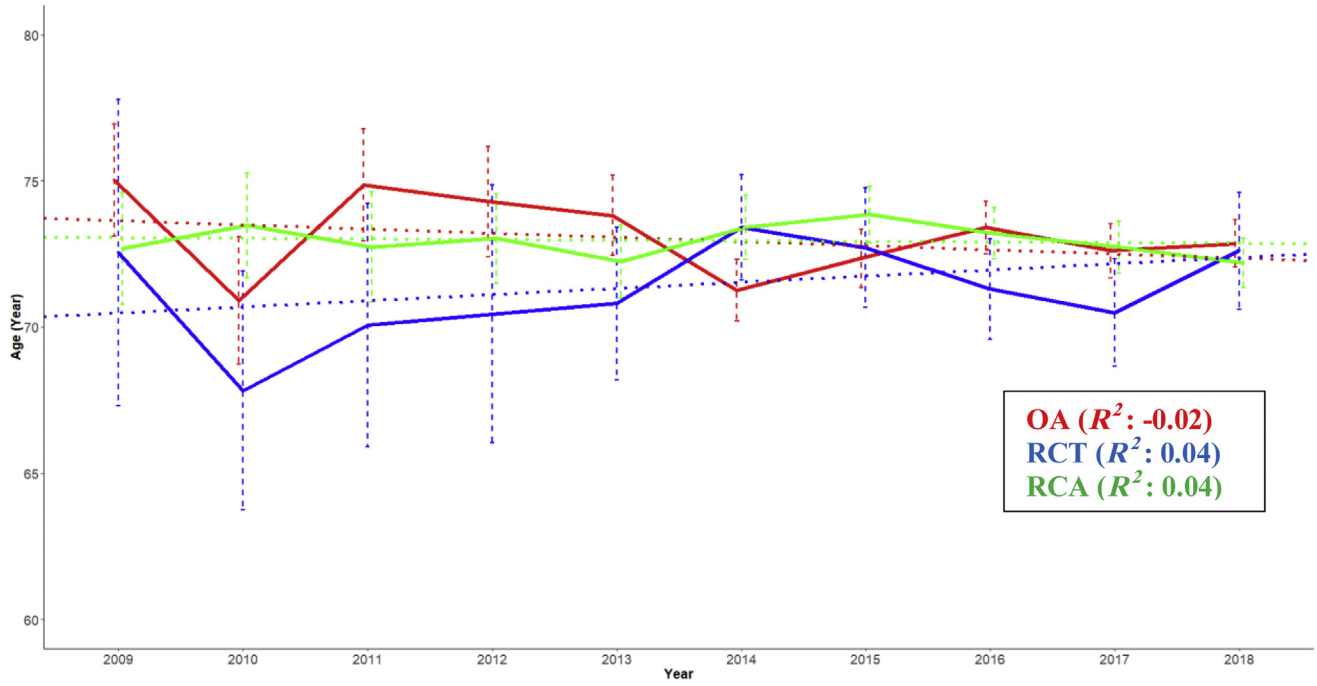

Figure 1 Mean age (with 95% confidence interval) of shoulders undergoing RSA by year as a function of preoperative diagnosis. *RSA*, reverse shoulder arthroplasty; *OA*, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *RCA*, rotator cuff tear arthropathy.

differences were isolated to the 2018 time period. Within the SST group, the tipping point for shoulders undergoing RSA in 2018 was significantly higher than those shoulders indicated in 2013 (0.7 [0.08; 1.4], $P = .02$) and 2015 (0.6 [0.09; 1.5], $P = .008$). Other year-to-year differences remained statistically similar (see Fig. 3). Similar to SST, the Constant score tipping point for shoulders undergoing RSA in 2018 was significantly higher than those indicated in 2013 (4.0 [0.1; 7.9], $P = .04$). The tipping point for shoulders undergoing RSA in 2010 was also significantly lower than those treated between 2014 and 2018 ($P < .04$) (Fig. 4).

