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Defining the tipping point for primary shoulder arthroplasty

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Background: Although risk factors for poor outcomes and complications have been studied, there remain limited objective criteria to guide surgeons about the timing of arthroplasty. The purpose of this study was to further characterize the tipping-point scores for a group of patient-reported outcome measures (PROMs) in patients undergoing primary shoulder arthroplasty.

Methods: We retrospectively reviewed 5670 primary shoulder arthroplasties (1833 anatomic total shoulder arthroplasties and 3837 reverse shoulder arthroplasties [RSAs]) performed over a 10-year period. Preoperative range of motion, PROMs (American Shoulder and Elbow Surgeons, Simple Shoulder Test, and Shoulder Pain and Disability Index scores), and Constant scores were evaluated. The tipping point for each PROM was evaluated. Univariate and multivariate analyses were performed to assess risk factors for lower tipping points.

Results: Patients undergoing RSA demonstrated lower tipping points for all range-of-motion parameters as well as American Shoulder and Elbow Surgeons, Shoulder Pain and Disability Index, and Simple Shoulder Test scores. Female sex was predictive of a lower tipping point prior to shoulder arthroplasty, regardless of implant type. When the total shoulder arthroplasty subgroup was evaluated, both female sex and a higher body mass index were shown to be associated with a lower tipping point.

Discussion: The choice to undergo shoulder arthroplasty is a multifactorial decision that encompasses both physical and social factors. Female patients and patients undergoing RSA are more likely to accept slightly worse shoulder function prior to making the decision to undergo shoulder arthroplasty.

In patients with pain and disability of the glenohumeral joint, the decision to undergo shoulder arthroplasty is a multifactorial choice made by patients in conjunction with the treating physician. It is not uncommon for patients to seek a surgeon's advice to help decide when shoulder arthroplasty may be an appropriate procedure. Although risk factors for poor outcomes and complications have been studied, there remain limited objective criteria to guide surgeons to definitively recommend arthroplasty.[2]

Early in the disease process, patients who complain of pain as a predominant symptom may be effectively treated with activity modification, over-the-counter pain medications, and corticosteroid injections.[7] Other patients may be unwilling to accept the functional limitations of their shoulder regardless of pain.[3] Eventually, when a patient determines that the risks of surgery are worth taking in exchange for the expected improvement in pain and function, shoulder arthroplasty is generally performed. Somerson et al[10] called this decision the "tipping point." They used preoperative Simple Shoulder Test (SST) scores to define a baseline score for patients electing to undergo shoulder arthroplasty.[10] This information is useful for preoperative counseling, as patients with higher preoperative American Shoulder and Elbow Surgeons (ASES) scores have been shown to be at higher risk of failure to improve after anatomic shoulder arthroplasty.[6] Although the SST is a simple validated test for evaluating shoulder function, the SST score is not uniformly collected across all practices.[4] The Constant score and ASES score remain the 2 most commonly used shoulder scores for scientific evaluation of shoulder arthroplasty.[9] The purpose of this study was to characterize the tipping point for

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patients undergoing primary shoulder arthroplasty based on preoperative range of motion (ROM) and patient-reported outcome measures (PROMs).

Materials and methods

We performed a retrospective review of all primary anatomic and reverse total shoulder arthroplasties performed between 2008 and 2018. All shoulders were prospectively enrolled in a multinational joint registry spanning 26 institutions with standardized data collection. We identified 6376 unique shoulder arthroplasties. Shoulders with a preoperative diagnosis of an acute proximal humeral fracture (281), locked dislocation (13), oncologic diagnosis (8), active infection (3), or nerve injury (1) were eliminated. An additional 68 shoulders without a preoperative diagnosis and 332 shoulders without documented preoperative PROMs were eliminated. The decision to undergo surgery was made between the performing surgeon and patient after failure of conservative measures. Surgical indications were not standardized among surgeons.

Patient information was reviewed for age, sex, body mass index (BMI), hand dominance, prior surgical procedures, and prior injections. Prior to undergoing index arthroplasty, patients were evaluated using a standardized registry protocol. All patients were examined by the performing surgeon or by clinical research assistants prior to surgery, and examination results were documented in the database. Active ROM measures included abduction (in degrees), forward elevation (in degrees), external rotation with the elbow at the side (in degrees), and internal rotation (vertebral level). Internal rotation was measured according the scale described by Flurin et al.[1] PROMs obtained included the SST score, ASES score, and Shoulder Pain and Disability Index (SPADI) score. The Constant score, which has both a patient-reported component and physical examination component, was also evaluated. The tipping point was considered the value of a preoperative ROM or PROM at the point a patient elected to undergo shoulder arthroplasty.[11]

