



Tear characteristics and surgeon influence repair technique and suture anchor use in repair of superior-posterior rotator cuff tendon tears

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Background: The factors that associate with surgical decisions about repair technique and the number of suture anchors used in rotator cuff repair have not been previously investigated. This study investigated the extent to which patient, surgeon, and surgical factors associate with performing single-row vs. double-row repair technique and ultimately with the number of suture anchors used.

Methods: Our institution's prospective surgical cohort was queried for patients undergoing suture anchor repair of superior-posterior rotator cuff tendon tears between February 2015 and August 2017. Exclusion criteria were patients with isolated subscapularis tears, tears that were not repaired, repairs without suture anchors, repairs involving graft augmentation, and repairs by surgeons with fewer than 10 cases. Multivariable statistical modeling was used to investigate associations between patient and surgical factors and the choice of repair technique and number of suture anchors used.

Results: A total of 925 cases performed by 13 surgeons met inclusion criteria. Tear type (full thickness), tear size (medium, large, and massive), a greater number of torn tendons, repair type (arthroscopic), and surgeon were significantly associated with performing a double-row over a single-row repair. Tear size, a greater number of torn tendons, double-row repair technique, and surgeon were significantly associated with a greater number of anchors used for repair.

Conclusions: Our findings suggest that in the absence of data to conclusively support a clinical benefit of one repair technique over another, surgeons' training, experience, and inherent practice patterns become the primary factors that define their surgical methods.

Level of evidence: Level III; Cross-Sectional Design; Epidemiology Study

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Keywords: shoulder; rotator cuff; double-row repair; single-row repair; suture anchor; surgeon variation; multivariable model; variation in clinical practice

This study used 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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Musculoskeletal diseases are the leading cause of disability and health care costs in the USA and affect 1 of every 2 adults. Annually in the USA, \$874 billion is spent on health care for persons with musculoskeletal disease, representing 5.7% of GDP.²⁶ In an era of rising health care costs and accountability for health care expenses, understanding the costs, cost-effectiveness, and factors that drive cost in musculoskeletal care is critical to implementing strategies to reduce costs while maximizing the effectiveness (value) of health care dollars spent.

In particular, rotator cuff disease is a common musculoskeletal problem in the USA, with more than 250,000 rotator cuff repairs performed annually.⁵ Rotator cuff repair in general has been shown to be cost-effective to the patient (by standard cost-effectiveness ratios)²⁸ and produces net societal cost savings when considering direct and indirect costs of treatment.¹⁵

There is, however, currently no consensus on the most effective and least costly way to repair a torn rotator cuff, and costs vary depending on the surgical techniques used. In particular, a recent systematic review and meta-analysis of *in vitro* biomechanical studies demonstrates that double-row repairs have superior biomechanical properties (significantly greater load to failure and less gap formation) than single-row repairs.¹¹

Clinical data remain mixed on the benefit of double-row fixation on patient-reported and structural outcomes. Recent meta-analyses and systematic reviews conclude that double-row repairs have higher structural healing rates than single-row repairs.^{3,16,19,23,31-33} Despite improved healing with double-row fixation, no clinical differences were seen between single-row and double-row repairs after follow-up ranging from 12 to 36 months, particularly in patients with small-sized to medium-sized tears (<3 cm).^{3,16,18,19,22,23,31-33} Yet in patients with large or massive tears (>3 cm), some studies have shown superior clinical outcomes associated with double-row compared with single-row repair technique.^{3,31-33}

Double-row repair methods are more time-consuming⁸ and use more suture anchors compared similar tears treated with single-row methods.^{1,6,16,31} Because suture anchors represent the greatest material expense in the total direct cost of rotator cuff repair,^{17,24,25} the cost of performing double-row repair is greater than the cost of single-row repair.^{1,4,9,17,25} Although one recent cost-effectiveness analysis demonstrated superior cost-effectiveness of double-row fixation only for larger tears (>3 cm),¹² other analyses have demonstrated that the increased cost of double-row repair is not offset by a commensurate increase in quality of life compared with single-row repair.^{1,9} More complete and accurate data on tear characteristics, number of anchors used, operative time, actual costs, patient-reported outcome scores, and rates of revision surgery are needed to improve the assumptions in cost-effectiveness models so as to more conclusively assess the value (outcome/cost) and indications of the more time consuming and costly double-row repair technique.