Similar to PROM, the tipping point for each ROM measure was first compared between diagnoses. Both forward elevation and abduction showed no significant differences among diagnoses and thus were combined for year-to-year comparisons. Significant differences were noted for the ER tipping point among diagnoses, which were evaluated individually. Forward elevated demonstrated significant differences by year ($P < .001$), with post hoc analysis demonstrating shoulders treated in 2018 to have significantly higher tipping points compared with those treated in 2010 and 2013-2017 ($P < .003$). The remaining year-to-year comparisons remained statistically similar (Fig. 5). Abduction also showed a significant year-to-year difference in the tipping point ($P < .001$), with a significantly higher tipping point noted for shoulders treated in 2018 compared with all other years ($P < .01$). Additionally, shoulders treated in 2010 also had significantly lower tipping points compared with shoulders treated in 2012-2018 ($P < .05$) (Fig. 6). External rotation showed a significant difference year-to-year ($P < .001$), with a significant increase in 2018 compared with other years (Fig. 7). External rotation also showed a significant

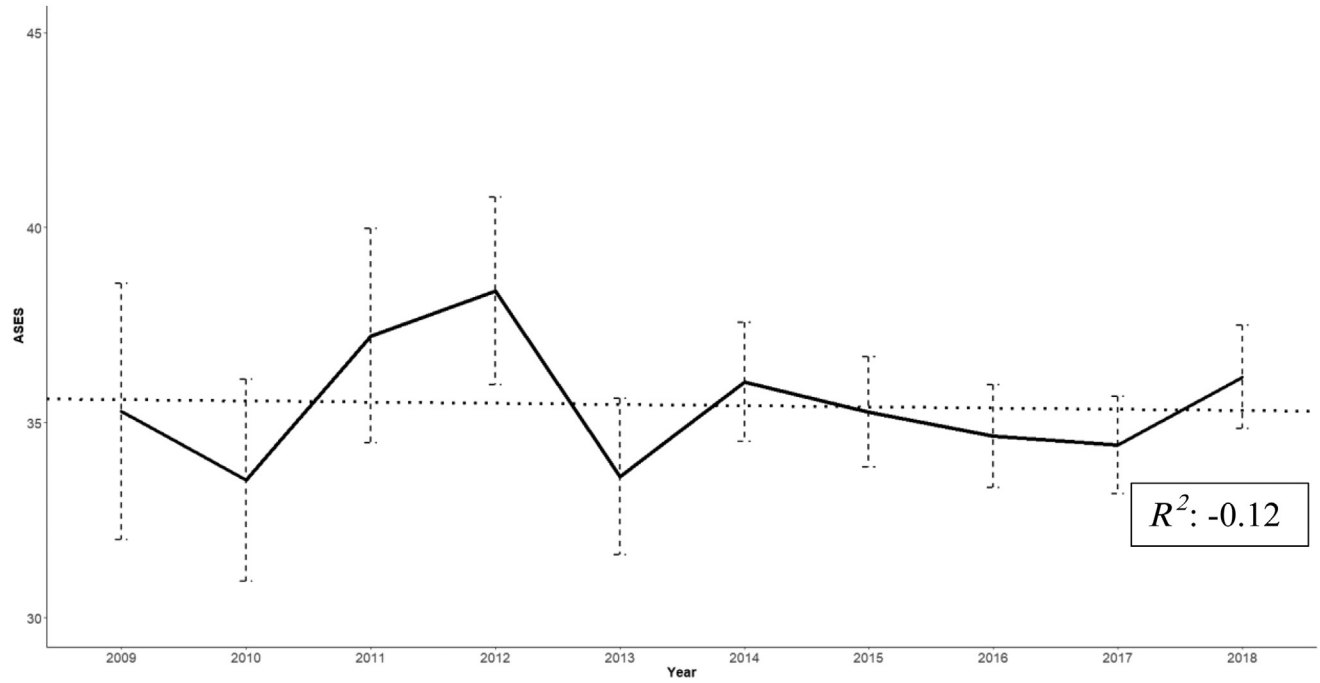

Figure 2 Mean tipping point (with 95% confidence interval) for ASES score by year. *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form.

