Published in final edited form as:

J Shoulder Elbow Surg. 2019 February ; 28(2): 227–236. doi:10.1016/j.jse.2018.07.028.

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

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Abstract

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. The purpose of this study was to investigate the extent to which patient and surgical factors, including surgeon, associate with performing single-vs. double-row repair technique and ultimately with the number of suture anchors used.

Methods: This study queried our institution's prospective surgical cohort 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 less 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: 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.

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Author Contribution Statement: K.A.D., S.S., K.P.S., J.P.I., and E.T.R. designed the study. K.A.D., S.S., A.Z., and G.S. executed the study and analyzed the data. All authors participated in data interpretation. K.A.D., S.S., and E.T.R. drafted the article. All authors participated in critical revision of the article and approved the final submitted manuscript.

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The other authors have no disclosures to report.

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.

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

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

Keywords

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

Musculoskeletal diseases are the leading cause of disability and healthcare costs in the US and affect 1 of every 2 adults. \$874 billion is spent annually in the US on healthcare for persons with musculoskeletal disease, representing 5.7% of GDP²⁷. In an era of rising healthcare 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 US, with over 250,000 rotator cuff repairs performed annually⁵. Rotator cuff repair in general has been shown to be cost-effective to the patient (by standard cost-effectiveness ratios)²⁹ and produces net societal cost savings when considering direct and indirect costs of treatment¹⁵.

However, there is 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 employed. 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 repairs¹¹. However, 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; 20; 24; 31–33}. Despite improved healing with double row fixation, however, no clinical differences were seen between single- and double-row repairs after follow-up ranging from 12–36 months, particularly in patients with small to medium sized tears (<3cm)^{3; 16; 19; 20; 23; 24; 31–33}. Yet in patients with large or massive tears (>3cm), some studies have shown superior clinical outcomes associated with double-row compared to single-row repair technique^{3; 31–33}.

Double-row repair methods are more time-consuming⁸ and utilize more suture anchors when comparing 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; 25; 26}, the cost of performing double-row repair is greater than the cost of single-row repair^{1; 4; 9; 17; 26}. While one recent cost-effectiveness analysis demonstrated superior cost-effectiveness of double- row fixation only for larger sized tears (>3cm)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 to 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 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 intra-operative surgical factors, including the individual surgeon as an independent factor, associate with the choice of performing single- vs. double-row repair technique and ultimately with the number of suture anchors used in rotator cuff repair. Our investigation is 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, and/or teres minor tendons. We hypothesize that tear characteristics including size as well as the individual surgeon associate with the variation in repair technique and suture anchor usage in superior-posterior rotator cuff repair.

Materials and Methods

Orthopaedic Minimal Data Set Episode of Care (OME)

This study utilized the Cleveland Clinic's Orthopaedic Minimal Data Set Episode of Care (OME) prospective surgical cohort^{21; 30}, which is approved by Cleveland Clinic's Institutional Review Board (IRB). The OME cohort collects demographic factors, joint specific intra-operative surgical variables of disease severity and treatment, and joint specific validated patient-reported outcome measurements (PROMs) at baseline and one year postoperation, 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, and/or teres minor tendons. Exclusion criteria were patients with isolated subscapularis tears, superior-posterior tears that were not repaired, repairs that did not use suture anchors (i.e., repairs using bone tunnels and sutures), repairs involving graft augmentation, and repairs performed by surgeons with less than 10 cases. A total of seventeen preoperative patient and intra-operative surgical factors were extracted from the OME registry to descriptively assess the eligible cohort. These included demographic factors (age, sex, body mass index (BMI), smoking status, education level), disease severity factors (prior shoulder surgery, tear type, tear size, number of torn tendons, surgery type, PENN

Shoulder Score), and treatment factors (repair type, repair technique, type of anchor, anchor manufacturer, number of concomitant soft tissues repaired and surgeon) (Table 1^{7; 18}).