Although the double-row repair technique has been investigated from a cost and cost-effectiveness perspective, the

factors that associate with surgical decisions about repair technique and more fundamentally the number of suture anchors used in rotator cuff repair have not been previously investigated. Hence the purpose of this study was to investigate the extent to which preoperative patient and intraoperative surgical factors, including the individual surgeon as an independent factor, associate with the choice of performing single-row vs. double-row repair technique and, ultimately, with the number of suture anchors used in rotator cuff repair. Our investigation was limited to surgeons from a single institution and to repair of superior-posterior rotator cuff tendon tears, defined as a tear of the supraspinatus, infraspinatus, or teres minor tendons, or a combination of these. We hypothesized that tear characteristics and the individual surgeon would be associated with the variation in repair technique and suture anchor use in superior-posterior rotator cuff repair.

Materials and methods

Orthopaedic Minimal Data Set Episode of Care

This study used the Cleveland Clinic's Orthopaedic Minimal Data Set Episode of Care (OME) prospective surgical cohort.^{20,29} The OME cohort collects demographic factors, joint-specific intraoperative surgical variables of disease severity and treatment, and joint-specific validated patient-reported outcome measurements at baseline and 1 year postoperatively for elective orthopedic procedures of the knee, hip, and shoulder, ranging from arthroscopy to total joint replacement. Data are electronically collected via tablet for the patient and via smartphone for the surgeon and are stored in a secure Research Electronic Data Capture (REDCap)¹⁰ database.

Rotator cuff repair surgical cohort

The OME cohort was retrospectively queried for patients undergoing rotator cuff repair between February 2015 and August 2017. Inclusion criteria were patients undergoing suture anchor repair of superior-posterior rotator cuff tendon tears, defined as a tear of the supraspinatus, infraspinatus, or teres minor tendons, or a combination of these. Exclusion criteria were patients with isolated subscapularis tears, superior-posterior tears that were not repaired, repairs that did not use suture anchors (ie, repairs using bone tunnels and sutures), repairs involving graft augmentation, and repairs performed by surgeons with fewer than 10 cases.

We extracted 17 preoperative patient and intraoperative surgical factors from the OME registry to descriptively assess the eligible cohort. These included demographic (age, sex, body mass index [BMI], smoking status, education level), disease severity (prior shoulder surgery, tear type, tear size, number of torn tendons, surgery type, Penn Shoulder Score), and treatment (repair type, repair technique, type of anchor, anchor manufacturer, number of concomitant soft tissues repaired, and surgeon) factors (Table 1^{7,30}).

Statistical modeling

Multivariable statistical modeling was performed on the eligible cohort to investigate the extent to which the extracted patient and surgical factors associated with (1) the choice of performing a single-row

Table I Variation in the preoperative and intraoperative characteristics and suture anchor use for patients undergoing superior-posterior rotator cuff tendon repair

Variable	Category or range	Cases		Anchors
		No.	(%)	Mean (SD) No.
Demographics				
Age, yr	<50	172	19	2.7 (1.4)
	50-55	161	17	2.6 (1.3)
	55-60	202	22	2.8 (1.3)
	60-65	163	18	2.9 (1.2)
	65 +	227	25	3.0 (1.3)
Sex	Male	559	60	2.9 (1.4)
	Female	366	40	2.6 (1.3)
Body mass index, ¹⁹ kg/m ²	<18.5 (underweight)	5	1	2.4 (0.9)
	18.5-24.9 (normal)	163	17	2.7 (1.3)
	25.0-29.9 (preobese)	349	38	2.8 (1.4)
	30.0-34.9 (obese I)	222	24	2.8 (1.3)
	35.0-39.9 (obese II)	103	11	2.8 (1.3)
	≥ 40.0 (obese III)	74	8	2.9 (1.2)
Smoking status	Data not available	9	1	3.6 (0.5)
	Never	445	48	2.8 (1.3)
	Quit	303	33	2.9 (1.3)
	Current	147	16	2.7 (1.4)
Education level, yrs	Data not available	30	3	2.7 (1.2)
	<8	15	2	2.5 (1.3)
	8-12	363	39	2.8 (1.3)
	12-16	391	42	2.7 (1.3)
	>16	126	14	3.0 (1.4)
	Data not available	30	3	2.7 (1.2)
Disease state				
Prior shoulder surgery	No	814	88	2.8 (1.3)
	Yes	111	12	2.8 (1.5)
Tear type	Partial	167	18	2.2 (1.4)
	Full	758	82	2.9 (1.3)
Tear size ⁸	Small (<1 cm)	122	13	1.2 (0.6)
	Medium (1-3 cm)	418	45	2.7 (1.1)
	Large (3-5 cm)	290	31	3.5 (1.2)
	Massive (>5 cm)	95	10	3.4 (1.3)
No. of torn superior-posterior rotator cuff tendons (supraspinatus, infraspinatus, teres)	1	567	61	2.4 (1.2)
	≥2	358	39	3.5 (1.2)
Surgery type	Primary	861	93	2.8 (1.3)
	Revision	64	7	2.9 (1.5)
Penn Shoulder Score	<25	479	52	2.9 (1.4)
	26-50	396	43	2.7 (1.3)
	51-75	18	2	3.0 (1.1)
	>75	0	0	NA
	Data not available	32	3	2.8 (1.2)
Treatment				
Repair type	Arthroscopic	877	95	2.8 (1.3)
	Mini-open	18	2	1.9 (1.0)
	Standard open	30	3	2.9 (1.2)
Repair technique	Single row	361	39	1.6 (0.8)
	Double row			
	Standard	214	23	3.2 (1.2)
	Suture-bridge	236	26	3.7 (0.8)
	Standard and suture-bridge	114	12	3.9 (0.8)
Type of anchor	Polymer (biodegradable and non-biodegradable)	419	45	2.3 (1.1)
	Biocomposite	209	23	2.8 (1.5)
	Metal	49	5	2.3 (1.2)
	Multiple	111	12	4.1 (0.9)
	Other	137	15	3.5 (1.1)

