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One-year patient-reported outcomes following primary arthroscopic rotator cuff repair vary little by surgeon

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Background: This study's purpose was to investigate the extent to which differences among operating surgeons may influence 1-year patient-reported outcome measures (PROMs) in patients undergoing rotator cuff repair (RCR) surgery, after controlling for general and disease-specific patient factors. We hypothesized that surgeon would be additionally associated with 1-year PROMs, specifically the baseline to 1-year improvement in Penn Shoulder Score (PSS).

Methods: We used mixed multivariable statistical modeling to assess the influence of surgeon (and alternatively surgical case volume) on 1-year PSS improvement in patients undergoing RCR at a single health system in 2018, controlling for eight patient- and six disease-specific preoperative factors as possible confounders. Contributions of predictors to explaining variation in 1-year PSS improvement were measured and compared using Akaike's Information Criterion.

Results: 518 cases performed by 28 surgeons met inclusion criteria, with median (quartiles) baseline PSS of 41.9 (31.9, 53.9) and 1-year PSS improvement of 42 (29.1, 55.3) points. Contrary to expectation, surgeon and surgical case volume were neither statistically significantly nor clinically meaningfully associated with 1-year PSS improvement. Baseline PSS and mental health status (VR-12 MCS) were the dominant and only statistically significant predictors of 1-year PSS improvement, with lower baseline PSS and higher VR-12 MCS predicting larger 1-year PSS improvement.

Conclusion: Patients generally reported excellent 1-year outcomes following primary RCR. This study did not find evidence that the individual surgeon or surgeon case volume influences 1-year PROMs, independently of case-mix factors, following primary RCR in a large employed hospital system.

Rotator cuff (RC) tears are a significant cause of shoulder pain and dysfunction and are present in approximately 30% of individuals by 70 years of age.[22,29] Rotator cuff repair (RCR) is often recommended for symptomatic full-thickness and high-grade partial-thickness RC tears that fail to respond to nonoperative treatment. More than 250,000 RCRs are performed annually in the United States,[6] with the number of cases steadily increasing over the last three decades.[9] However, RCR success is somewhat variable regardless of the structural or patient-reported outcome being measured, and the reasons for such variation are poorly understood. Besides general patient factors such as age and comorbidities and disease-specific factors such as tear type and size, it is possible that variation among operating surgeons contributes importantly to determining the success of RCR approaches. Yet the extent of surgeon-associated variation in RCR outcomes has only rarely been rigorously assessed.[1,16,32]

This study utilized the Cleveland Clinic's Orthopaedic Minimal Data Set Episode of Care (OME) prospective surgical cohort, which has been approved by Cleveland Clinic's Institutional Review Board (IRB #06-196).

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A few studies have investigated associations of surgeon-related factors to RCR techniques and outcomes.[8,16,31] In a previous study,[8] we found that surgeons differed significantly in their use of double-row vs. single-row repairs and the number of anchors used for repair across different RC tear sizes. We concluded that their surgical methods were primarily determined, in the absence of data to conclusively support the clinical benefits of some repair techniques over others, by training, experience, and/or local practice patterns. However, the relationship between surgeon and RCR outcomes was not investigated.

In February 2015, to address the need for high-quality, prospective, standardized data surrounding orthopedic procedures, the Cleveland Clinic Health System (CCHS) implemented the prospectively collected, comprehensive, and standardized Outcomes Management and Evaluation (OME) surgical cohort database.[17] Baseline demographic, disease-specific, and surgical treatment data for many elective orthopedic procedures, with joint-specific validated baseline and 1-year patient-reported outcome measures (PROMs), are routinely electronically stored in a secure OME Research Electronic Data Capture[11] database. Shoulder status is routinely assessed using shoulder-specific PROMs including the PENN Shoulder Score (PSS), which measures shoulder pain, function, and satisfaction, and has been specifically validated for assessment of rotator cuff pathology.[14] We have shown that OME is an efficient, valid tool for collection of comprehensive, standardized RCR data.[26]

This study's purpose was to investigate the extent of surgeon-associated variability in 1-year PROMs in patients with RCR remaining after controlling for general patient- and disease-specific preoperative case-mix factors by mixed effects multivariable statistical modeling. We hypothesized that the surgeon would be associated with 1-year PROMs, specifically the baseline to 1-year improvement in PSS, after such case-mix adjustment. We tested this hypothesis and examined additional relationships in the OME RCR 2018 subcohort.

