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Factors associated with healing failure after early repair of acute, trauma-related rotator cuff tears

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Background: Healing failure after rotator cuff repair is a challenging problem. Acute, trauma-related tears are considered a separate entity and are often treated surgically. The aim of this study was to identify factors associated with healing failure in previously asymptomatic patients with trauma-related rotator cuff tears treated with early arthroscopic repair.

Methods: This study included 62 consecutively recruited patients (23% women; median age, 61 years; age range, 42-75 years) with acute symptoms in a previously asymptomatic shoulder and a magnetic resonance imaging–verified full-thickness rotator cuff tear after shoulder trauma. All patients were offered, and underwent, early arthroscopic repair, during which a biopsy specimen was harvested from the supraspinatus tendon and analyzed for signs of degeneration. Of the patients, 57 (92%) completed 1-year follow-up and underwent assessment of repair integrity on magnetic resonance images according to the Sugaya classification. Risk factors for healing failure were investigated using a causal-relation diagram where age, body mass index, tendon degeneration (Bonar score), diabetes mellitus, fatty infiltration (FI), sex, smoking, tear location regarding integrity of the rotator cable, and tear size (number of ruptured tendons and tendon retraction) were included and analyzed.

Results: Healing failure at 1 year was identified in 37% of patients (n = 21). A high degree of FI of the supraspinatus muscle ($P = .01$), a tear location including disruption of rotator cable integrity ($P = .01$), and old age ($P = .03$) were associated with healing failure. Tendon degeneration as determined by histopathology was not associated with healing failure at 1-year follow-up ($P = .63$).

Conclusion: Older age, increased FI of the supraspinatus muscle, and a tear including disruption of the rotator cable increased the risk of healing failure after early arthroscopic repair in patients with trauma-related full-thickness rotator cuff tears.

Level of evidence: Level I; Prospective Cohort Design; Prognosis Study

Keywords: Rotator cuff tear; tendon healing; subacute repair; risk factors; healing failure; tendon degeneration; rotator cable

This study was approved by the Regional Ethical Review Board in Lund, Sweden (registration no. 2011/119). All patients signed a consent form giving permission to use their anonymous data for research.

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Patients with trauma-related rotator cuff tears (TRCTs) without previous shoulder complaints are typically recommended to undergo early repair.[22,48,60] The treatment goals of TRCT repair are tendon healing and restoration of anatomy and biomechanics leading to regained normal shoulder function. Several prognostic factors for repair healing and risk factors for nonhealing have been studied during the past few decades, but to our knowledge, investigations of solely trauma-related tears have not been published.[32,37,66] Among factors independently associated with lower rates of repair healing, 3 different variables for cuff muscle degeneration have been reported: high grade of fatty infiltration (FI) of the supraspinatus[42,63]; high grade of FI of the infraspinatus[13,14,31,36,52,63]; and elevation of the combined, calculated Global Fatty Degeneration Index.[12,21,51] In addition, large tear size,[12,15,27,36,42,43,52,55,56] older patient age,[15-17,27,42,43,52,61] hyperlipidemia,[20,26,36] increased body mass index,[17,36] muscle atrophy,[36] and low bone mineral density[14] have been reported as independent risk factors for healing failure. A large proportion of TRCTs in previously asymptomatic patients have recently been shown to have histologically verified degenerative changes.[1] Identifying risk factors for healing failure is required to understand current limitations in achieving a successful repair and, furthermore, to guide both patients and surgeons in treatment decision making.

We hypothesized that tear location and degenerative changes might predict healing failure. These relationships have not been investigated or reported in similar cohorts. The aim of this study was therefore to identify risk factors associated with healing failure in patients with TRCTs treated with arthroscopic repair within 6 weeks of trauma.

Materials and methods

Patient selection

All data were collected from patients in a prospective clinical study at Helsingborg Hospital. The study enrolled 62 consecutive patients, aged between 42 and 75 years, with pain and limited range of motion following shoulder trauma and with normal preinjury function between November 2010 and March 2014. Details of the study have recently been published.[2] In brief, the inclusion criteria were a full-thickness rotator cuff tear verified by magnetic resonance imaging (MRI), no previous shoulder complaints, and willingness to undergo surgical treatment within 6 weeks of trauma. The exclusion criteria were previous surgery on the affected shoulder; history of shoulder dysfunction; and presence of rheumatoid arthritis, glenohumeral osteoarthritis, nerve injury, or severe comorbidity (American Society of Anesthesiologists class $\geq$4). Eligible patients were examined by a dedicated physiotherapist in the orthopedic department at a median of 12 days (interquartile range [IQR], 10-16 days) after injury when data on smoking habits, body weight, and height were collected.