(Continued on next page)

Table I (Continued)

Variable	Category or range	Cases		Anchors	
		No.	(%)	Mean (SD) No.	
Anchor manufacturer	Arthrex	665	72	2.6 (1.2)	
	DePuy-Mitek	38	4	2.4 (1.2)	
	Smith & Nephew	32	3	1.6 (0.6)	
	Multiple	131	14	4.2 (0.9)	
	Other	59	6	3.0 (1.2)	
No. of concomitant soft tissues repaired (biceps, subscapularis, labrum, capsule)	0	347	38	2.7 (1.3)	
	1	359	39	2.8 (1.4)	
	2	191	21	3.0 (1.2)	
	≥3	28	3	2.4 (1.3)	
	Surgeon	1	145	16	2.2 (1.2)
		2	186	20	3.4 (1.3)
		3	133	14	1.9 (1.1)
		4	88	10	2.8 (1.4)
		5	79	9	3.8 (0.8)
		6	61	7	2.6 (1.1)
		7	54	6	2.7 (1.2)
		8	46	5	4.5 (1.1)
		9	44	5	2.9 (1.4)
10		33	4	2.2 (1.1)	
11	23	2	2.9 (1.4)		
12	17	2	3.4 (0.9)		
13	16	2	1.9 (0.9)		

SD, standard deviation; NA, not applicable.

vs. double-row repair technique and with (2) the number of suture anchors used for rotator cuff repair. Of the 17 patient and surgical factors, 13 were prospectively considered likely to influence repair technique or suture anchor usage and were included as model covariates (Table II). Age and BMI were treated as continuous variables.

Because the number of degrees of freedom allowed in statistically rigorous multivariable analysis is limited by the size of the cohort, the sample counts for the remaining 11 factors of interest were subsequently assessed a priori for clinically appropriate opportunities to perform categoric binning (Table II). For example, the factor, “concomitant repair of other soft tissue structures (eg, biceps, subscapularis, labrum, capsule),” was reduced to a number—1, 2, or 3 or more—to investigate whether the total number of additional procedures affected anchor use because of increased time or case complexity. Similarly, all double-row repair techniques (standard, suture-bridge, combination standard and suture-bridge) were binned into 1 category in the statistical model because our clinical interest was to determine whether using double-row repair affected anchor use, not the influence of a specific double-row repair technique. Binning was also performed when the frequency of events within a given category was too low to allow for multivariable analysis of certain factors. For example, the involved tendons (eg, supraspinatus, infraspinatus, teres minor) were reduced to 2 numeric categories—1 or 2 or more—because the frequency of cases involving 3 tendons was too low to model.

Statistical analyses were performed using R 3.2.3 (2015-12-10) software (The R Foundation for Statistical Computing, Vienna, Austria). For modeling purposes, missing values for BMI (n = 9) and smoking status (n = 30) were imputed using multivariate imputation by chained equations (MICE) via the R package mice.²⁷ All testing was 2-sided and considered significant at the 5% level ($P < .05$).