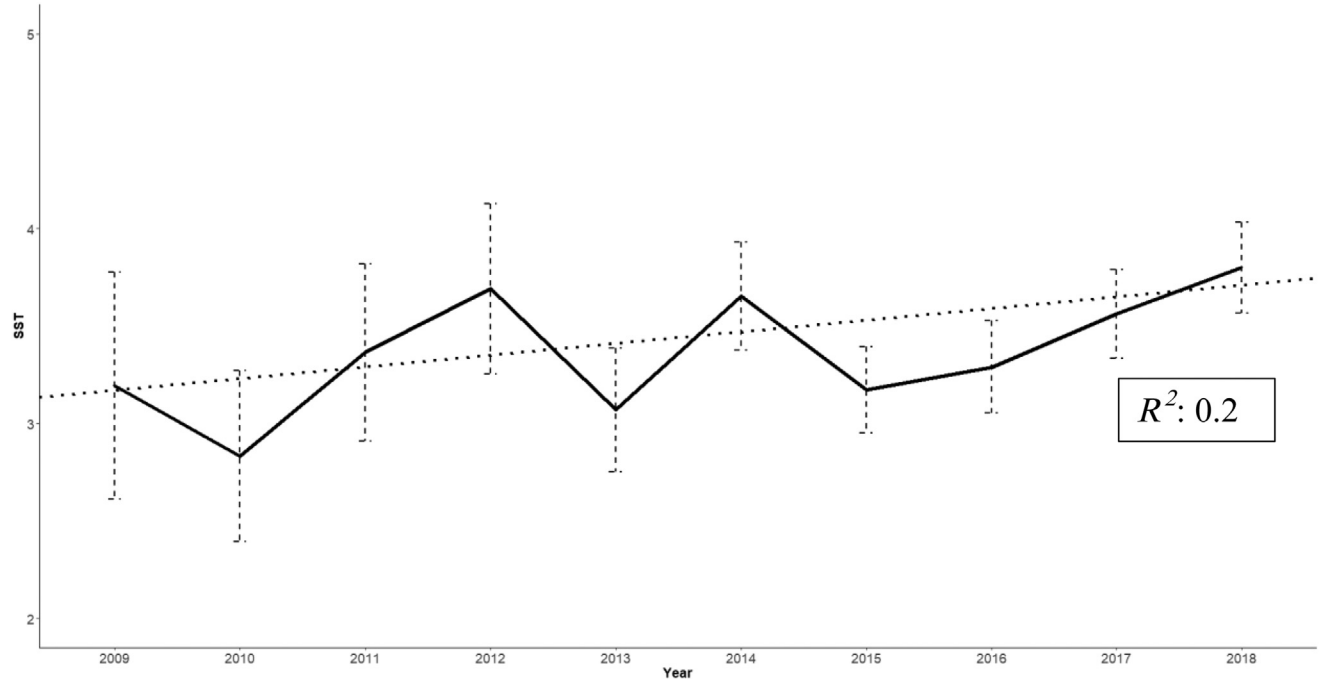

Figure 3 Mean tipping point (with 95% confidence interval) for SST score by year. *SST*, Simple Shoulder Test.

difference by diagnosis ($P = .01$), with OA having significantly less ER than in RCT (3.0 [0.2; 5.7], $P = .03$) or RCA (1.7 [–0.03; 3.5], $P = .05$). Overall, ROM increased over time, demonstrating higher ROM tipping points in later years.

Trend analysis

To evaluate the overall trend in the tipping point over time, linear regression modeling was performed. When evaluating changes in age over time, there was no observed