MRI of the affected shoulder was performed within a median of 19 days (IQR, 15-24 days) after injury. Eligible patients with a full-thickness rotator cuff tear were offered early arthroscopic repair, which was performed by a single-row technique within a median of 30 days (IQR, 25-37 days) after injury. All surgical procedures were performed by 1 of 3 experienced orthopedic surgeons at Helsingborg Hospital. After visualization, the type of tear was categorized and the tear size was measured in both the coronal plane (retraction in millimeters) and the sagittal plane (number of tendons involved) with a calibrated probe. Measurements and concomitant pathology were recorded in a predefined surgical protocol (Table I). Isolated crescent tears of the supraspinatus and crescent tears involving the most anterior part of the infraspinatus were, together with single-tendon subscapularis tears, classified as rotator cable (RC)–stable tears. All other tears involving the anterior and/or posterior cable structures were considered RC-unstable tears (Fig. 1).[11,23,38,47] Biceps pathology was treated with tenotomy or tenodesis according to the surgeon's preference. All subscapularis tears were repaired with Fastin RC 5.0-mm anchors (DePuy Synthes Sports Medicine [Mitek], Raynham, MA, USA), whereas for infraspinatus and supraspinatus tears, triple-loaded Healix 4.5- and 5.5-mm anchors (DePuy Synthes Sports Medicine) were used. Subacromial decompression with a burr was performed in all patients except those undergoing isolated subscapularis repair. After surgery, all patients followed a standardized rehabilitation protocol including use of a sling for 4-6 weeks (dependent on infraspinatus involvement, described in detail in a previous report[2]). A biopsy specimen was harvested from the most lateral part of the supraspinatus tendon stump before any use of radiofrequency instruments. Tissue material was fixed in neutral buffered formalin in a standard fashion and sent to the Department of Pathology at Lund University for dehydration and paraffin embedding. Sections of 2 μm were obtained; stained with hematoxylin-eosin, alcian blue, and Masson trichrome; and finally assessed for tendon degeneration according to the Bonar score.[18] The median Bonar score of patients with trauma-related tears was 10.5, not statistically significantly different from that of a control group comprising patients with chronic tears. The complete results of the histopathologic analyses have recently been published.[1]

Magnetic resonance imaging

A standardized protocol with 7 diverse sequences was applied, and all MRI examinations were conducted with the same 1.5-T scanner (Siemens Medical Systems, Erlangen, Germany). All preoperative images were interpreted and classified by a single senior radiologist. A full-thickness rotator cuff tear was defined as tendon discontinuity or increased signal on T2-weighted images, isointense compared with fluid, extending from the articular side to the bursal side of the tendon.[29] The integrity of the different cuff tendons was documented, together with the grade of FI of the subscapularis, supraspinatus, and infraspinatus muscles according to the 3 stages of the Fuchs scale[19]: stage 1, no to some fatty streaks; stage 2, pronounced FI but fat area smaller than muscle area; and stage 3, fat area equal to or larger than muscle area. The Global Fatty Degeneration Index was calculated for each patient using the mean FI value of the 3 rotator cuff muscles as described by Goutallier et al.[21] Intraobserver reliability of the radiologist's

Table I Patient demographic characteristics and preoperative and intraoperative assessment findings

Variable	Data (N = 62)
Age, median (IQR), yr	61 (54-65)
Female sex, n (%)	14 (23)
BMI, kg/m^2	28 (25-30)
Diabetes mellitus, n (%)	4 (6)
Smoker, n (%)	6 (10)
Preoperative WORC score, median (IQR)	29 (21-37)
Preoperative CS, median (IQR)	23 (17-31)
Time to surgery, median (IQR), d	30 (24-38)
Preoperative MRI findings	
FI grade 1/2/3, n (%)	
SSC	48 (79)/13 (21)/0 (0)
SSP	49 (79)/13 (21)/0 (0)
ISP	47 (76)/14 (23)/1 (1)
Intraoperative findings	
1-Tendon tear, n (%)	12 (19)
SSP	6 (10)
ISP	6 (10)
2-Tendon tear, n (%)	35 (57)
SSP + ISP	18 (29)
SSP + SSC	17 (27)
3-Tendon tear, n (%)	15 (24)
SSC + SSP + ISP	14 (23)
SSP + ISP + TM	1 (2)
Tear retraction, median (IQR), mm	23 (15-35)
Tear location, n (%)	
No RC involvement (RC−)	19 (31)
RC involvement (RC+)	43 (69)

IQR, interquartile range; *BMI*, body mass index; *WORC*, Western Ontario Rotator Cuff index; *CS*, Constant-Murley score; *MRI*, magnetic resonance imaging; *FI*, fatty infiltration; *SSC*, subscapularis; *SSP*, supraspinatus; *ISP*, infraspinatus; *TM*, teres minor; *RC*, rotator cable.

grading of FI was tested by Cohen κ calculation with the 95% confidence interval by reassessment of one-third of the images, randomly selected, 2 months after initial assessment (Table II). As suggested previously, κ values between 0.41 and 0.60 were considered moderately reliable; between 0.61 and 0.80, substantially reliable; and >0.80, almost perfectly reliable.[39]

In 57 patients (92%), a follow-up MRI scan was performed at a median of 63 weeks (IQR, 58-69 weeks) after surgery to evaluate the structural integrity of the repair according to the Sugaya classification.[59] Loss to follow-up has been reported in detail.[2] Structural integrity was defined and dichotomized based on the Sugaya grade as healing failure (Sugaya grade 4 or 5) and intact repair (Sugaya grade 1-3). PAGE ＼# "'Page: '#'" [25,33] Healing failure was denoted by ≥1 repaired tendon showing Sugaya grade 4 or 5. A second senior radiologist reassessed the follow-up MRI scans blinded to clinical findings.