Materials and methods

Rotator cuff repair surgical cohort

All data were obtained from CCHS's OME database[17] (Institutional Review Board (IRB) #06-196). Patients undergoing surgery for a RC tear between January and December 2018 were considered included if undergoing outpatient primary RCR of a tear of the subscapularis, supraspinatus, infraspinatus, and/or teres minor tendons. Patients of age <18 years or with superior-posterior RC tears that were not repaired (due to the tears being low-grade partial-thickness or irreparable), revision RCRs, or inpatient RCRs were excluded, as were patients without 1-year PROMs or otherwise missing baseline or 1-year PSS data. The calendar year of 2018 was chosen to allow a comprehensive look at all surgeons performing RCR surgery at all 13 CCHS hospitals and surgery centers which participated in the OME data collection program. We assumed non-completion of 1-year PROMs up and other missing data mechanisms were random and independent of outcome conditional on the modeled predictors.

Variable selection

The primary study outcome was "1-year PSS improvement," that is, the difference between 1-year and baseline total PSS. Fourteen preoperative patient- and disease-specific factors were identified *a priori* as possible confounders of the effects of surgeon on 1-year PSS improvement. These included eight general patient factors (age, sex, race, body mass index (BMI), smoking status, years of education, mental health status (VR-12 MCS), and baseline PSS), and six disease-specific factors (superior-posterior RC tear size, RCR technique, subscapularis status, biceps status, glenoid/humeral head cartilage status, and adhesive capsulitis treatment)[8,25,26] (Table I). Patient Acceptable Symptom State (PASS) at 1 year, return to work by 1 year, and additional surgery during the 1 year following RCR were collected as secondary outcomes.

Table I
Baseline general patient- and disease-specific characteristics of 518 patients undergoing primary superior-posterior rotator cuff tendon repair.

	Value
General patient characteristics	
Age (y)*	61 (55-67)
BMI*	29.4 (26.1-33.8) (n = 352)
Education (y)*	14 (12-16)
VR-12 MCS*	53.9 (45.8-60.5)
PSS*	41.9 (31.9-53.9)
Sex	
Female	209 (40.3%)
Male	309 (59.7%)
Race	
White	445 (85.9%)
Black	45 (8.7%)
Other	28 (5.4%)
Smoking status	
Never	289 (55.8%)
Quit	172 (33.2%)
Current	57 (11.0%)
Disease-specific characteristics	
RC tear size[9]	
Large/Massive	202 (39.0%)
Medium	237 (45.8%)
Small	79 (15.2%)
RCR technique	
Double row	323(62.4%)
Single row	195 (37.6%)
Subscapularis status	
Normal/not repaired	449 (86.7%)
Repaired	69 (13.3%)
Bicep status	
Normal/Débrided/No treatment	314 (60.6%)
Tenotomy/Tenodesis	204 (39.4%)
Glenoid/humeral cartilage status	
Both normal/G1/G2	478 (92.3%)
G3/G4	40 (7.7%)
Adhesive capsulitis	
None/No treatment	502 (96.9%)
Yes	16 (3.1%)

BMI, body mass index; *VR-12 MCS*, Veterans RAND 12-Item Health Survey mental component score; *PSS*, Penn Shoulder Score; *RC*, rotator cuff; *RCR*, rotator cuff repair.
*Results are presented as median (quartiles) for numeric variables, and counts (%) for categorical variables.