Statistical Modeling

Multivariable statistical modeling was then performed on the eligible cohort in order to investigate the extent to which the extracted patient and surgical factors associate with (1) the choice of performing a single- vs. double-row repair technique and with (2) the number of suture anchors used for rotator cuff repair. Thirteen of the 17 patient and surgical factors were prospectively considered likely to influence repair technique or suture anchor usage and were included as model covariates (Table 2). 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 eleven factors of interest were subsequently assessed *a priori* for clinically appropriate opportunities to perform categorical binning (Table 2). For example, the factor, “concomitant repair of other soft tissue structures (e.g., biceps, subscapularis, labrum, capsule),” was reduced to a number—one, two, or three or more—to investigate whether the total number of additional procedures impacted 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 a single category in the statistical model because our clinical interest was to determine whether using double row repair impacted 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 (e.g., supraspinatus, infraspinatus, teres minor) were reduced to two numerical categories—one or two or more—because the frequency of cases involving three tendons was too low to model.

All statistical analyses were performed using R software (R version 3.2.3 (2015–12–10), Vienna, Austria). For modeling purposes, missing values for body mass index (n=9) and smoking status (n=30) were imputed using multivariate imputation by chained equations (MICE) via the R package mice²⁸. All testing was two-sided and considered significant at the 5% level ($p < 0.05$).

Statistical Modeling—Choice of Single 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 vs. double row repair). Excepting ‘repair technique’, the other twelve factors listed in Table 2 were investigated as covariates in the model. 95% confidence intervals were computed 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 eleven variables were treated as *fixed* effects to determine the ‘odds ratio’ of performing a double row repair vs. a single row repair, compared to 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 zero) to determine factors that influence the number of anchors used for rotator cuff repair. All thirteen factors listed in Table 2 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 to 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 so as 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 intra-operative surgery data on 1,176 rotator cuff repairs performed by a total of 18 surgeons at seven 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 (Figure 1). Fifty-three of these cases were excluded because they were isolated subscapularis repairs, i.e., 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 they did not use suture anchors ($n=162$), used graft augmentation ($n=21$), or were performed by a surgeon with less than 10 cases in the cohort ($n=15$). There were ultimately 925 cases performed by 13 surgeons available for investigation. All thirteen surgeons were five or more years into practice and 92% (12 of 13 were fellowship trained, 83% of these (10 of 12) in sports and/or shoulder surgery.

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

Table 1 describes the variation in the preoperative characteristics and suture anchor usage for patients from the OME cohort undergoing superior-posterior rotator cuff tendon repair and meeting inclusion criteria. Specifically, Table 1 reports the frequency of cases performed for each variable, as well as the mean number of anchors used for those cases by variable. The majority 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 more commonly than single row repairs (61% vs. 39%). Polymer anchors were used most commonly (in 45% of cases), and the majority of repairs (over 70%) 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 1). Surgeons varied widely in their anchor usage, averaging between 1.9 and 4.5 anchors per case.

Single or Double Row Repair

The statistical model for ‘repair technique’ showed that five variables -- tear type (full thickness tears), tear size (medium, large and massive tears), a greater number of torn tendons, repair type (arthroscopic repairs), as well as surgeon-- were significantly associated with performing a double row repair over a single row repair, after adjusting for all other model variables. Table 3 displays the 95% confidence intervals for the adjusted odds ratios for double row vs. single row repairs, for the eleven factors treated as fixed effects. For example, on average, the odds of performing a double row vs. single row repair are between 1.46 and 4.81 times greater for a full thickness tear compared to a partial thickness tear. Because ‘surgeon’ is a random effect in this model, an odds ratio cannot 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 to the overall average.

Figure 2 demonstrates the model findings empirically by graphically depicting the number of single vs. double row repairs performed by individual surgeons for each of the significant model variables related to tear characteristics: tear size (Figure 2A), tear type (Figure 2B) and number of torn tendons (Figure 2C). Inspection of Figure 2 reveals that the choice of single vs. double row repair technique varied with surgeon preference as well as tear characteristics. For example, surgeons 3, 4, 7, and 8 appear to 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 (e.g., 1, 2 and 9) performed both single and double row repairs across all tear characteristics, with generally increasing use of double row technique.

Number of Anchors Used

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

The best-fitting statistical model for ‘number of anchors used’ contained five variables: tear type, tear size, number of tendons, repair technique, and surgeon. The model had an AIC value of 2453, compared to 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 4 displays the fold-change for the covariates in the best-fit model for ‘number of anchors used’ compared to the reference category for each variable.

Four of five model parameters - tear size (medium, large and massive tears), a greater number of torn tendons, double row repair technique, and surgeon were significantly associated with number of anchors used (Table 4). 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. The 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. Two surgeons (#5 and #7) were found to use significantly more anchors per case (up to 1.67 times) and two surgeons (#3 and #8) significantly less anchors per case (as few as 0.58 times) than the reference surgeon (Table 4).