Table II Multivariable predictors and their respective categories or ranges used in statistical models

Predictor	Category or range
Demographic	
Age	Continuous
Body mass index	Continuous
Sex	Male, female
Smoking status	Never, quit, current
Disease state	
Prior shoulder surgery on affected arm	No, yes
Tear type	Partial-thickness, full-thickness
Tear size	Small, medium, large, massive
No. of torn superior-posterior rotator cuff tendons (supraspinatus, infraspinatus, teres)	1, 2, or more
Surgery type	Primary, revision
Treatment	
Repair type	Open (standard, mini), arthroscopic
Repair technique	Single row, double row (standard, suture-bridge, combination standard and suture-bridge)
No. of concomitant soft tissues repaired (biceps, subscapularis, labrum, capsule)	0, 1, 2, 3, or more
Surgeon	1-13

Statistical modeling—choice of single-row or double-row repair

Multivariable modeling was performed using a generalized linear mixed model to determine factors that influence the choice of repair technique (single-row vs. double row repair). Excepting repair technique, the other 12 factors listed in [Table II](#) were investigated as covariates in the model. We computed 95% confidence intervals for the model's parameters after bootstrap resampling to 500 iterations. The *surgeon* variable was treated as a random effect to assess the variability among individual surgeons with respect to repair technique, after adjusting for all other covariates. The other 11 variables were treated as fixed effects to determine the odds ratio of performing a double-row repair vs. a single-row repair compared with the reference category for that variable, after adjusting for all other covariates.

Statistical modeling—number of anchors used

Multivariable modeling was performed using a zero-truncated Poisson regression model (because the response variable “number of anchors” cannot be 0) to determine factors that influence the number of anchors used for rotator cuff repair. All 13 factors listed in [Table II](#) were investigated as covariates and treated as fixed effects in the model. Best-subsets model selection¹⁴ was implemented to find the most parsimonious model containing the most important predictors.

Using Akaike's information criterion (AIC) as the model selection metric, every combination of covariates was searched ($2^{13} = 8192$ models) to find the best-fitting model with only the variables yielding the smallest value of AIC. For each variable in the best-fit model, the fold-change in the average number of anchors used, compared with the reference category for that variable, was determined after adjusting for all other covariates in the best-fit model. Ten-fold cross-validation¹⁴ was used to obtain predicted anchor counts for every patient to assess how well the best-fit model predicted the total number of anchors.

Results

Cleveland Clinic's OME cohort contained preoperative patient demographics and intraoperative surgery data on 1176 rotator cuff repairs performed by 18 surgeons at 7 Cleveland Clinic facilities between February 2015 and August 2017, representing 100% of the patients eligible for OME data collection and undergoing rotator cuff repair during that time ([Fig. 1](#)). We excluded 53 of these cases because they were isolated subscapularis repairs (ie, not repairs of the superior-posterior rotator cuff [$n = 40$]), or because the tear was not repaired ($n = 13$). Another 198 cases were excluded because the surgeon did not use suture anchors ($n = 162$), used graft augmentation ($n = 21$), or the surgeon had performed fewer than 10 cases ($n = 15$). There were ultimately 925 cases performed by 13 surgeons available for investigation. All 13 surgeons were 5 or more years into practice, and 12 of 13 (92%) were fellowship trained, with 10 of these 12 (83%) in sports or shoulder surgery, or both.

Variation in the clinical practice of superior-posterior rotator cuff tendon repair

[Table I](#) describes the variation in the preoperative characteristics and suture anchor use for patients from the OME cohort who underwent superior-posterior rotator cuff tendon repair and met inclusion criteria. Specifically, [Table I](#) reports the frequency of cases performed for each variable and the mean number of anchors used for those cases by variable. Most of the 925 cases performed were arthroscopic (95%), primary (93%) repair of full-thickness tears (82%) in patients who had not had prior shoulder surgery (88%). Double-row repairs using standard technique (23%), suture-bridge (26%), or a combination of the techniques (12%) were collectively performed

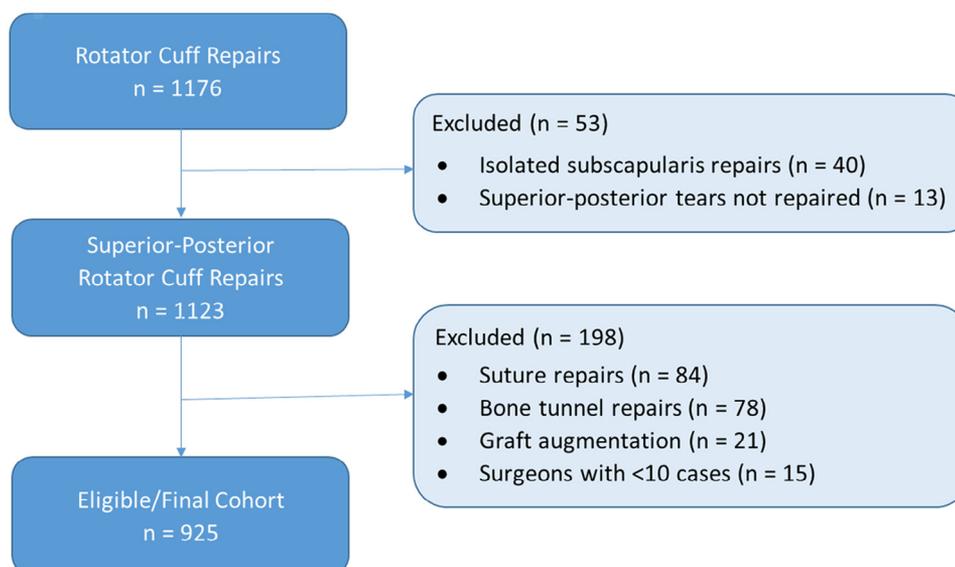


Figure 1 Flowchart of the inclusion and exclusion of rotator cuff repair patients.