Statistical analysis

Descriptive statistics were used to define distributions of continuous variables, and frequencies, and proportions of categorical variables. Variables previously suggested to influence healing[12-15,17,20,26,27,31,42,43,51,52,55,56,61,63] were included in a directed acyclic graph (DAG) model (Fig. 2) to assess causal relations. PAGE ＼# "'Page: '#'" [58,62] Compliance with the rehabilitation protocol, genetic factors, and bone mineral density were included as uncontrolled variables (light gray in Fig. 2), whereas surgeon's experience and rehabilitation protocol (white in Fig. 2) were fixed variables and thus labeled "adjusted." All blue factors in the DAG were generated by the model to have potential impact on the outcome ("ancestor of outcome" in Fig. 2) and were compared between the intact repair group and the healing failure group using the Mann-Whitney U test and χ^2 test. The Fisher exact test was used in place of the χ^2 test in instances of a 2-by-2 table with frequency value ≤5 in at least 1 cell. To investigate intraobserver and interobserver reliability between MRI examiners, κ statistics were used. SPSS software (version 27; IBM, Armonk, NY, USA) was used for all statistical analysis. $P < .05$ was considered significant.

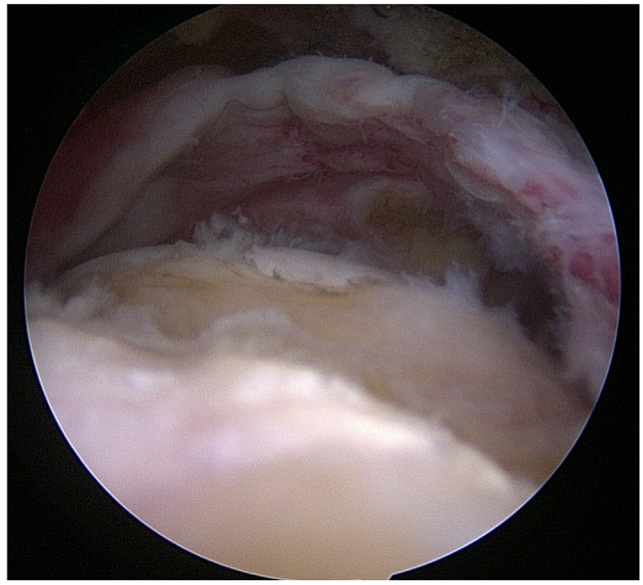

Figure 1 Example of crescent tear involving both supraspinatus and infraspinatus with disruption of posterior insertion of rotator cable (lateral view in right shoulder).

Results

Patient demographic characteristics and preoperative MRI and intraoperative findings are shown in Table I. Of the 57 patients with MRI scans at follow-up, 36 (63%) had intact repairs and 21 (37%) had healing failure according to the Sugaya classification. Interobserver reliability, calculated by κ analysis, showed a κ value of 0.88 (95% confidence interval, 0.75-1.00), which indicated almost perfect reliability.[39] In the univariate analyses, tendon degeneration as determined by histopathology was not associated with healing failure at 1-year follow-up ($P = .63$). Factors significantly associated with healing failure were a tear location including disruption of RC integrity ($P = .01$), a

Table II Intraobserver reliability testing

	ICC	95% CI	*P* value
SSC	0.77	0.50-0.90	<.001
SSP	0.74	0.45-0.89	<.001
ISP	0.93	0.84-0.97	<.001

ICC, intraclass correlation coefficient; *CI*, confidence interval; *SSC*, subscapularis; *SSP*, supraspinatus; *ISP*, infraspinatus.

higher degree of FI of the supraspinatus muscle ($P = .01$), and older age ($P = .03$) (Table III).

Discussion

This prospective study demonstrated that older age, increased FI of the supraspinatus muscle, and disruption of the RC attachments were associated with healing failure after early arthroscopic repair. The findings are based on a well-defined cohort of acute, trauma-related cuff tears. Only 1 previous report has suggested a disrupted RC as a negative predictor for healing,[11] whereas age and FI have been more commonly described as negative predictors for healing of degenerative tears.[13,42,51,52,63,66] It is interesting to note that degeneration of the supraspinatus tendon as determined by histopathology was not associated with healing failure in this study.

The RC, first described by Burkhart et al,[7] was suggested to be critical for mechanical properties such as force transmission within the rotator cuff. Disruption of its anterior attachment has been described to be associated with fatty muscle infiltration, tear progression,[49] and failed repair of degenerative tears.[11] As opposed to tear location, tear size—determined by the number of involved tendons, as well as tear retraction—was not found to be a risk factor for healing failure in our study. This may suggest that RC involvement is more important than the actual tear size in millimeters. Restoration of anatomy and secure fixation of the RC anchor sites seem important to shield mechanical stress, tallying with the conclusion in a biomechanical study by Nguyen et al.[50] Thus, disruption of the RC should possibly be targeted in specifically designed future trials. Our results may be interpreted to support rotator cuff repairs with augmentation to enhance healing by securing the construct. The use of biceps superior capsular reconstruction is one option with promising results.[3,5,9,10]