Discussion

The purpose of this study was to investigate the extent to which preoperative patient and intra-operative surgical factors, including the individual surgeon as an independent factor, associate with the choice of performing single-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. While an increased likelihood of performing double row repair technique in the setting of larger, full thickness tears involving two 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 to 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 techniques²². 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 if this is true. Finally, we note that age, sex, BMI, smoking status, prior *Suture anchor usage rotator cuff repair* 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 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 to 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 other²⁴, in combination with the surgeons' training, experience and/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 and/or shoulder surgery, it was not possible to statistically test the influence of fellowship training as an independent factor in this study.

Suture anchor usage 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 usage in rotator cuff repair^{2; 25; 26; 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 usage with larger tears involving two 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 two or more tendons) and with clinical practice (it is well-documented that the extra row of fixation with double row repair results in greater suture anchor usage compared to 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, while 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, two surgeons were found to use significantly more anchors per case (up to 1.67 times) and two surgeons significantly less 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 2 (AIC =2473), we explored the role of case volume in influencing the 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 usage, similar to the empirical findings of a prior report²⁶. 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 vs double row) and suture anchors usage 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 as to 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 one year clinical outcomes 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 usage 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 derives 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 either cited or judged to influence repair technique and suture anchor usage were prospectively chosen and used in multivariable models to identify statistically significant associations. Furthermore, this is the first study to our knowledge that determines predictors of repair technique and suture anchor usage in a rotator cuff patient population that comprehensively controlled for patient characteristics (age, BMI, gender, smoking status), disease severity (prior shoulder on the affected arm, tear type, tear size, number of torn tendons, surgery type) and treatment variables (repair type, number of concomitant soft tissues repairs, repair technique and the individual surgeon).

However, this study is not without limitations. First, our prospective database does not include all possible factors that might influence repair technique or anchor usage, and some potentially important factors such as tendon retraction and reparability, muscle fatty infiltration and atrophy, anchor type, and suture construct configuration were not investigated in this study. Secondly, we did not report on the total costs or cost-per-case variation associated with variation in the number of anchors used. While we did have a record of the product/manufacture for the majority (85%) of the 2,591 anchors (a total of 22 distinct products from three manufacturers) used in our cohort, actual costs for specific anchors to our healthcare system were not readily available. A wide variation in cost-per-anchor has been previously reported²⁶, so we would expect variation in both the product and number of anchors used to introduce significant cost-per-case variation,²⁶ although this was not formally investigated in this study. Further, we have not reported on 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. Finally, we limited our investigation 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.

Conclusion

Our data demonstrate that larger, full thickness rotator cuff tears involving two or more tendons were significantly associated with performing double row repair over a single row repair, and larger tears involving two or more tendons and utilizing double row technique were associated with using significantly more suture anchors. Importantly, however, significant variation in the repair technique (single 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. 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. Future work could also investigate the influence of repair technique and suture anchor usage on cost and long-term clinical and structural outcomes (healing/retears), as well as investigate the factors that influence surgeon decision-making in rotator cuff repair. 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.

Acknowledgement:

The acknowledge the following Cleveland Clinic surgeons who contributed patient and surgical data to the OME database for investigation in this study: Thomas Anderson, MD, Peter Evans, MD, Lutul Farrow, MD, Gregory Gilot, MD, Joseph Iannotti, MD, PhD, Morgan Jones, MD, Brian Leo, MD, Anthony Miniaci, MD, Eric Ricchetti, MD, James Rosneck, MD, Mark Schickendantz, MD, William Seitz, MD, and Kim Stearns, MD.

Source of Support: The authors acknowledge the Orthopaedic and Rheumatologic Institute at Cleveland Clinic for support of the OME database and related infrastructure. Research reported in this publication was also supported in part by the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health under Award Number **5R01AR068342**. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Financial Remuneration: G.S. and K.P.S. are inventors with rights to royalties from nPhase/REDCap Cloud for technology related to the subject of this article.

Institutional Review Board: 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).