Statistical analysis

Continuous variables were described by median (quartiles) and categorical variables by frequency counts and percentages. Missing data were multiply (k = 20) imputed using multivariate imputation by chained equations, an iterative fully conditional approach (mice R package[3]). These data sets were analyzed in parallel and fixed effects inference results were pooled in the usual manner using Rubin's method.[24]

Initially, 1-year PSS improvement was examined using a fixed effect Gaussian linear model with maximum likelihood estimation. No data-driven variable selection was performed and all 14 prospectively chosen patient and disease factors were included as model covariates, assuming no surgeon effect. Age, BMI, years of education, VR-12 MCS, and baseline PSS were treated as continuous variables. Because the number of degrees of freedom (df) allowed in

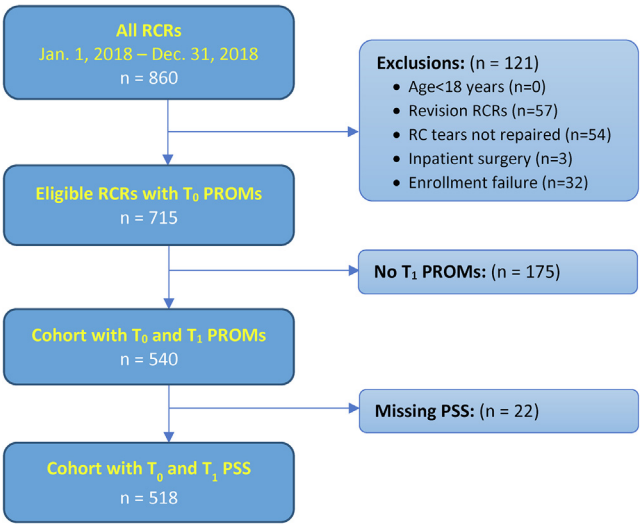

Figure 1 Flowchart of the inclusion and exclusion of rotator cuff repair patients. *PROMs*, patient-reported outcome measures; *PSS*, Penn Shoulder Score; *RCR*, rotator cuff repair.

multivariable analysis is limited by the cohort size,[23] the sample counts for categorical variables were assessed *a priori* for appropriate opportunities to group clinically similar categories or ones likely to be too small to allow identification of distinguishable effects (Table I). For example, glenoid and humeral head cartilage statuses were each reduced to little or no arthritis (normal/grade 1/grade 2) vs. significant arthritis (grade 3/grade 4) based on the Outerbridge classification.[19] Trichotomous predictors (race, smoking status, RC tear size) were incorporated categorically with omnibus 2 df tests used for primary inference, and other categories compared descriptively against reference categories of white, nonsmokers, and small tear size, respectively. Model results were summarized by estimated differences in PSS improvement between levels of each predictor, with their 95% confidence intervals (CIs) and *P* values. The predictive abilities of these models were measured by bootstrapped bias-corrected R^2. The relative importances of each variable in explaining variation in 1-year PSS improvement were assessed by the basic method of calculating and ranking the increases in Akaike's Information Criterion (AIC)[12] upon removal of the respective variables individually from the full model.

To assess the extent of variability between outcomes of different surgeons that was unaccounted for by the 14 modeled patient and surgical factors, for each imputation we augmented the preceding fixed effects model with random surgeon intercepts, estimated the surgeon variance component, used a parametric bootstrap[18] of the likelihood ratio statistic to test its statistical significance, and summarized the results across imputations. Finally, we replaced the surgeon random effects with the number of RCR surgeries performed by each surgeon during 2018 as a fixed covariate and tested for a trend of 1-year PSS improvement with increasing surgeon case volume.

All statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria).[30] All testing was two-sided and considered significant at the 5% level ($P < .05$).