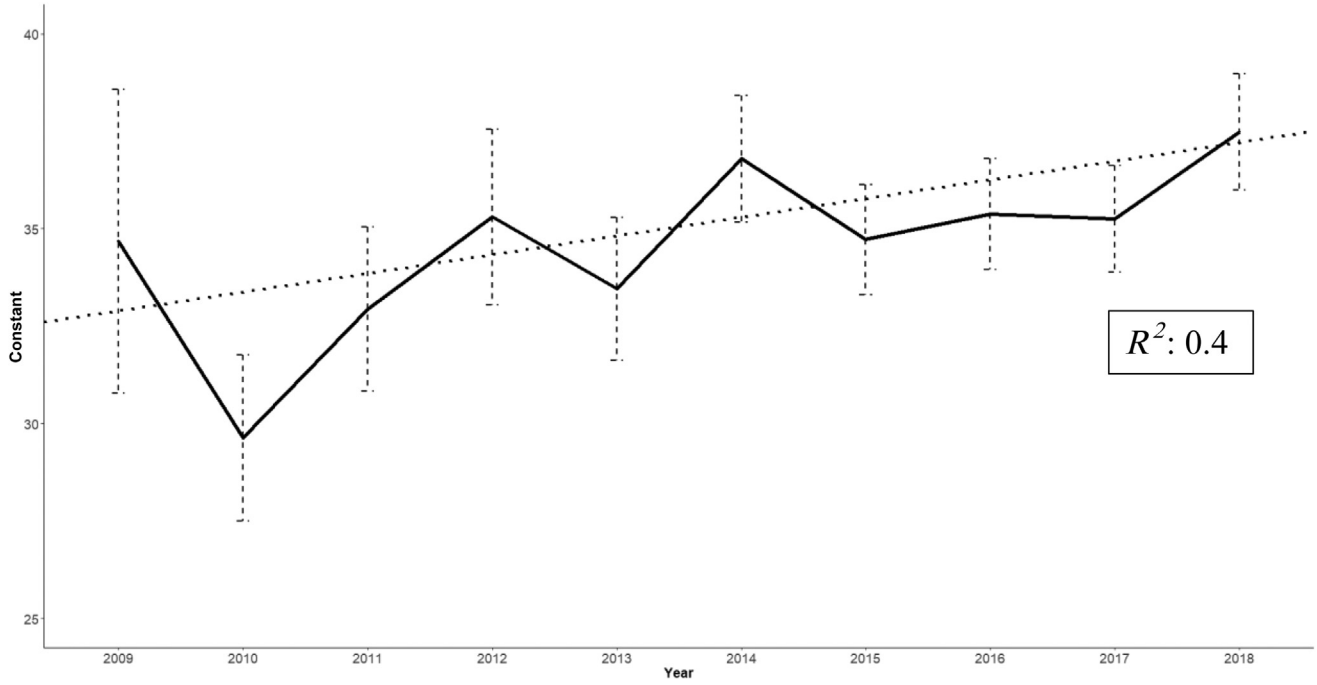

Figure 4 Mean tipping point (with 95% confidence interval) for Constant score by year.