more commonly than single-row repairs (61% vs. 39%). Polymer anchors were used most commonly (in 45% of cases), and more than 70% of repairs used anchors from the same single company. Although not common, multiple anchor types (12%) and manufacturers (14%) were used in a small percentage of cases, and these cases appeared to be associated with greater anchor usage (Table I). Surgeons varied widely in their anchor usage, averaging between 1.9 and 4.5 anchors per case.

Single-row or double-row repair

The statistical model for repair technique showed that 5 variables—tear type (full-thickness tears), tear size (medium, large, and massive tears), a greater number of torn tendons, repair type (arthroscopic repairs), and surgeon—were significantly associated with performing a double-row repair over a single-row repair, after adjusting for all other model variables. Table III provides the 95% confidence intervals for the adjusted odds ratios for double-row vs. single-row repairs, for the 11 factors treated as fixed effects. For example, on average, the odds of performing a double-row vs. single-

Variable/range or category	95% confidence interval of adjusted odds ratio
Age	(0.99-1.03)
Sex	Male —
	Female (0.78-2.01)
Body mass index	(0.96-1.02)
Smoking status	Never —
	Quit (0.57-1.55)
	Current (0.97-3.67)
Prior shoulder surgery	Yes —
	No (0.27-1.77)
Tear type	Partial —
	Full (1.46-4.81)*
Tear size	Small —
	Medium (8.41-30.57)*
	Large (7.85-47.47)*
	Massive (2.46-16.61)*
No. of torn superior-posterior rotator cuff tendons	1 —
	≥2 (1.43-4.71)*
Surgery type	Primary —
	Revision (0.17-1.48)
Repair type	Open —
	Arthroscopic (2.63-33.3)*
No. of concomitant soft tissues repaired (biceps, subscapularis, labrum, capsule)	0 —
	1 (0.39-1.09)
	2 (0.51-1.84)
	≥3 (0.12-1.45)

Intervals that do not contain 1 (*) are significantly different from their respective reference category at a 0.05 significance level.