Results

A total of 860 cases undergoing primary RCR at 13 CCHS hospitals and surgery centers between January 2018 and December 2018 were captured in the OME database (Fig. 1). 121 of these cases were excluded because they either had a revision repair (n = 57), a superior-posterior RC tear that was not repaired (n = 54), inpatient surgery (n = 3) or enrollment failure (n = 24), leaving 715 eligible cases. Another 175 cases did not complete 1-year PROMs. Among the 540 eligible cases that completed 1-year PROMs, twenty-two cases had missing baseline or 1-year PSS data, and there were ultimately 518 of 715 (72.4%) cases available for 1-year investigation.

General patient- and disease-specific characteristics

Table I presents the general patient- and disease-specific characteristics of those 518 patients. Baseline BMI data were missing in 173 patients and multiply imputed. Patients had a median age of 61 years, BMI of 29.4, 14 years of education, VR-12 MCS of 53.9, and baseline PSS score of 41.9 points. Patients were predominantly white (85.9%), male (59.7%), undergoing double-row repair (62.4%) of a medium-sized (45.8%) tear. 44.2% were current or former smokers. Most cases had a subscapularis tendon that was normal or not repaired (86.7%); a biceps that was normal, not treated or treated only by débridement (60.6%); little or no arthritis on the glenoid or humeral head (92.3%); and no adhesive capsulitis requiring treatment (96.9%). 28 surgeons performed the 518 cases with individual case volumes ranging from 1 to 69 (median, IQR: 30, 17-46) (Supplementary Table S1). Of the 28 surgeons, 18 were fellowship trained in shoulder, hand, or sports surgery and had 15 ± 11 years of experience. Ten surgeons were not fellowship trained and had 24 ± 10 years of experience.

1-year outcomes

Median (quartiles) were 42 (29.1-55.3) points for 1-year PSS improvement and 90.2 (77-97) points for 1-year PSS. 93% of 518 patients with baseline and 1-year PSS data demonstrated improvement in PSS of at least the 11.4-point minimal clinically important difference (MCID)[14] and 83% of 437 respondents to the PASS question had reached an acceptable state at 1 year. In addition, 86% of 326 employed patients returned to work and only 1% of 518 patients (n = 5) required additional surgery during the 1 year following RCR.

Multivariable analyses

Table II displays mutually adjusted estimates for 1-year PSS improvement in patients undergoing RCR, with 95% CIs and *P* values for each predictor. The 14 general patient- and disease-specific factors accounted for 25% of the variability (adjusted R^2) in 1-year PSS change. Baseline PSS and VR-12 MCS were the only statistically significant and also the dominant predictors of 1-year PSS improvement as indicated by Akaike's Information Criterion comparisons (Fig. 2). Other predictors held constant, 1-year PSS improvement increased approximately three points per four points lower baseline PSS, and one point per three points higher baseline VR-12 MCS.

Surgeon influence

Surgeon was not found to be significantly associated with 1-year PSS improvement (estimated variance component <0.001 with $P > .3$ in each imputed dataset). Replacing the surgeon random effect with a fixed case volume covariate had negligible effects on other model parameters and case volume was not significantly associated with 1-year PSS improvement (estimate: 0.37 points for change from the 25th to the 75th percentile of case volume, 95% CI: −1.89, 2.63, $P = .75$; Supplementary Table S2). Other predictors

Table II
Multivariable test results for 1-y PSS improvement in 518 patients undergoing primary superior-posterior rotator cuff tendon repair.