As previously reported, 37% of our patients with an assumingly fresh cuff tear were identified with healing failure 1 year after surgery, despite early arthroscopic repair.[2] This is comparable to the 24%-35% healing failure rates reported in other studies on similar trauma-related tear cohorts.[6,24,30,65] Still, a failure rate as low as 6.5% has been presented in a cohort with smaller tear sizes (median, 10 mm) and, in most cases, with an intact RC.[54]

In degenerative tears, an association between age and cuff integrity after repair has been well documented.[15,16,42,52] However, whether age is an independent factor or a confounding factor is not clear, as age is closely related to other important features such as tendon degeneration, osteoporosis, and FI.[4,34,35] Multivariate analyses performed in studies with larger cohorts of patients with degenerative tears have suggested that age, tear size, follow-up duration, and FI of the supraspinatus are independent risk factors for healing failure.[42,61]

Proxies for tendon degeneration, such as surgeon-rated tissue quality,[28,41,64] as well as inflammatory and matrix remodeling biomarkers,[45] have been reported as potential risk factors for healing failure. Surprisingly, histopathologic degenerative changes of the involved supraspinatus tendons, recently shown to be as common in this trauma-related tear cohort as in chronic nontraumatic tears,[1] were not associated with healing failure in this study. This agrees with a report by Sethi et al,[57] who similarly failed to find a relationship between the Bonar score, gross appearance of the rotator cuff, and repair healing. One possible explanation is that tendon degeneration precedes more devastating muscle changes such as FI. Although smoking has a well-known negative influence on different tissue qualities, including increased apoptosis and histopathologic changes in rotator cuff tissue,[44] we failed to find a relationship to repair failure in this study. This is most likely a result of an underpowered analysis because the cohort only included 6 smokers (10%).

In our study, FI was analyzed as a global index, as well as in individual muscles separately. Surprisingly, only 79% of the individuals had a normal index of global FI preoperatively despite the fact that our cohort comprised trauma-related tears in individuals without any history of shoulder dysfunction. It appears unlikely that the observed muscle changes would have occurred during the relatively short period between the traumatic event and the examination, and an asymptomatic preceding degenerative process over time prior to the traumatic event seems probable. In agreement with the authors of several other studies on degenerative tears,[12,21,40,42,63] we identified a relationship between increased FI of the supraspinatus and healing failure in our cohort. This association is possibly of high importance for healing failure in repaired supraspinatus tears; an odds ratio of 9.3 for healing failure was suggested in a meta-analysis.[53] In theory, FI may directly affect the structural outcome after rotator cuff repair by reduced muscle strength and secondary superior migration of the humeral head, leading to impingement and repair damage as suggested by Goutallier et al.[21]

The use of a DAG model (Fig. 2) to avoid bias, where included variables were collected from previous studies and arranged from a clinical perspective, is a strength of this study. However, this resulted in a large number of potential variables that could confound or mediate the causal effect

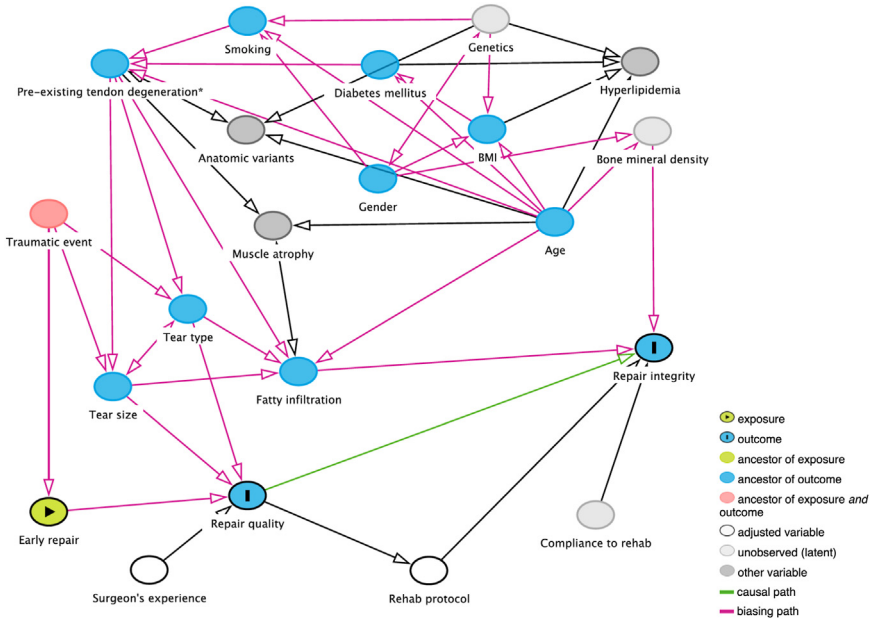

Figure 2 Directed acyclic graph. *As determined by Bonar score. *BMI*, body mass index; *rehab*, rehabilitation.