References

1. Bisson L, Zivaljevic N, Sanders S, Pula D. A cost analysis of single-row versus double-row and suture bridge rotator cuff repair methods. *Knee Surg Sports Traumatol Arthrosc* 2015; 23:487–93. 10.1007/s00167-012-2338-2 [PubMed: 23229385]
2. Burks RT, Crim J, Brown N, Fink B, Greis PE. A prospective randomized clinical trial comparing arthroscopic single-and double-row rotator cuff repair: magnetic resonance imaging and early clinical evaluation. *Am J Sports Med* 2009; 37:674–82. 10.1177/0363546508328115. [PubMed: 19204365]
3. Chen M, Xu W, Dong Q, Huang Q, Xie Z, Mao Y. Outcomes of single-row versus double-row arthroscopic rotator cuff repair: a systematic review and meta-analysis of current evidence. *Arthroscopy* 2013; 29:1437–49. 10.1016/j.arthro.2013.03.076. [PubMed: 23711754]
4. Churchill RS, Ghorai JK. Total cost and operating room time comparison of rotator cuff repair techniques at low, intermediate, and high volume centers: mini-open versus all-arthroscopic. *J Shoulder Elbow Surg* 2010; 19:716–21. 10.1016/j.jse.2009.10.011. [PubMed: 20137974]
5. Colvin AC, Egorova N, Harrison AK, Moskowitz A, Flatow EL. National trends in rotator cuff repair. *J Bone Joint Surg Am* 2012; 94:227–33. 10.2106/JBJS.J.00739. [PubMed: 22298054]
6. DeHaan AM, Axelrad TW, Kaye E, Silvestri L, Puskas B, Foster TE. Does double-row rotator cuff repair improve functional outcome of patients compared with single-row technique? A systematic review. *Am J Sports Med* 2012; 40:1176–85. 10.1177/0363546511428866. [PubMed: 22156169]
7. DeOrto JK, Cofield RH. Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. *J Bone Joint Surg Am* 1984; 66:563–7. [PubMed: 6707035]
8. Franceschi F, Ruzzini L, Longo UG, Martina FM, Zobel BB, Maffulli N, et al. Equivalent clinical results of arthroscopic single-row and double-row suture anchor repair for rotator cuff tears: a

- randomized controlled trial. *Am J Sports Med* 2007; 35:1254–60. 10.1177/0363546507302218. [PubMed: 17554104]
9. Genuario JW, Donegan RP, Hamman D, Bell JE, Boublik M, Schlegel T, et al. The cost-effectiveness of single-row compared with double-row arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2012; 94:1369–77. 10.2106/jbjs.J.01876. [PubMed: 22854989]
 10. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of biomedical informatics* 2009; 42:377–81. 10.1016/j.jbi.2008.08.010 [PubMed: 18929686]
 11. Hohmann E, Konig A, Kat CJ, Glatt V, Tetsworth K, Keough N. Single- versus double-row repair for full-thickness rotator cuff tears using suture anchors. A systematic review and meta-analysis of basic biomechanical studies. *European journal of orthopaedic surgery & traumatology : orthopedie traumatology* 2018;28:859–868. 10.1007/s00590-017-2114-6.
 12. Huang AL, Thavorn K, van Katwyk S, MacDonald P, Lapner P. Double-Row Arthroscopic Rotator Cuff Repair Is More Cost-Effective Than Single-Row Repair. *J Bone Joint Surg Am* 2017; 99:1730–36. 10.2106/JBJS.16.01044. [PubMed: 29040127]
 13. Jain NB, Kuye I, Higgins LD, Warner JJ. Surgeon volume is associated with cost and variation in surgical treatment of proximal humeral fractures. *Clin Orthop Relat Res* 2013; 471:655–64. 10.1007/s11999-012-2481-6. [PubMed: 22826013]
 14. James G, Witten D, Hastie T, Tibshirani RJ. Linear Model Selection and Regularization. In. *An Introduction to Statistical Learning*: Springer; 2013, p. 203–64. (ISBN No. ISBN 978–1-4614–7138-7)
 15. Mather RC, 3rd, Koenig L, Acevedo D, Dall TM, Gallo P, Romeo A, et al. The societal and economic value of rotator cuff repair. *J Bone Joint Surg Am* 2013; 95:1993–2000. 10.2106/jbjs.L.01495. [PubMed: 24257656]
 16. Millett PJ, Warth RJ, Dornan GJ, Lee JT, Spiegl UJ. Clinical and structural outcomes after arthroscopic single-row versus double-row rotator cuff repair: a systematic review and meta-analysis of level I randomized clinical trials. *J Shoulder Elbow Surg* 2014; 23:586–97. 10.1016/j.jse.2013.10.006. [PubMed: 24411671]
 17. Narvy SJ, Ahluwalia A, Vangsness CT, Jr. Analysis of Direct Costs of Outpatient Arthroscopic Rotator Cuff Repair. *Am J Orthop (Belle Mead NJ)* 2016; 45:E7–e11.[no doi] [PubMed: 26761928]
 18. Organization WH. Obesity: preventing and managing the global epidemic: World Health Organization; 2000 (ISBN No. 9241208945)
 19. Perser K, Godfrey D, Bisson L. Meta-analysis of Clinical and Radiographic Outcomes After Arthroscopic 455 Single-Row Versus Double-Row Rotator Cuff Repair. *Sports health* 2011; 3:268–74. 10.1177/1941738111403106. [PubMed: 23016017]
 20. Prasathaporn N, Kuptniratsaikul S, Kongrukreatiyos K. Single-row repair versus double-row repair of full-thickness rotator cuff tears. *Arthroscopy* 2011; 27:978–85. 10.1016/j.arthro.2011.01.014. [PubMed: 21693349]
 21. Ramanathan D, Gad BV, Luckett MR, Klika AK, Spindler KP, Higuera CA. Validation of a New Web-Based System for Point-of-Care Implant Documentation in Total Knee Arthroplasty. *The journal of knee surgery* 2017 [Epub ahead of print]. 10.1055/s-0037-1608822.
 22. Rhee YG, Cho NS, Yoo JH. Clinical outcome and repair integrity after rotator cuff repair in patients older 463 than 70 years versus patients younger than 70 years. *Arthroscopy* 2014; 30:546–54. 10.1016/j.arthro.2014.02.006 [PubMed: 24630958]
 23. Sheibani-Rad S, Giveans MR, Arnoczky SP, Bedi A. Arthroscopic single-row versus double-row rotator cuff repair: a meta-analysis of the randomized clinical trials. *Arthroscopy* 2013; 29:343–8. 10.1016/j.arthro.2012.11.019. [PubMed: 23369480]
 24. Spiegl UJ, Euler SA, Millett PJ, Hepp P. Summary of Meta-Analyses Dealing with Single-Row versus Double-Row Repair Techniques for Rotator Cuff Tears. *Open Orthop J* 2016; 10:330–38. 10.2174/1874325001610010330 [PubMed: 27708735]