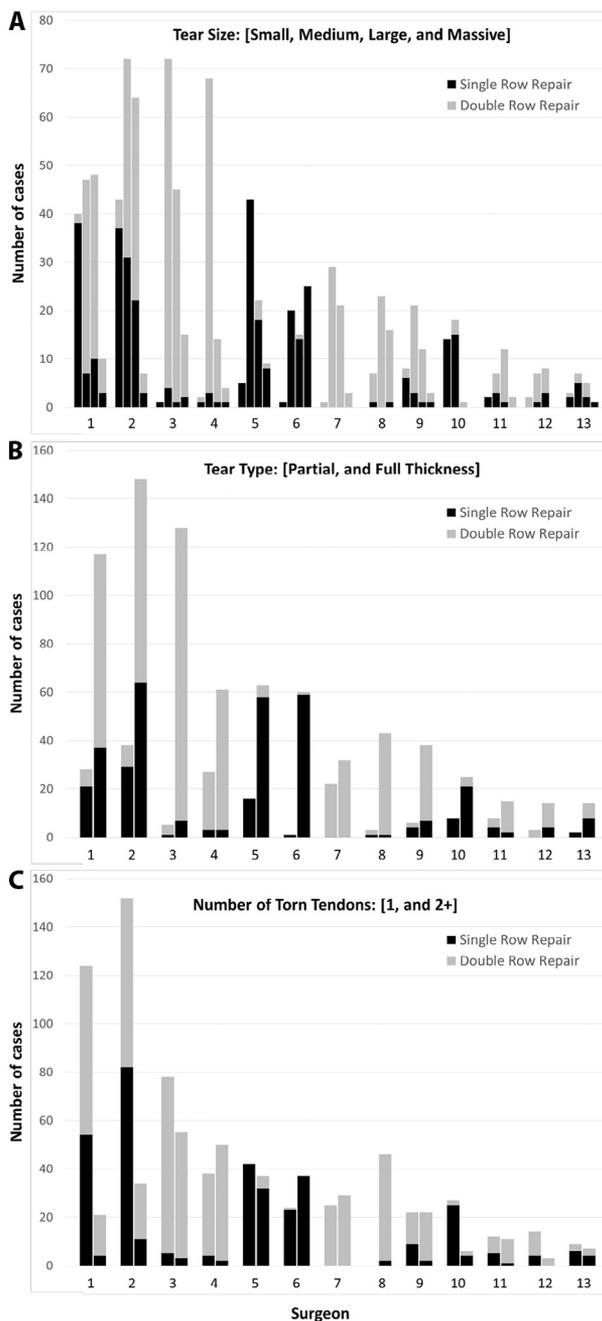


Figure 2 The number of single-row vs. double-row repairs performed by each surgeon based on tear characteristics of (A) size, (B) type, and (C) number of torn tendons.

row repair were between 1.46- and 4.81-times greater for a full-thickness tear than for a partial-thickness tear. Because “surgeon” was a random effect in this model, an odds ratio could not be computed and the significant finding can be interpreted simply as indicating that there is individual variation between surgeons in the odds of performing double-row repairs compared with the overall average.

Fig. 2 demonstrates the model findings empirically by graphically depicting the number of single-row vs. double-row repairs performed by individual surgeons for each of the

significant model variables related to tear characteristics: tear size (Fig. 2, A), tear type (Fig. 2, B), and number of torn tendons (Fig. 2, C). Inspection of Fig. 2 reveals that the choice of single-row vs. double-row repair technique varied with surgeon preference as well as tear characteristics. For example, surgeons 3, 4, 7, and 8 almost exclusively performed double-row repairs, and surgeons 5, 6 and 10, almost exclusively performed single-row repairs, regardless of the tear size, tear type, or numbers of tendons involved. Other surgeons (eg, 1, 2 and 9) performed both single-row and double-row repairs across all tear characteristics, with generally increasing use of double-row technique.

Number of anchors used

Suture anchor use for repair of superior-posterior rotator cuff tendon tears averaged 2.80 ± 1.32 (range, 1-7; Table I, Fig. 3). Table I demonstrates empirically that small tears and single-row repairs were associated with fewer anchors and that there was variation among surgeons in the average number of anchors used in repairing the superior-posterior rotator cuff. In 93% (861 of 925) of cases, 4 or fewer anchors were used, and in 32% (293 of 925) of cases, 4 anchors were used (Fig. 3).

The best-fitting statistical model for “number of anchors used” contained 5 variables: tear type, tear size, number of tendons, repair technique, and surgeon. The model had an AIC value of 2453 compared with an AIC value of 2473 from the full model containing all 13 variables. The best-fit model was able to explain 71.2% of the variability existing in the overall anchor count distribution based on the cross-validated estimate of the sum of squared errors. Table IV provides the fold-change for the covariates in the best-fit model for “number of anchors used” compared with the reference category for each variable.

A significant association was found for 4 of 5 model parameters—tear size (medium, large and massive tears), a greater number of torn tendons, double row repair technique, and surgeon—with number of anchors used (Table IV).

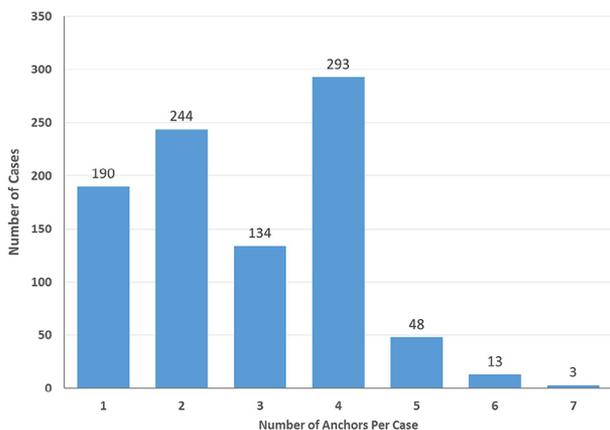


Figure 3 Number of anchors used per case for the repair of superior-posterior rotator cuff tendon tears.

Table IV Fold-change for the number of anchors used compared with the reference category for each variable

Variable/range or category		95% confidence interval of fold-change
Tear type	Partial	—
	Full	(0.97-1.29)
Tear size	Small	—
	Medium	(2.08-4.55)*
	Large	(2.66-5.92)*
	Massive	(3.07-7.10)*
Number of torn superior-posterior rotator cuff tendons	1	—
	≥2	(1.02-1.29)*
Repair technique	Single	—
	Double	(2.52-3.64)*
Surgeon	1	—
	2	(0.84-1.14)
	3	(0.61-0.85)*
	4	(0.95-1.36)
	5	(1.00-1.67)*
	6	(0.73-1.38)
	7	(1.04-1.50)*
	8	(0.58-0.90)*
	9	(0.62-1.02)
	10	(0.95-1.94)
	11	(0.60-1.09)
	12	(0.87-1.59)
	13	(0.39-1.09)

Intervals that do not contain 1 (*) are significantly different from their respective reference category at a .05 significance level.