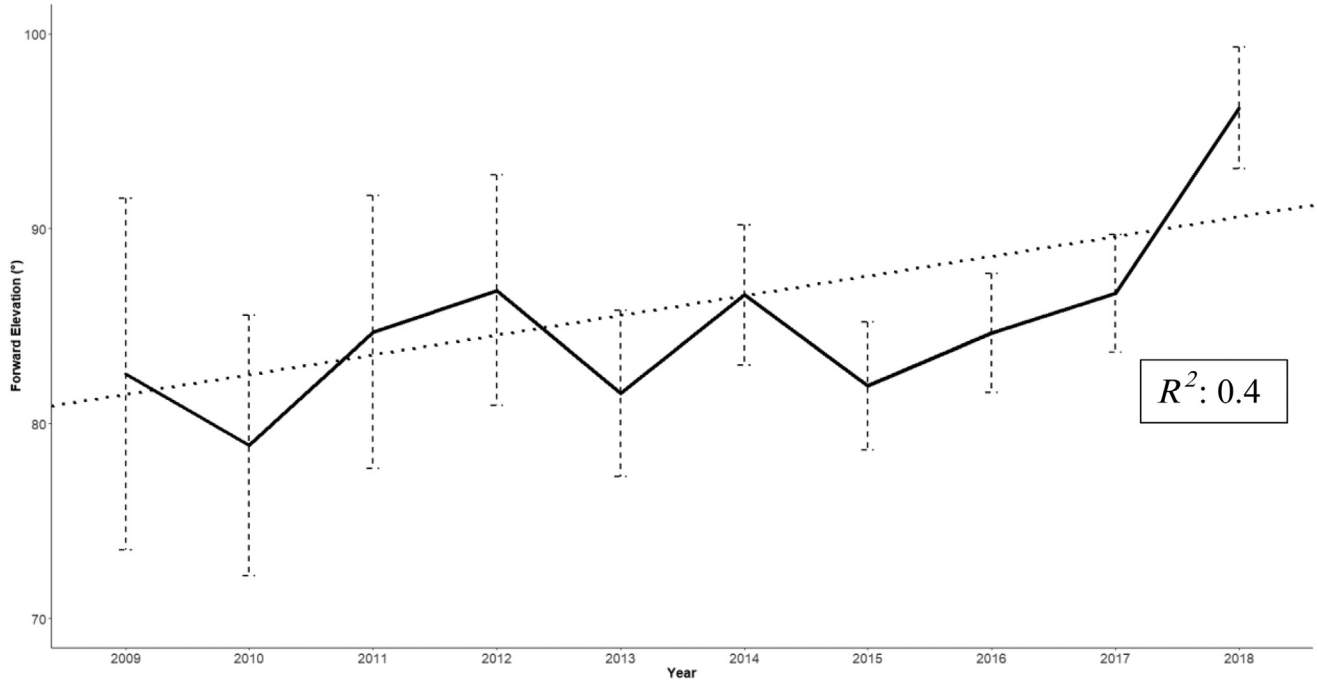

Figure 5 Mean tipping point (with 95% confidence interval) for forward elevation by year.

trending of increasing or decreasing age over time (P = .6) (Fig. 1). Significant trends were noted in overhead range of motion, with both forward elevation and abduction increasing over time. When modeled over time, forward elevation increased at a rate of 1° per year (P = .002). Abduction also increased at a modeled rate of 1.9° per year (P = .002). However, despite reaching statistical significance, the R^2 values for these trend lines remained low

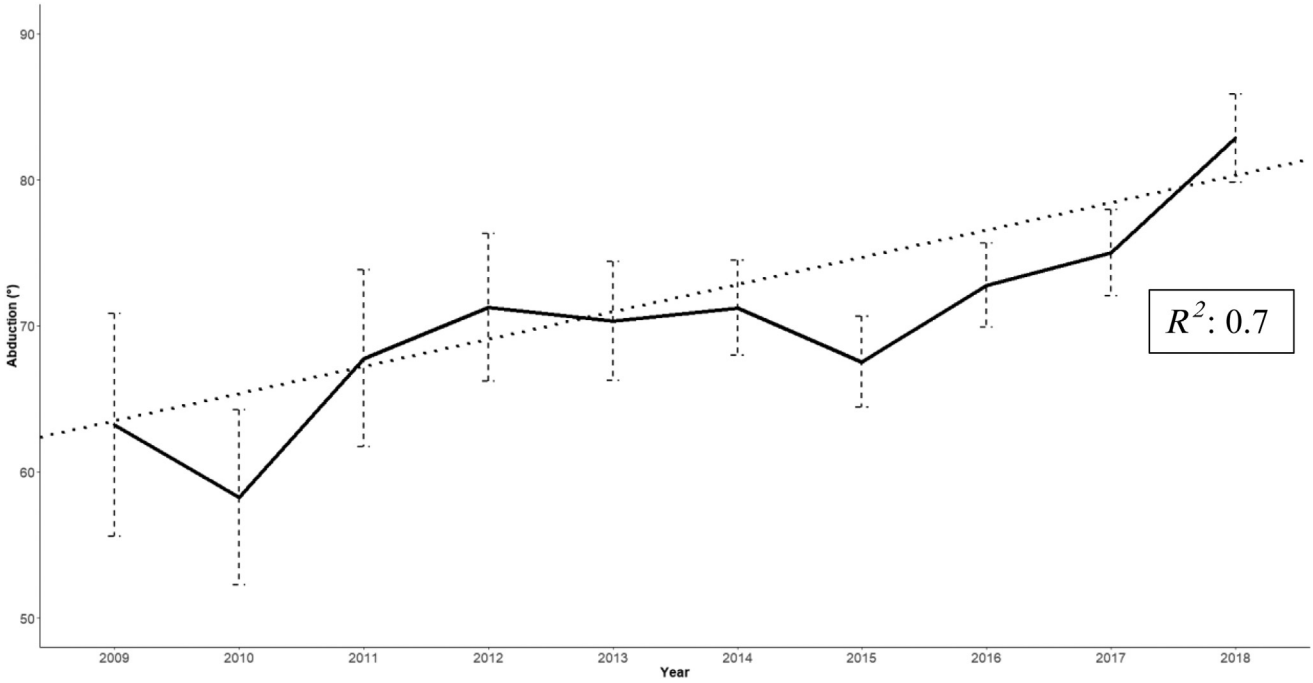

Figure 6 The mean tipping point (with 95% confidence interval) for abduction by year.