Table III Results of univariate analyses

Variable	Intact repair (n = 36)	Healing failure (n = 21)	*P* value
Age, median (IQR), yr	60 (51-62)	63 (58-69)	.03*
Female sex, %	28	19	.54
BMI, kg/m^2	27.1 (25.3-30.1)	27.3 (25.1-28.9)	.76
DM, n (%)	1 (3)	2 (10)	.55
Smoking, n (%)	3 (8)	3 (14)	.66
Bonar score	10.5 (7.5-13.5)	10.5 (8.0-15.5)	.63
No. of involved tendons: 1/2/3, n	12/18/6	4/11/6	.18
Tear location: no RC involvement (RC−)/RC involvement (RC+), n	16/20	2/19	.01*
GFDI	1.0 (1.0-1.3)	1.0 (1.0-1.7)	.22
FI grade 1/2/3, n			
SSC	29/7/0	18/2/0	.36
SSP	32/4/0	12/9/0	.01*
ISP	29/7/0	13/7/1	.11
Tear retraction, mm	20 (15-31)	25 (20-40)	.12

IQR, interquartile range; *BMI*, body mass index; *DM*, diabetes mellitus; *RC*, rotator cable; *GFDI*, Global Fatty Degeneration Index; *FI*, fatty infiltration; *SSC*, subscapularis; *SSP*, supraspinatus; *ISP*, infraspinatus.
* Statistically significant ($P < .05$).

on the outcome. The relationships between FI, muscle atrophy, tear location, size, and age are drawn in the DAG model, yet the quantity of the causal effect of different variables is not known. The selection of variables and their potential relationship was based on the systematic review and meta-analysis by Zhao et al[8,12,26,46,63,66] from 2021, together with other recent studies on healing after rotator cuff repair.[8,12,26,46,63,66]

There are limitations to this study. First, the number of patients is relatively small, and the results should be interpreted with caution because the analyses could have been underpowered. Second, although we used a clear definition of acute, trauma-related tears, it is possible that some of our patients had asymptomatic tears before the traumatic event, which could explain the FI observed on the preoperative MRI scans in 20% of the patients. Third, a few potential risk factors were not studied, such as reduced bone mineral density and genetic factors, and their relationship to healing failure remains to be determined in studies with larger samples. Finally, the process of finding a

patient suitable for surgical treatment is always susceptible to selection bias. A specific study strength is that this is the first study on a selected cohort with trauma-related tears analyzed in relation to repair integrity. The patients were prospectively studied according to a predetermined protocol, which improves representativeness, and we used standardized methodology with blinded examiners performing radiologic and histologic assessments.

The clinical implication of our findings is that patients with trauma-related tears should be informed about the risk of healing failure related to tear location, older age, and FI. Specific attention should be focused on RC disruption and the possibility of repair augmentation.

Conclusion

Tear location including disruption of rotator cable integrity, older age, and increased FI of the supraspinatus muscle increased the risk of healing failure after early arthroscopic repair in patients with trauma-related full-thickness rotator cuff tears. These factors are therefore recommended to be considered before surgery. A relationship between histopathologic degenerative changes within the supraspinatus tendon and repair integrity was not found.

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References

1. Aagaard KE, Björnsson Hallgren HC, Lunsjö K, Frobell R. No differences in histopathological degenerative changes found in acute, trauma-related rotator cuff tears compared with chronic, nontraumatic tears. Knee Surg Sports Traumatol Arthrosc 2022;30:2521-7. https://doi.org/10.1007/s00167-022-06884-w
2. Aagaard KE, Lunsjö K, Frobell R. Early repair of trauma-related full-thickness rotator cuff tears does not eliminate the problem of healing failure. Bone Joint J 2019;101-B:603-9. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-0867.R1
3. Adrian SC, Field LD. Biceps transposition for biological superior capsular reconstruction. Arthrosc Tech 2020;9:e841-6. https://doi.org/10.1016/j.eats.2020.02.020
4. Barry JJ, Lansdown DA, Cheung S, Feeley BT, Ma CB. The relationship between tear severity, fatty infiltration, and muscle atrophy in the supraspinatus. J Shoulder Elbow Surg 2013;22:18-25. https://doi.org/10.1016/j.jse.2011.12.014
5. Barth J, Olmos MI, Swan J, Barthelemy R, Delsol P, Boutsiadis A. Superior capsular reconstruction with the long head of the biceps autograft prevents infraspinatus retear in massive posterosuperior retracted rotator cuff tears. Am J Sports Med 2020;48:1430-8. https://doi.org/10.1177/0363546520912220
6. Bjornsson HC, Norlin R, Johansson K, Adolfsson LE. The influence of age, delay of repair, and tendon involvement in acute rotator cuff tears: structural and clinical outcomes after repair of 42 shoulders. Acta Orthop 2011;82:187-92. https://doi.org/10.3109/17453674.2011.566144
7. Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". Arthroscopy 1993;9:611-6.
8. Carbone S, Gumina S, Arceri V, Campagna V, Fagnani C, Postacchini F. The impact of preoperative smoking habit on rotator cuff tear: cigarette smoking influences rotator cuff tear sizes. J Shoulder Elbow Surg 2012;21:56-60. https://doi.org/10.1016/j.jse.2011.01.039
9. Cheppalli NS, Purudappa PP, Metikala S, Reddy KI, Singla A, Patel HA, et al. Superior capsular reconstruction using the biceps tendon in the treatment of Irreparable massive rotator cuff tears improves patient-reported outcome scores: a systematic review. Arthrosc Sports Med Rehabil 2022;4:e1235-43. https://doi.org/10.1016/j.asmr.2022.04.003
10. Chillemi C, Mantovani M, Gigante A. Superior capsular reconstruction of the shoulder: the ABC (Arthroscopic Biceps Chillemi) technique. Eur J Orthop Surg Traumatol 2018;28:1215-23. https://doi.org/10.1007/s00590-018-2183-1
11. Cho NS, Moon SC, Hong SJ, Bae SH, Rhee YG. Comparison of clinical and radiological results in the arthroscopic repair of full-thickness rotator cuff tears with and without the anterior attachment of the rotator cable. Am J Sports Med 2017;45:2532-9. https://doi.org/10.1177/0363546517709772
12. Choi S, Kim MK, Kim GM, Roh YH, Hwang IK, Kang H. Factors associated with clinical and structural outcomes after arthroscopic rotator cuff repair with a suture bridge technique in medium, large, and massive tears. J Shoulder Elbow Surg 2014;23:1675-81. https://doi.org/10.1016/j.jse.2014.02.021
13. Chung SW, Kim JY, Kim MH, Kim SH, Oh JH. Arthroscopic repair of massive rotator cuff tears: outcome and analysis of factors associated with healing failure or poor postoperative function. Am J Sports Med 2013;41:1674-83. https://doi.org/10.1177/0363546513485719
14. Chung SW, Oh JH, Gong HS, Kim JY, Kim SH. Factors affecting rotator cuff healing after arthroscopic repair: osteoporosis as one of the independent risk factors. Am J Sports Med 2011;39:2099-107. https://doi.org/10.1177/0363546511415659
15. Cole BJ, McCarty LP 3rd, Kang RW, Alford W, Lewis PB, Hayden JK. Arthroscopic rotator cuff repair: prospective functional