Statistical analysis

Total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA) groups were evaluated independently. Continuous variables were assessed using the Student *t* test or analysis of variance with the post hoc Tukey test. Ordinal variables were assessed using the Mann-Whitney *U* test. Categorical variables were assessed with the χ^2 test. Descriptive statistics are presented as mean (range) for continuous measures and number (percentage) for discrete variables. Univariate association of risk factors with the preoperative scores was quantified by a linear regression. Beta and standard error were first estimated in univariate analyses. Factors that were statistically significant in the univariate analysis were entered into a multivariate linear regression and were selected thereafter by using a backward selection method. A final model in which all variables had $P < .05$ was obtained. All statistical analyses were performed using SPSS software (version 24; IBM, Armonk, NY, USA).

Results

A total of 5670 shoulders were evaluated prior to undergoing elective primary shoulder arthroplasty. The mean age at the time of surgery was 70.2 years (range, 25-96 years). The study group included more female patients than male patients (3393 vs. 2768). The group included 1833 anatomic TSAs and 3837 RSAs. Patients undergoing RSA were 6 years older than those undergoing TSA on average (72 years vs. 66 years, $P < .001$). Patients undergoing RSA were also more commonly women and were more likely to have undergone prior shoulder surgery ($P < .001$). Table I shows full demographic data.

Table I
Group demographic characteristics by implant type

	TSA (n = 1833)	RSA (n = 3837)	*P* value
Age, yr	66 (8.9)	72 (7.7)	<.001
Sex: M/F, n	908/925	1370/2467	<.001
Height, cm	169 (10.6)	165 (10.2)	.007
Weight, kg	86.4 (20.2)	78.6 (18.8)	<.001
BMI	30.0 (6.3)	28.5 (5.9)	.01
Prior surgery, %	18	23	<.001
Prior injection, %	44	37	<.001
Comorbidities, %			
Inflammatory arthritis	11	7	<.001
Hypertension	48	52	.004
Coronary artery disease	14	15	.06
Diabetes	13	13	.9
Nicotine abuse	10	6	<.001

TSA, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *M*, male; *F*, female; *BMI*, body mass index.
Data are reported as mean (standard deviation) unless otherwise indicated.

The average tipping point for overhead ROM for shoulders undergoing shoulder arthroplasty was 89° of forward flexion (standard deviation [SD], 37.0°) and 76° of abduction (SD, 35.1°). The mean tipping point for external rotation was 19° (SD, 20.6°). The mean tipping point for internal rotation was to the sacroiliac joint. The median tipping points for preoperative PROMs were as follows: ASES score, 35.3 (SD, 15.9); Constant score, 36.1 (SD, 14.6); SPADI score, 84.3 (SD, 22.9); and SST score, 3.6 (SD, 2.9).

Shoulders undergoing TSA showed significantly better function (a higher tipping point) than those undergoing RSA when assessed by the ASES, SST, and SPADI scores. The tipping point for anatomic shoulder arthroplasty also demonstrated significantly greater preoperative ROM for all measures (Table II). Despite these differences reaching statistical significance, all measures were below the minimal clinically important difference as defined by Simovitch et al.[8] The distribution of tipping points for each PROM was similar for both TSA and RSA, with both groups demonstrating unimodal shifts toward a lower functional tipping point within the population (Figs. 1 and 2). The RSA group demonstrated slightly worse function at the tipping point as demonstrated by the unimodal peak shift seen in all PROM measures. Furthermore, the median tipping points for all PROMs were lower in the RSA group, with the ASES, SPADI, and SST scores reaching statistical significance (Table II).

Univariate analysis showed RSA, female sex, and a history free of surgery to be predictors of a lower tipping point for all measured

Table II
Tipping points for TSA vs. RSA

	TSA	RSA	*P* value
Abduction, °	80 (31.6)	70 (36.0)	<.001
Forward elevation, °	93 (32.6)	80 (38.3)	<.001
External rotation, °	20 (19.7)	15 (20.9)	.02
Internal rotation, vertebral level	3.0 (1.6)	2.0 (1.8)	.001
Constant score	37 (14.8)	33 (14.3)	.1
ASES score	35 (16.3)	33 (15.7)	.04
SPADI score	83 (23.6)	88 (22.4)	.04
SST score	4 (3.0)	3 (2.8)	<.001

TSA, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *ASES*, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test.
Data are reported as median (standard deviation).