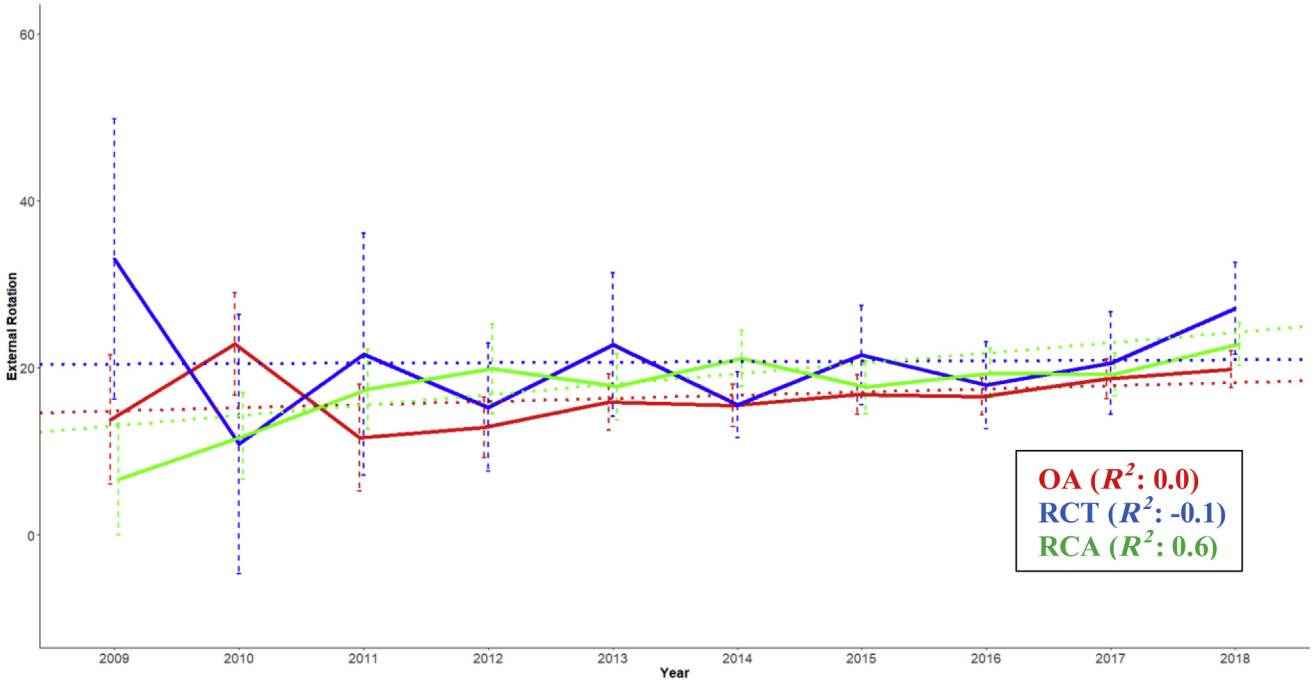

Figure 7 The mean tipping point (with 95% confidence interval) for external rotation by year as a function of diagnosis. *OA*, osteoarthritis with rotator cuff deficiency; *RCT*, rotator cuff tear; *RCA*, rotator cuff tear arthropathy.

(forward elevation, $R^2 = 0.4$; abduction, $R^2 = 0.7$) (Figs. 5 and 6). When evaluating ER, only patients with a preoperative diagnosis of RCA demonstrated a trend toward an increased tipping point over the study period (1.2° per year, $P = .007$; $R^2 = 0.6$). No trend was noted for ER when evaluating patients with a preoperative diagnosis of OA ($P = .4$) or RCT ($P > .99$) (Fig. 7). For PROM, both ASES and SST scores were stable over the study period (ASES,

$P = .9$; SST, $P = .1$) (Figs. 2 and 3). There was a small increase in the Constant score over time, with a modeled rate of 0.5 points per year ($P = .04$; $R^2 = 0.4$) (Fig. 4).