25. Tashjian RZ, Belisle J, Baran S, Granger EK, Nelson RE, Burks RT, et al. Factors influencing direct clinical costs of outpatient arthroscopic rotator cuff repair surgery. *J Shoulder Elbow Surg* 2018; 27:237–41. 10.1016/j.jse.2017.07.011. [PubMed: 28965686]
26. Terhune EB, Cannamela PC, Johnson JS, Saad CD, Barnes J, Silbernagel J, et al. Surgeon-Directed Cost Variation in Isolated Rotator Cuff Repair. *Orthop J Sports Med* 2016; 4:2325967116677709 10.1177/2325967116677709. [PubMed: 28203590]
27. United States Bone and Joint Initiative: The Burden of Musculoskeletal Diseases in the United States (BMUS) Available at: <http://www.boneandjointburden.org>. Accessed 01/25/2018, 2018.
28. van Buuren S, Groothuis-Oudshoorn K. mice: Multivariate Imputation by Chained Equations in R. *J Stat Soft* 2011; 45:1–67. 10.18637/jss.v045.i03
29. Vitale MA, Vitale MG, Zivin JG, Braman JP, Bigliani LU, Flatow EL. Rotator cuff repair: an analysis of utility scores and cost-effectiveness. *J Shoulder Elbow Surg* 2007; 16:181–7. 10.1016/j.jse.2006.06.013. [PubMed: 17399623]
30. Westermann RW, Lynch TS, Jones MH, Spindler KP, Messner W, Strnad G, et al. Predictors of Hip Pain and Function in Femoroacetabular Impingement: A Prospective Cohort Analysis. *Orthop J Sports Med* 2017; 5:2325967117726521 10.1177/2325967117726521. [PubMed: 28944250]
31. Xu C, Zhao J, Li D. Meta-analysis comparing single-row and double-row repair techniques in the arthroscopic treatment of rotator cuff tears. *J Shoulder Elbow Surg* 2014; 23:182–8. 10.1016/j.jse.2013.08.005. [PubMed: 24183478]
32. Ying ZM, Lin T, Yan SG. Arthroscopic single-row versus double-row technique for repairing rotator cuff tears: a systematic review and meta-analysis. *Orthopaedic surgery* 2014; 6:300–12. 10.1111/os.12139. [PubMed: 25430714]
33. Zhang Q, Ge H, Zhou J, Yuan C, Chen K, Cheng B. Single-row or double-row fixation technique for full-thickness rotator cuff tears: a meta-analysis. *PloS one* 2013; 8:e68515 10.1371/journal.pone.0068515. [PubMed: 23874649]

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

Figure 2.