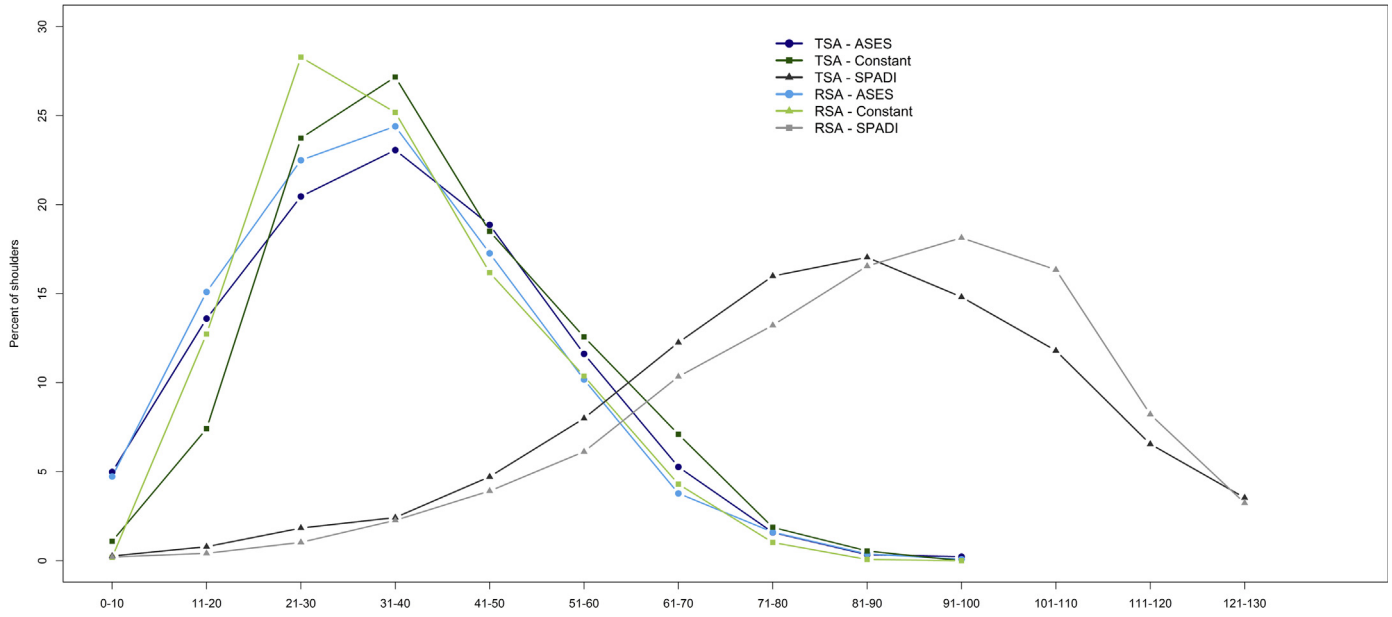

Figure 1 Tipping point for patient-reported outcome measures by implant type. *TSA*, total shoulder arthroplasty; *ASES*, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *RSA*, reverse shoulder arthroplasty.

PROMs. After multivariate analysis, only female sex was predictive of a lower tipping point prior to shoulder arthroplasty. Full results of the univariate and multivariate analyses including all arthroplasties are shown in Supplementary Appendix S1.

Anatomic TSA

Within the TSA subgroup, the tipping point for electing to undergo surgery did not significantly differ for any ROM parameter or PROM based on patients' hand dominance. Similarly, the tipping point for all evaluated parameters was similar regardless of prior surgery. Female patients demonstrated significantly lower tipping points for shoulder arthroplasty for all PROMs compared with male patients treated with TSA (Table III). Following multivariate analysis, both female patients and patients with a higher BMI were shown to be significantly more likely to have a lower tipping point prior to undergoing TSA. Full details for all PROMs are presented in Supplementary Appendix S2.

Reverse shoulder arthroplasty

The tipping points for all ROM parameters and PROMs did not significantly differ based on hand dominance, except for the ASES score, which had a statistically significantly lower tipping point for shoulders treated on the nondominant side (34.8 vs. 35.3, $P = .018$). Patients with a history of surgery demonstrated significantly higher tipping points (better ROM and PROMs) for all measures prior to electing to undergo shoulder arthroplasty. Similarly to the TSA group, female patients showed significantly lower tipping points for all ROM and PROM data points compared with male