For example, the estimated average number of anchors used for double-row repairs was between 2.5 and 3.6 times the number of anchors used for single-row repairs, holding all other covariates fixed. Surgeon 1, whose average number of anchors was the median of all surgeons’ averages, was used as the reference category for evaluating the surgeon variable. Surgeons 5 and 7 used significantly more anchors per case (up to 1.67 times), and surgeons 3 and 8 used significantly fewer anchors per case (as few as 0.58 times) than the reference surgeon (Table IV).

Discussion

This study investigated the extent to which preoperative patient and intraoperative surgical factors, including the individual surgeon as an independent factor, associate with the choice of performing single-row vs. double-row repair technique and with the number of suture anchors used in repair of superior-posterior rotator cuff tendon tears. We found that tear type (full-thickness tears), tear size (medium, large, and massive tears), a greater number of torn tendons, repair type (arthroscopic repairs), and surgeon were significantly

associated with performing a double-row repair over a single-row repair.

Although an increased likelihood of performing double-row repair technique in the setting of larger, full-thickness tears involving 2 or more tendons might be intuitively expected, this is the first study to objectively demonstrate these findings from a large, prospectively collected surgical data set. These findings are consistent with an interpretation that surgeons in general may choose the more mechanically robust double-row technique for more severe tears. The increased likelihood of performing a double-row repair technique in the setting of arthroscopic surgery could be a consequence of improved visualization and access for anchor placement in arthroscopic compared with open surgery or practice patterns that indicate open surgery primarily for massive tears with poor tendon quality and severe retraction that are irreparable with arthroscopic double-row techniques.²¹

The extreme skewness in our data toward arthroscopic repairs (95%) could also artificially result in this finding; a larger sample size of mini-open/open repairs would be required to confirm whether this is true. Finally, we note that age, sex, BMI, smoking status, prior shoulder surgery, revision surgery, or number of concomitant soft tissues repaired did not influence the likelihood of performing a double-row repair technique over a single-row technique.

Importantly, we showed that there was significant individual variation among surgeons in the choice of *repair technique* that is irrespective of the tear size, tear type, or numbers of tendons involved. In our cohort of 13 surgeons, some almost exclusively performed double-row repairs, some almost exclusively performed single-row repairs, and others performed both single-row and double-row repairs across all tear characteristics.

This uneven distribution in repair technique prevented “surgeon” from being investigated as a fixed effect in the statistical model, so odds ratios for each surgeon could not be calculated. However, the model did statistically confirm a significant individual variation among surgeons in the odds of performing double-row repairs compared with the overall average. This finding of variation even among experienced surgeons may be explained by the absence of data to conclusively support a clinical benefit of one repair technique over the other,²³ in combination with the surgeons’ training, experience or inherent practice patterns, which become the primary factors that define their surgical methods. Because so few in the surgeon cohort were other than fellowship trained in sports or shoulder surgery, it was not possible to statistically test the influence of fellowship training as an independent factor in this study.

Suture anchor use for repair of superior-posterior rotator cuff tendon tears in our cohort ranged from 1 to 7, with a mean of 2.80 ± 1.32 anchors per case, which is similar to previous reports of suture anchor use in rotator cuff repair.^{2,24,25,31} Tear size (medium, large, and massive tears), a greater number of torn tendons, double-row repair technique, and surgeon were significantly associated with a greater

number of anchors used in the repair. Increased suture anchor use with larger tears involving 2 or more tendons as well as double-row technique are both internally consistent with the results of our first model (that demonstrated an increased likelihood of performing double-row technique for repairing larger tears involving 2 or more tendons) and with clinical practice. It has been well documented that the extra row of fixation with double-row repair results in greater suture anchor use compared with similar sized tears treated with single-row techniques.^{1,6,16,31} Indeed, by holding all other covariates fixed, our model estimated that double-row repairs used 2.5 to 3.6 times the average number of anchors as single-row repairs. Again, although these results might be intuitively expected, this is the first study to objectively demonstrate these findings from a large, prospectively collected surgical data set.

Significant variation in the number of anchors used could also be attributed to the surgeon, after controlling for tear characteristics and repair technique. Specifically, 2 surgeons used significantly more anchors per case (up to 1.67 times), and 2 surgeons used significantly fewer anchors per case (as few as 0.58 times) than the median number. Previously, surgeon variation in procedure costs was shown to be related to case volume in the repair of proximal humeral fractures.¹³ Hence, using our full model with the 13 variables listed in [Table II](#) (AIC, 2473), we explored the role of case volume in influencing the surgeon variation in anchor usage.