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

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

Table 1.

Variation in the preoperative and intra-operative characteristics and suture anchor usage for patients undergoing superior-posterior rotator cuff tendon repair

Variable	Category or Range	Number Cases	Percent Cases	Number Anchors Mean (SD)
1. Age (year)	<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)
2. Sex	Male	559	60%	2.9 (1.4)
	Female	366	40%	2.6 (1.3)
3. BMI ¹⁹	< 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)
	Data Not Available	9	1%	3.6 (0.5)
4. Smoking status	Never	445	48%	2.8 (1.3)
	Quit	303	33%	2.9 (1.3)
	Current	147	16%	2.7 (1.4)
	Data Not Available	30	3%	2.7 (1.2)
5. Education Level (years of education)	< 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)
6. Prior shoulder surgery	No	814	88%	2.8 (1.3)
	Yes	111	12%	2.8 (1.5)
7. Tear type	Partial	167	18%	2.2 (1.4)
	Full	758	82%	2.9 (1.3)
8. 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)
9. Number of torn superior-posterior rotator cuff tendons (supraspinatus, infraspinatus, teres)	1	567	61%	2.4 (1.2)
	2 or more	358	39%	3.5 (1.2)

Variable	Category or Range	Number Cases	Percent Cases	Number Anchors Mean (SD)
10. Surgery type	Primary	861	93%	2.8 (1.3)
	Revision	64	7%	2.9 (1.5)
11. 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)
12. 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)
13. Repair technique	Single row	361	39%	1.6 (0.8)
	Double row (Standard)	214	23%	3.2 (1.2)
	Double row (Suture-bridge)	236	26%	3.7 (0.8)
	Double row (Combination Standard and Suture-bridge)	114	12%	3.9 (0.8)
14. 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)
15. Anchor manufacturer	Arthrex	665	72%	2.6 (1.2)
	DePuy-Mitek	38	4%	2.4 (1.2)
	Smith and Nephew	32	3%	1.6 (0.6)
	Multiple	131	14%	4.2 (0.9)
	Other	59	6%	3.0 (1.2)
16. Number 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 or more	28	3%	2.4 (1.3)
17. 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)

Variable	Category or Range	Number Cases	Percent Cases	Number Anchors Mean (SD)
	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)

Table 2.

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

1. Age	<i>continuous</i>
2. BMI	<i>continuous</i>
3. Sex	Male, Female
4. Smoking status	Never, Quit, Current
5. Prior shoulder surgery on affected arm	No, Yes
6. Tear type	Partial-thickness, Full-thickness
7. Tear size	Small, Medium, Large, Massive
8. Number of torn superior-posterior rotator cuff tendons (supraspinatus, infraspinatus, teres)	1, 2 or more
9. Surgery type	Primary, Revision
10. Repair type	Open (standard, mini), Arthroscopic
11. Repair technique	Single row, Double row (standard, suture-bridge, combination standard and suture-bridge)
12. Number of concomitant soft tissues repaired (biceps, subscapularis, labrum, capsule)	0, 1, 2, 3 or more
13. Surgeon	1–13

Table 3.

Odds ratios for performing a double row repair vs. a single row repair. Intervals that do not contain one (*) are significantly different from their respective reference category at a 0.05 significance level.

Variable / Range or Category		Adjusted Odds Ratio (95% confidence interval)
Age		(0.99, 1.03)
Sex	Male	--
	Female	(0.78, 2.01)
BMI		(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)*
Number 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)*
Number 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)

Table 4.

Fold-change for the number of anchors used compared to the reference category for each variable. Intervals that do not contain one (*) are significantly different from their respective reference category at a 0.05 significance level.

Variable / Range or Category		Fold-change (95% confidence interval)
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)