Discussion

Although the concept of the ''tipping point'' for shoulder arthroplasty is fairly new, its stability over time is not well understood. Over a 10-year period, preoperative PROMs remained relatively stable despite small year-to-year differences. In contrast, preoperative ROM gradually increased over the 10-year study period. This information suggests that although RSA patients today have better preoperative ROM than 10 years ago, they elect to undergo surgery at the same perceived level of disability.

The introduction of the ''tipping point'' for patients undergoing shoulder arthroplasty has been a useful tool with regard to preoperative patient counseling. Somerson et al[18] first introduced this concept and evaluated how preoperative SST and other demographic factors affected the point at which a patient decides to undergo shoulder arthroplasty. They did find that RSA had the lowest average preoperative SST score (1.5 ± 1.8), compared with anatomic total shoulder arthroplasty (3.0 ± 2.4), hemiarthroplasty (3.1 ± 3.3), and ream and run (5.0 ± 2.5). This is lower than the average SST score for RSA performed in this study (3.4 vs. 1.5). One possible cause of the higher SST scores reported in this study may be patient age. The mean age of shoulders undergoing RSA was lower in this study (72 vs. 80), which may have affected the preoperative SST. Additionally, Somerson reported on a closed population of patients treated in a single practice. In contrast, patients for this study were acquired from multiple countries and multiple surgeons, representing a more generalizable population.

Despite the observed increase in ROM over time, the tipping point for PROM and the Constant score remained stable. This is likely related to the poor correlation of objective ROM metrics to PROMs. Matsen et al[10] evaluated the relationship between SST and active abduction in patients with shoulder OA. They found a poor correlation between SST score and active abduction. Thus, it is important to understand that ROM measures taken as an isolated measurement at a single time point may not fully characterize a patient's perceived level of dysfunction. When counseling a patient on the decision to undergo surgery, PROM metrics may be more appropriate given their stability over time.

In this study, we evaluated 2 different PROMs (ASES, SST). Overall, both PROMs demonstrated similar stable trends over the study period. A recent study by Michael et al[11] examined the correlation of various PROMs at different follow-up points following primary shoulder arthroplasty. Strong correlations were demonstrated between ASES, SST, and SPADI scores, which became stronger with increasing follow-up after surgery. Specifically, when comparing ASES and SST preoperatively in shoulders undergoing RSA, these scores demonstrated a strong correlation ($r = 0.870$, $P < .001$). These correlations likely explain the similar trends over time seen for these scores.

This study represents the first evaluation of how implementation of RSA has changed over time from a patient selection perspective. The use of a multinational database with more than 3500 patients covers a demographically diverse population, which makes the data more widely applicable. However, because of the multi-institutional nature of these data, there will inevitably be differences in the practice and selection biases of the various surgeons, which could affect the timing of surgery. We also did not attempt to evaluate or control for individual surgeon in this study. Although visual trends were seen over time, which in some cases reached statistical significance, the year-to-year data remained widely distributed. This variability led to low R^2 values, indicating that the visual trends identified by linear regression modeling were likely not caused by the independent variable examined. Another weakness is that only the diagnoses of OA, RCT, and RCA were included in the analysis. Although we did have data collected from patients with diagnoses of rheumatoid arthritis, osteonecrosis, and post-traumatic arthritis, we did not have sufficient numbers of patients in these categories to yield high-powered results. Finally, we did not perform correlation studies between the preoperative PROMs (ASES, SST), the Constant score, and preoperative ROM measures, as this has been previously reviewed and found to have no significant correlation.[10]

Conclusion

Despite the increasing use of RSA over the last decade, the tipping point for patients electing to undergo surgery remains stable with regard to preoperative PROMs. This indicates that patients and surgeons continue to offer/choose primary RSA at a similar preoperative level of disability over the last 10 years despite clinical advancements.

Disclaimer

Bradley Schoch is a paid consultant for and receives royalties from Exactech Inc.