Factor	Level	1-y PSS improvement	
		Estimate (95% CI)	*P* value
Age*	75th percentile (vs. 25th percentile)	−0.19 (−2.15, 1.76)	.846
BMI*	75th percentile (vs. 25th percentile)	−1.00 (−3.08, 1.07)	.342
Education*	75th percentile (vs. 25th percentile)	1.13 (−1.20, 3.46)	.342
Baseline VR-12 MCS*	75th percentile (vs. 25th percentile)	5.08 (2.96, 7.20)	<.001†
Baseline PSS*	75th percentile (vs. 25th percentile)	−16.23 (−18.47, −13.98)	<.001†
Sex	Female (vs. male)	0.36 (−2.70, 3.43)	.816
Race	Black (vs. white)	−2.75 (−8.15, 2.64)	.085
	Other (vs. white)	−6.73 (−13.14, −0.31)	
Smoking	Quit (vs. never)	1.18 (−2.06, 4.42)	.358
	Current (vs. never)	−2.5 (−7.57, 2.58)	
RC tear size	Medium (vs. small)	−0.79 (−5.46, 3.87)	.52
	Large/Massive (vs. small)	−2.38 (−7.29, 2.52)	
RCR technique	Double (vs. single)	0.74 (−2.59, 4.06)	.664
Subscapularis status	Repaired (vs. normal/not repaired)	−0.68 (−5.15, 3.8)	.768
Biceps status	Tenotomy/Tenodesis (vs. normal)	−2.67 (−5.78, 0.43)	.092
Glenoid/humeral cartilage status	Other (vs. both normal/G1/G2)	−4.47 (−10.01, 1.06)	.114
Adhesive capsulitis	Treated (vs. normal/none)	1.82 (−6.64, 10.28)	.672

PSS, Penn Shoulder Score; *CI*, confidence interval; *BMI*, body mass index; *VR-12 MCS*, Veterans RAND 12-Item Health Survey mental component score; *RC*, rotator cuff; *RCR*, rotator cuff repair.
*The effects for numeric variables compare the 75th to the 25th percentiles shown in Table I.
†Statistically significant.

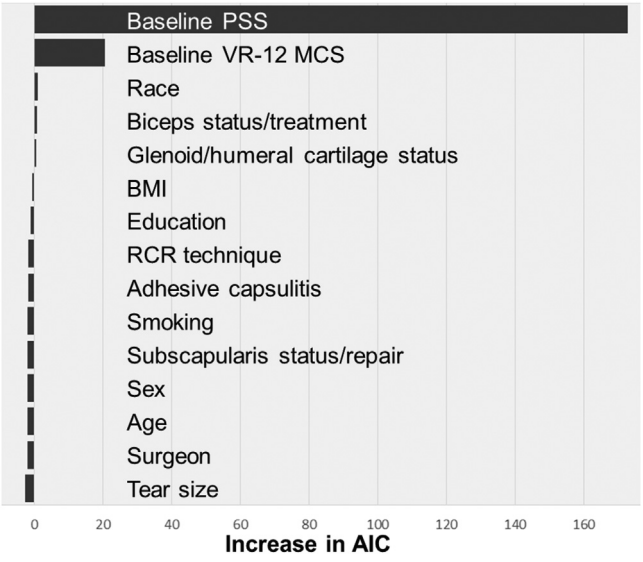

Figure 2 Variable importance of general patient- and disease-specific factors for 1-year PSS improvement. Baseline PSS and baseline VR-12 MCS contributed far more than other factors, none of whose contributions reached statistical significance. *PSS*, Penn Shoulder Score; *VR-12 MCS*, Veterans RAND 12-Item Health Survey mental component score; *BMI*, body mass index; *RCR*, rotator cuff repair; *AIC*, Akaike's Information Criterion.

held constant, 1-year PSS improvement increased approximately 0.13 points per 10 cases increase in surgeon case volume.

Discussion

This study's purpose was to investigate the extent to which surgeons influence 1-year PROMs in patients undergoing primary RCR. We analyzed data from RCRs performed by 28 different surgeons with varying case volumes in 13 hospitals and surgery centers in our tertiary health system and found no indication that the individual surgeon had a substantial effect on 1-year improvement in PSS following primary RCR after controlling for general patient- and disease-specific factors.