outcome and repair integrity at minimum 2-year follow-up. J Shoulder Elbow Surg 2007;16:579-85. https://doi.org/10.1016/j.jse.2006.12.011
16. Diebold G, Lam P, Walton J, Murrell GAC. Relationship between age and rotator cuff retear: a study of 1,600 consecutive rotator cuff repairs. J Bone Joint Surg Am 2017;99:1198-205. https://doi.org/10.2106/jbjs.16.00770
17. Erşen A, Şahin K, Albayrak MO. Older age and higher body mass index are independent risk factors for tendon healing in small- to medium-sized rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2023;31:681-90. https://doi.org/10.1007/s00167-022-07234-6
18. Fearon A, Dahlstrom JE, Twin J, Cook J, Scott A. The bonar score revisited: region of evaluation significantly influences the standardized assessment of tendon degeneration. J Sci Med Sport 2014;17:346-50. https://doi.org/10.1016/j.jsams.2013.07.008
19. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elbow Surg 1999;8:599-605.
20. Garcia GH, Liu JN, Wong A, Cordasco F, Dines DM, Dines JS, et al. Hyperlipidemia increases the risk of retear after arthroscopic rotator cuff repair. J Shoulder Elbow Surg 2017;26:2086-90. https://doi.org/10.1016/j.jse.2017.05.009
21. Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S. Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. J Shoulder Elbow Surg 2003;12:550-4. https://doi.org/10.1016/s1058-2746(03)00211-8
22. Gutman MJ, Joyce CD, Patel MS, Kirsch JM, Gutman BS, Abboud JA, et al. Early repair of traumatic rotator cuff tears improves functional outcomes. J Shoulder Elbow Surg 2021;30:2475-83. https://doi.org/10.1016/j.jse.2021.03.134
23. Gyftopoulos S, Bencardino J, Nevsky G, Hall G, Soofi Y, Desai P, et al. Rotator cable: MRI study of its appearance in the intact rotator cuff with anatomic and histologic correlation. Am J Roentgenol 2013;200:1101-5. https://doi.org/10.2214/AJR.12.9312
24. Hantes ME, Karidakis GK, Vlychou M, Varitimidis S, Dailiana Z, Malizos KN. A comparison of early versus delayed repair of traumatic rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2011;19:1766-70. https://doi.org/10.1007/s00167-011-1396-1
25. Hantes ME, Ono Y, Raoulis VA, Doxariotis N, Venouziou A, Zibis A, et al. Arthroscopic single-row versus double-row suture bridge technique for rotator cuff tears in patients younger than 55 Years: a prospective comparative study. Am J Sports Med 2018;46:116-21. https://doi.org/10.1177/0363546517728718
26. Harada N, Gotoh M, Ishitani E, Kakuma T, Yano Y, Tatara D, et al. Combination of risk factors affecting retear after arthroscopic rotator cuff repair: a decision tree analysis. J Shoulder Elbow Surg 2021;30:9-15. https://doi.org/10.1016/j.jse.2020.05.006
27. Harryman DT 2nd, Mack LA, Wang KY, Jackins SE, Richardson ML, Matsen FA 3rd. Repairs of the rotator cuff. Correlation of functional results with integrity of the cuff. J Bone Joint Surg Am 1991;73:982-9.
28. Huijsmans PE, Pritchard MP, Berghs BM, van Rooyen KS, Wallace AL, de Beer JF. Arthroscopic rotator cuff repair with double-row fixation. J Bone Joint Surg Am 2007;89:1248-57. https://doi.org/10.2106/JBJS.E.00743
29. Iannotti JP, Zlatkin MB, Esterhai JL, Kressel HY, Dalinka MK, Spindler KP. Magnetic resonance imaging of the shoulder. Sensitivity, specificity, and predictive value. J Bone Joint Surg Am 1991;73:17-29.
30. Ide J, Tokiyoshi A, Hirose J, Mizuta H. Arthroscopic repair of traumatic combined rotator cuff tears involving the subscapularis tendon. J Bone Joint Surg Am 2007;89:2378-88. https://doi.org/10.2106/JBJS.G.00082
31. Jeong HY, Kim HJ, Jeon YS, Rhee YG. Factors predictive of healing in large rotator cuff tears: is it possible to predict retear preoperatively? Am J Sports Med 2018;46:1693-700. https://doi.org/10.1177/0363546518762386