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 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. Barco R, Savvidou OD, Sperling JW, Sanchez-Sotelo J, Cofield RH. Complications in reverse shoulder arthroplasty. EFORT Open Rev 2016;1:72-80. https://doi.org/10.1302/2058-5241.1.160003
2. Berliner JL, Regalado-Magdos A, Ma CB, Feeley BT. Biomechanics of reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:150-60. https://doi.org/10.1016/j.jse.2014.08.003
3. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14(Suppl S):147S-61S. https://doi.org/10.1016/j.jse.2004.10.006
4. Chalmers PN, Salazar DH, Romeo AA, Keener JD, Yamaguchi K, Chamberlain AM. Comparative utilization of reverse and anatomic total shoulder arthroplasty: a comprehensive analysis of a high-volume center. J Am Acad Orthop Surg 2018;26:e504-10. https://doi.org/10.5435/JAAOS-D-17-00075
5. Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients. J Bone Joint Surg Am 2005;87:1697-705. https://doi.org/10.2106/JBJS.D.02813
6. Grammont PM, Baulot E. Delta shoulder prosthesis for rotator cuff rupture. Orthopedics 1993;16:65-8.
7. 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
8. Kang JR, Dubiel MJ, Cofield RH, Steinmann SP, Elhassan BT, Morrey ME, et al. Primary reverse shoulder arthroplasty using contemporary implants is associated with very low reoperation rates. J Shoulder Elbow Surg 2019;28(Suppl):S175-80. https://doi.org/10.1016/j.jse.2019.01.026
9. Lévigne C, Garret J, Boileau P, Alami G, Favard L, Walch G. Scapular notching in reverse shoulder arthroplasty: is it important to avoid it and how? Clin Orthop Relat Res 2011;469:2512-20. https://doi.org/10.1007/s11999-010-1695-8
10. Matsen FA 3rd, Tang A, Russ SM, Hsu JE. Relationship between patient-reported assessment of shoulder function and objective range-of-motion measurements. J Bone Joint Surg 2017;99:417-26. https://doi.org/10.2106/JBJS.16.00556
11. Michael RJ, Williams BA, Laguerre MD, Struk AM, Schoch BS, Wright TW, et al. Correlation of multiple patient-reported outcome measures across follow-up in patients undergoing primary shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:1869-76. https://doi.org/10.1016/j.jse.2019.02.023
12. Nyffeler RW, Werner CML, Gerber C. Biomechanical relevance of glenoid component positioning in the reverse Delta III total shoulder prosthesis. J Shoulder Elbow Surg 2005;14:524-8. https://doi.org/10.1016/j.jse.2004.09.010
13. Rittmeister M, Kerschbaumer F. Grammont reverse total shoulder arthroplasty in patients with rheumatoid arthritis and non-reconstructible rotator cuff lesions. J Shoulder Elbow Surg 2001;10:17-22. https://doi.org/10.1067/mse.2001.110515
14. 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.
15. Schoch BS, King JJ, Wright TW, Vigan M, Werthel JD. Defining the tipping point for primary shoulder arthroplasty. JSES Open Access 2019;3:273-7. https://doi.org/10.1016/j.jses.2019.09.009
16. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. https://doi.org/10.2106/JBJS.F.00226
17. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388-95. https://doi.org/10.1302/0301-620x.86b3.14024
18. Somerson JS, Hsu JE, Neradilek MB, Matsen FA 3rd. The "tipping point" for 931 elective shoulder arthroplasties. J Shoulder Elbow Surg 2018;27:1614-21. https://doi.org/10.1016/j.jse.2018.03.008
19. Vanhove B, Beugnies A. Grammont's reverse shoulder prosthesis for rotator cuff arthropathy. A retrospective study of 32 cases. Acta Orthop Belg 2004;70:219-25.
20. 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
21. Werner CML, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476-86. https://doi.org/10.2106/JBJS.D.02342
22. Wierks C, Skolasky RL, Ji JH, McFarland EG. Reverse total shoulder replacement: intraoperative and early postoperative complications. Clin Orthop Relat Res 2009;467:225-34. https://doi.org/10.1007/s11999-008-0406-1