We ran the model without *surgeon* or *case volume* (AIC, 2512) and again without *surgeon* but including *case volume* (AIC, 2507). The marginal improvement in AIC with the addition of case volume indicates that case volume only minimally explains the surgeon variation in anchor use, similar to the empirical findings of a prior report.²⁵ Again, the finding of significant variation even among experienced surgeons may be explained by the absence of clinical data to conclusively support a particular surgical approach combined with variation in the training and inherent practice patterns among individual surgeons.

Our data demonstrate that significant variation in the repair technique (single-row vs. double-row) and suture anchors use in superior-posterior rotator cuff repair can be attributed to the individual surgeon. However, our current data do not provide insight into why surgeons choose their particular surgical methods. In future work, we will survey our surgeon cohort to inquire about the rationale around their surgical decision making and compare their responses to their actual practice patterns. We also plan to use multivariable models to investigate the relationship between repair technique, anchor usage, and clinical outcomes at 1 year in this patient cohort, while adjusting for other covariates that may influence outcome. Understanding the extent to which double-row repair technique, and greater suture anchor use in general, associate with clinical outcomes after superior-posterior rotator cuff repair, will provide improved data for cost-effectiveness modeling and evidence-based surgeon education, which may ultimately lead to cost-savings in these procedures.

The present study has several strengths. The data derive from a large prospective cohort ($n = 925$) that captures a wide range of patient and surgical factors relevant to rotator cuff repair surgery. The enrollment rate was 100%, thereby avoiding patient selection bias. A group of patient and surgical factors cited or judged to influence repair technique and suture anchor use were prospectively chosen and used in multivariable models to identify statistically significant associations.

Furthermore, this is the first study, to our knowledge, to determine predictors of repair technique and suture anchor use in a rotator cuff patient population that comprehensively controlled for patient characteristics (age, BMI, sex, and smoking status), disease severity (prior shoulder on the affected arm, tear type, tear size, number of torn tendons, and surgery type) and treatment variables (repair type, number of concomitant soft tissues repairs, repair technique, and the individual surgeon).

This study is not without limitations, however. First, our prospective database does not include all possible factors that might influence repair technique or anchor use, and the study did not investigate some potentially important factors such as tendon retraction and reparability, muscle fatty infiltration and atrophy, anchor type, and suture construct configuration. Future work could investigate factors such as tendon retraction and reparability, muscle fatty infiltration and atrophy, anchor type, and suture construct configuration on suture anchor usage. However, the decision to investigate additional factors must be made prospectively and judiciously in light of the size of the cohort and the corresponding number of degrees of freedom allowed in the multivariable analysis.

Second, we did not report the total costs or cost-per-case variation associated with variation in the number of anchors used. Although we did have a record of the product/manufacturer for the 85% of the 2591 anchors (22 distinct products from 3 manufacturers) used in our cohort, actual costs for specific anchors to our health care system were not readily available. A wide variation in cost per anchor has been previously reported,²⁵ so we would expect variation in the product and number of anchors used to introduce significant cost-per-case variation,²⁵ although this was not formally investigated in this study. Further, we have not reported the structural or clinical outcomes associated with repair technique or number of anchors used, and these data are ultimately necessary to evaluate the cost-effectiveness of any surgical technique. Future work could also investigate the influence of repair technique and suture anchor use on cost and long-term clinical and structural outcomes (healing/retars), as well as investigate the factors that influence surgeon decision making in rotator cuff repair.

Finally, our investigation was limited to repairs of the posterior-superior cuff using suture anchors, and our study was performed in a single tertiary hospital network. Hence, our findings may not be generalizable to all rotator cuff repair types, patient populations, or surgical practice settings. Investigation of these questions in large, multicenter, prospective cohorts, while controlling for patient and surgical factors that

influence rotator cuff repair technique and outcomes, will allow for more conclusive assessment of the value (outcome/cost) and, ultimately, the appropriate indication of different repair techniques for a given type and size of rotator cuff tear.

Conclusion

Our data demonstrate that larger, full-thickness rotator cuff tears involving 2 or more tendons were significantly associated with performing double-row repair over a single-row repair and that larger tears involving 2 or more tendons and using the double-row technique were associated with using significantly more suture anchors. Importantly, however, significant variation in the repair technique (single-row vs. double-row) and the number of suture anchors used in superior-posterior rotator cuff repair could also be attributed to the individual surgeon after adjusting for tear characteristics.

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