32. Jeong HJ, Kim HS, Rhee S-M, Oh JH. Risk factors for and prognosis of folded rotator cuff tears: a comparative study using propensity score matching. J Shoulder Elbow Surg 2021;30:826-35. https://doi.org/10.1016/j.jse.2020.07.010
33. Jeong JY, Song SY, Yoo JC, Park KM, Lee SM. Comparison of outcomes with arthroscopic repair of acute-on-chronic within 6 months and chronic rotator cuff tears. J Shoulder Elbow Surg 2017;26:648-55. https://doi.org/10.1016/j.jse.2016.09.032
34. Kannus P, Paavola M, Józsa L. Aging and degeneration of tendons. In: Maffulli N, Renström P, Leadbetter WB, editors. Tendon Injuries. London: Springer London; 2005. p. 25-31.
35. Khosla S, Riggs BL. Pathophysiology of age-related bone loss and osteoporosis. Endocrinol Metab Clin North Am 2005;34:1015-30. https://doi.org/10.1016/j.ecl.2005.07.009. xi.
36. Kim Y-K, Jung K-H, Kim J-W, Kim U-S, Hwang D-H. Factors affecting rotator cuff integrity after arthroscopic repair for medium-sized or larger cuff tears: a retrospective cohort study. J Shoulder Elbow Surg 2018;27:1012-20. https://doi.org/10.1016/j.jse.2017.11.016
37. Kwon J, Kim SH, Lee YH, Kim TI, Oh JH. The rotator cuff healing index: a new scoring system to predict rotator cuff healing after surgical repair. Am J Sports Med 2019;47:173-80. https://doi.org/10.1177/0363546518810763
38. Ladermann A, Denard PJ, Collin P. Massive rotator cuff tears: definition and treatment. Int Orthop 2015;39:2403-14. https://doi.org/10.1007/s00264-015-2796-5
39. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
40. Lansdown DA, Lee S, Sam C, Krug R, Feeley BT, Ma CB. A prospective, quantitative evaluation of fatty infiltration before and after rotator cuff repair. Orthop J Sports Med 2017;5:2325967117718537. https://doi.org/10.1177/2325967117718537
41. Le BT, Wu XL, Lam PH, Murrell GA. Factors predicting rotator cuff retears: an analysis of 1000 consecutive rotator cuff repairs. Am J Sports Med 2014;42:1134-42. https://doi.org/10.1177/0363546514525336
42. Lee YS, Jeong JY, Park CD, Kang SG, Yoo JC. Evaluation of the risk factors for a rotator cuff retear after repair surgery. Am J Sports Med 2017;45:1755-61. https://doi.org/10.1177/0363546517695234
43. Lee KW, Seo DW, Bae KW, Choy WS. Clinical and radiological evaluation after arthroscopic rotator cuff repair using suture bridge technique. Clin Orthop Surg 2013;5:306-13. https://doi.org/10.4055/cios.2013.5.4.306
44. Lundgreen K, Lian OB, Scott A, Nassab P, Fearon A, Engebretsen L. Rotator cuff tear degeneration and cell apoptosis in smokers versus nonsmokers. Arthroscopy 2014;30:936-41. https://doi.org/10.1016/j.arthro.2014.03.027
45. Ma J, Piuzzi NS, Muschler GF, Iannotti JP, Ricchetti ET, Derwin KA. Biomarkers of rotator cuff disease severity and repair healing. JBJS Rev 2018;6:e9. https://doi.org/10.2106/JBJS.RVW.17.00178
46. McElvany MD, McGoldrick E, Gee AO, Neradilek MB, Matsen FA 3rd. Rotator cuff repair: published evidence on factors associated with repair integrity and clinical outcome. Am J Sports Med 2015;43:491-500. https://doi.org/10.1177/0363546514529644
47. Mochizuki T, Sugaya H, Uomizu M, Maeda K, Matsuki K, Sekiya I, et al. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. Surgical technique. J Bone Joint Surg Am 2009;91(Suppl 2 Pt 1):1-7. https://doi.org/10.2106/JBJS.H.01426
48. Mukovozov I, Byun S, Farrokhyar F, Wong I. Time to surgery in acute rotator cufftear: a systematic review. Bone Joint Res 2013;2:122-8. https://doi.org/10.1302/2046-3758.27.2000164
49. Namdari S, Donegan RP, Dahiya N, Galatz LM, Yamaguchi K, Keener JD. Characteristics of small to medium-sized rotator cuff tears with and without disruption of the anterior supraspinatus tendon. J