We have previously demonstrated using baseline data from our health system that surgeons' training, experience, and/or inherent practice patterns primarily define their RCR surgical methods.[8] Lower surgeon case volume has also been reported to be associated with worse outcomes (increased length of stay, increased operating room time, and increase in reoperation rate) following RCR.[34] However, results from the current study suggest that despite differences in surgical method, 1-year patient-reported outcomes following RCR remain consistently excellent and are not related to the surgeon (or their case volume). PSS increased by 42.0 (29.1, 55.3) points from baseline values of 41.9 (31.9, 53.9) to 1-year values of 90.2 (77, 97) points. 93% of patients demonstrated PSS improvement exceeding its MCID[14] and 83% reached an acceptable state (based on PASS) at 1 year. In addition, 86% of employed patients returned to work and only 1% of patients required additional surgery during the 1 year following RCR.

Baseline PSS and VR-12 MCS were the only statistically significant predictors for 1-year PSS improvement. Our findings indicate that patients with worse preoperative shoulder status experience more improvement following RCR, presumably reflecting more room for improvement in patients undergoing a procedure that generally leads to very favorable 1-year patient-reported outcomes. Our findings also indicate that patients with higher mental health scores at surgery experience more improvement in outcomes following RCR, even after adjusting for the effect of baseline PSS. This finding, together with a prior study showing that a higher baseline mental health score was the most prominent factor associated with a higher baseline PSS,[27] is in agreement with several previous studies that have shown baseline mental health status to be closely associated with shoulder pain and disability at baseline[2,4,5,7,20,36,37] as well as with outcomes following RCR.[10,21,33,35] Additional longitudinal studies with more rigorous psychological evaluations are needed to fully understand the relationships between baseline mental health status and outcomes after RCR.

The strength of this study is the comprehensive nature of data collection and robust statistical methodology that assessed the surgeon both as a random-effect (viewing participating surgeons as representative of broader surgeon population) and also in terms of

case volume (as a surrogate for surgeon experience). The study also has noteworthy limitations. *First*, we only evaluated 1-year PSS following RCR in patients within a single tertiary health system. Therefore, our results may not extrapolate to other PROMs, longer-term outcomes, or other health care systems. However, in a recent meta-analysis,[28] we have shown that several shoulder-specific PROMs (American Shoulder and Elbow Surgeons [ASES], Constant, and/or Western Ontario Rotator Cuff [WORC] scores) demonstrate only very small gains below MCIDs between 1 and 2 years following RCR, suggesting that patient-reported outcomes for RCR can be accurately assessed at 1 year. *Second*, the surgeon variable may be more reflective of the surgeon's practice environment, for example, case volume, payer mix, geographic location, referral patterns, patient socioeconomic factors, and postoperative physical therapy protocol, than of individual surgeon technical abilities. We investigated case volume, but other potentially associated factors were not investigated in this study. *Third*, the study did not assess structural outcomes (e.g., preoperative and postoperative fatty infiltration and muscle atrophy, postoperative retear assessed by magnetic resonance imaging/ultrasound,[15] tendon retraction by CT[13]), functional outcomes (strength and range of motion), or other patient factors (e.g., preoperative opioid use, socioeconomic status, workers' compensation claim) that could potentially influence RCR outcomes. Hence it cannot be definitively concluded that the surgeon does not significantly influence the structural or functional RCR outcomes. *Finally*, our analysis is confined to the 72.4% of patients who completed 1-year PSS, and its estimated effects are susceptible to bias if non-completion of 1-year PSS was influenced by 1-year outcomes or by potential confounders either measured (Table II) or not.

Conclusions

Patients generally reported excellent 1-year outcomes following primary RCR in a large academic tertiary referral employed hospital system. One-year PSS improvement was significantly associated with patient baseline shoulder status and mental health status but not with individual surgeon or surgeon case volume after adjustment for these and other baseline patient- and disease-specific characteristics. Only 25% of the variation in 1-year PSS improvement was explained by modeling, suggesting that the study of additional relevant patient and surgical factors, potentially in larger cohorts, is needed to learn to accurately predict RCR outcomes.

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Supplementary data

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