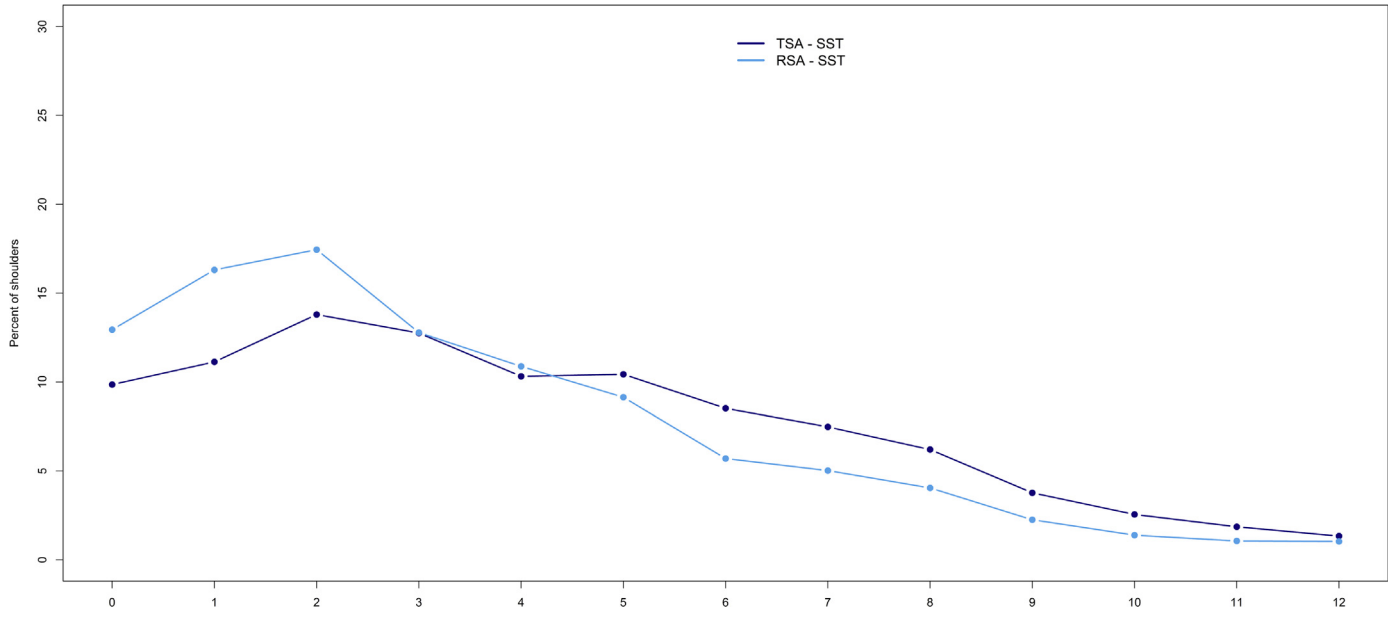

Figure 2 Tipping point for Simple Shoulder Test *(SST)* score by implant type. *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty.

Table III
Tipping points based on sex

	TSA			RSA		
	F	M	*P* value	F	M	*P* value
Abduction, °	80 (30.8)	85 (32.0)	.2	70 (34.3)	71 (38.1)	<.001
Forward elevation, °	90 (33.2)	100 (31.6)	.2	80 (37.6)	90 (39.0)	.3
External rotation, °	20 (19.8)	20 (19.5)	.3	15 (20.0)	20 (22.3)	.001
Internal rotation, vertebral level	3 (1.6)	3 (1.6)	.4	3 (1.8)	3 (1.8)	<.001
Constant score	34 (13.6)	40 (15.3)	.001	31 (13.8)	37 (14.5)	.6
ASES score	32 (15.1)	38 (16.9)	<.001	32 (15.0)	38 (16.0)	.001
SPADI score	89 (21.4)	76 (24.0)	.002	93 (21.3)	79 (22)	.004
SST score	3 (2.7)	5 (3.1)	<.001	2 (2.5)	4 (3.0)	<.001

TSA, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *F*, female; *M*, male; *ASES*, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test.
Data are reported as median (standard deviation).

patients (Table III). Multivariate analysis demonstrated female patients to exhibit a lower tipping point before electing to undergo RSA. Full details for all PROMs are displayed in Supplementary Appendix S3.

Discussion

The decision to pursue shoulder arthroplasty remains a multifactorial decision based on discussions between the patient and physician. Factors taken into account may include the level of disability, general health, and activity requirements to maintain a satisfactory lifestyle. Patients may remain reluctant to undergo shoulder arthroplasty even with its clinical track record of improving pain and function. One risk factor for a poor outcome following shoulder arthroplasty remains high preoperative function.[6,12] However, exact cutoffs for individual PROMs that constitute high preoperative function are not readily defined. Previous work by Somerson et al[10] defined the tipping point of patients undergoing shoulder arthroplasty regarding the SST score. Despite the ease of administering the SST, the SST score remains less commonly collected and reported than other measures.[9] Building on the work of Somerson et al, we were able to define the tipping point for patients undergoing primary shoulder arthroplasty with multiple commonly used PROMs. Knowledge of the average and median preoperative scores for various PROMs will help surgeons counsel patients on when shoulder arthroplasty may be an appropriate decision based on the historical pain and function of patients undergoing a similar surgical procedure as measured by validated shoulder function scores.