Shoulder Elbow Surg 2014;23:20-7. https://doi.org/10.1016/j.jse.2013.05.015
50. Nguyen ML, Quigley RJ, Galle SE, McGarry MH, Jun BJ, Gupta R, et al. Margin convergence anchorage to bone for reconstruction of the anterior attachment of the rotator cable. Arthroscopy 2012;28:1237-45. https://doi.org/10.1016/j.arthro.2012.02.016
51. Oh JH, Kim SH, Ji HM, Jo KH, Bin SW, Gong HS. Prognostic factors affecting anatomic outcome of rotator cuff repair and correlation with functional outcome. Arthroscopy 2009;25:30-9. https://doi.org/10.1016/j.arthro.2008.08.010
52. Park JS, Park HJ, Kim SH, Oh JH. Prognostic factors affecting rotator cuff healing after arthroscopic repair in small to medium-sized tears. Am J Sports Med 2015;43:2386-92. https://doi.org/10.1177/0363546515594449
53. Raman J, Walton D, MacDermid JC, Athwal GS. Predictors of outcomes after rotator cuff repair—a meta-analysis. J Hand Ther 2017;30:276-92. https://doi.org/10.1016/j.jht.2016.11.002
54. Ranebo MC, Bjornsson Hallgren HC, Holmgren T, Adolfsson LE. Surgery and physiotherapy were both successful in the treatment of small, acute, traumatic rotator cuff tears: a prospective randomized trial. J Shoulder Elbow Surg 2020;29:459-70. https://doi.org/10.1016/j.jse.2019.10.013
55. Rhee YG, Cho NS, Yoo JH. Clinical outcome and repair integrity after rotator cuff repair in patients older than 70 years versus patients younger than 70 years. Arthroscopy 2014;30:546-54. https://doi.org/10.1016/j.arthro.2014.02.006
56. Rimmke N, Maerz T, Cooper R, Yadavalli S, Anderson K. Arthroscopic suture bridge rotator cuff repair: functional outcome, repair integrity, and preoperative factors related to postoperative outcome. Phys Sportsmed 2016;44:126-32. https://doi.org/10.1080/00913847.2016.1168271
57. Sethi PM, Sheth CD, Pauzenberger L, McCarthy MBR, Cote MP, Soneson E, et al. Macroscopic rotator cuff tendinopathy and histopathology do not predict repair outcomes of rotator cuff tears. Am J Sports Med 2018;46:779-85. https://doi.org/10.1177/0363546517746986
58. Shrier I, Platt RW. Reducing bias through directed acyclic graphs. BMC Med Res Methodol 2008;8:70. https://doi.org/10.1186/1471-2288-8-70
59. Sugaya H, Maeda K, Matsuki K, Moriishi J. Repair integrity and functional outcome after arthroscopic double-row rotator cuff repair. A prospective outcome study. J Bone Joint Surg Am 2007;89:953-60. https://doi.org/10.2106/JBJS.F.00512
60. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. Clin Sports Med 2012;31:589-604. https://doi.org/10.1016/j.csm.2012.07.001
61. Tashjian RZ, Hollins AM, Kim HM, Teefey SA, Middleton WD, Steger-May K, et al. Factors affecting healing rates after arthroscopic double-row rotator cuff repair. Am J Sports Med 2010;38:2435-42. https://doi.org/10.1177/0363546510382835
62. Textor J, van der Zander B, Gilthorpe MS, Liskiewicz M, Ellison GT. Robust causal inference using directed acyclic graphs: the R package 'dagitty'. Int J Epidemiol 2016;45:1887-94. https://doi.org/10.1093/ije/dyw341
63. Tsuchiya S, Bois AJ, Matthewson G, Oiwa S, More KD, Lo IKY. The relationship between preoperative Goutallier stage and retear rates following posterosuperior rotator cuff repair: a systematic review. J Shoulder Elbow Surg 2023;32:435-43. https://doi.org/10.1016/j.jse.2022.09.011
64. Wu XL, Briggs L, Murrell GA. Intraoperative determinants of rotator cuff repair integrity: an analysis of 500 consecutive repairs. Am J Sports Med 2012;40:2771-6. https://doi.org/10.1177/0363546512462677
65. Zhaeentan S, Von Heijne A, Stark A, Hagert E, Salomonsson B. Similar results comparing early and late surgery in open repair of traumatic rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2016;24:3899-906. https://doi.org/10.1007/s00167-015-3840-0
66. Zhao J, Luo M, Pan J, Liang G, Feng W, Zeng L, et al. Risk factors affecting rotator cuff retear after arthroscopic repair: a meta-analysis and systematic review. J Shoulder Elbow Surg 2021;30:2660-70. https://doi.org/10.1016/j.jse.2021.05.010