Somerson et al[10] reported a mean preoperative SST score (tipping point) of 3.6 ± 2.7 in patients undergoing elective primary shoulder arthroplasty. This is nearly identical to the value in the group of patients in our study (3.6 ± 2.9). Our results support those of Somerson et al, who reported that male patients had a significantly higher SST score (tipping point) than female patients (4 vs. 2, $P < .001$). We observed similar significant differences for both anatomic TSA (5 vs. 3.5, $P < .001$) and RSA (4.3 vs. 2.9, $P < .001$). Similar significant differences were noted for the ASES and SPADI scores, with female patients having lower tipping-point scores for both TSA and RSA. Differences in ROM between sexes were only seen in the RSA group, in which abduction, external rotation, and internal rotation were significantly lower in female patients prior to electing to undergo primary RSA. However, it is important to note that the differences in motion were all small, and the clinical significance of these small differences should be questioned.

This study also showed significant differences in the tipping point according to implant type. Patients electing to undergo RSA demonstrated lower tipping points for all ROM parameters, as well as the ASES, SPADI, and SST scores. This finding supports the findings of Somerson et al,[11] who also showed a significant interaction between implant type and preoperative SST score. However, in our larger cohort, the SST score's tipping point for RSA was 3.4, compared with 1 as reported by Somerson et al. This difference may be in part related to differing patient populations. Somerson et al collected data from a smaller cohort of RSAs (79 vs. 3837) from a single institution. The database used for our study collected data from multiple institutions across the world, and the data are likely more generalizable. The SST score's tipping point for TSA was also slightly higher in this study (4.2 vs. 3).

When we evaluated risk factors for a lower tipping point using a multivariate analysis, female sex was shown to be a risk factor for a lower tipping point prior to primary shoulder arthroplasty. An increasing BMI was found to be associated with a lower tipping point only for TSA. We found no difference in the tipping point based on age or implant type, which is in contrast to the findings of Somerson et al.[10] Previously, a lower tipping point for the SST score was shown to be associated with alcohol use, a higher American Society of Anesthesiologists score, work status, marriage status, and insurance type.[10] However, this information is not captured in our database; thus, we are unable to confirm similar interactions with the tipping point of other PROMs.

Knowledge of the tipping point of patients undergoing elective primary shoulder arthroplasty is likely to be helpful for future patients considering shoulder arthroplasty who may question if they are “ready” for surgery. Prior studies on shoulder arthroplasty have evaluated the effect of preoperative PROMs on postoperative outcomes. Mahony et al[6] reported on 459 primary TSAs and determined that a higher baseline ASES score was associated with a higher risk of failing to improve following arthroplasty. They did not outline a cutoff for what was considered a high score. However, a study by Jacobs et al[5] suggested that ASES score improvements of less than 12 are associated with postoperative patient dissatisfaction. Similar risks of failure to improve have been shown following RSA, but no score cutoff has been described.[11] Knowledge of the median tipping point (ASES score of 35 for TSA and 33 for RSA and Constant score of 37 for TSA and 33 for RSA) may help surgeons counsel patients with higher baseline scores, who may benefit from waiting before considering shoulder arthroplasty.

The strength of this study is the use of a large multicenter database with over 5000 shoulders. Despite this, our study has some limitations. The decision on when to undergo shoulder arthroplasty was not controlled and likely differed among surgeons. However, the use of multiple surgeons may make the data more generalizable. Moreover, ROM measures were performed by both surgeons and research assistants, which may have led to some level of self-evaluation bias. However, given that only preoperative measures were evaluated, the effect of this bias is likely small.

The identification of the tipping point can be used to counsel patients who are considering primary shoulder arthroplasty. However, these tipping-point markers should not be used as a

threshold for offering surgery. These represent an average patient, and the decision to perform surgery remains multifactorial. Furthermore, we are unable to comment on a threshold for preoperative PROM scores being too high to achieve meaningful clinical benefit following shoulder arthroplasty.

Conclusion

The choice to undergo shoulder arthroplasty is a multifactorial decision that encompasses both physical and social factors. Female patients are more likely to accept worse shoulder function prior to undergoing shoulder arthroplasty, according to PROMs. Surgeons may consider discussing the reported tipping points of study populations with patients who are uncertain about their decision to proceed with primary shoulder arthroplasty.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jses.2019.09.009.

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