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Combination of risk factors affecting retear after arthroscopic rotator cuff repair: a decision tree analysis

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Background: Several risk factors for postoperative retear after arthroscopic rotator cuff repair (ARCR) have been cited in a large number of reports; various combinations of these seem to be present in the clinical setting.
Purpose: Using a combination model for decision tree analysis, we aimed to investigate the combination of risk factors that affect postoperative retear the most.
Methods: A total of 286 patients who underwent magnetic resonance (MR) imaging at 6 months after surgery were included in this study. Based on the structural integrity of the MR images taken 6 months after surgery, the patients were divided into a healed group (intact tendon, 254 patients) and a retear group (ruptured tendon, 32 patients). Using univariate and decision tree analyses, we selected a combination of 11 risk factors that drastically affected postoperative retear.
Results: The mean age was 64.9 ± 7.1 years, and the mean symptom duration was 9.7 ± 11.6 months. The tear was small/medium in 177 patients and large/massive in 109 patients. The technique for surgical repair was single row in 42 patients, double row in 60 patients, and suture bridging in 216 patients. On univariate analysis, both groups had significant differences in the anteroposterior (AP) tear size ($P < .0001$), mediolateral tear size ($P < .0001$), hyperlipidemia ($P = .0178$), global fatty degeneration index ($P < .0001$), supraspinatus fatty degeneration stage ($P < .0001$), and critical shoulder angle (CSA) ($P = .0015$). All of these 5 risk factors, except for mediolateral tear size, were selected as candidates for the decision tree analysis. Eight combination patterns were determined to have prediction probabilities that ranged from 4.3% to 86.1%. In particular, the combination of an AP tear size of ≥40 mm, hyperlipidemia, and a CSA of ≥37° affected retear after ARCR the most.

The study was approved by the Health Sciences Institutional Review Board of Fukuoka Shion Hospital (approval no. 7).

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Conclusions: Decision tree analysis lead to the extraction of different retear factor combinations, which were divided into 5 retear groups. The worst combination was of AP tear size ≥40 mm, hyperlipidemia, and CSA ≥37°, and the prediction probability of this combination was 86.2%. Therefore, our data may offer a new index for the prediction of retear after ARCR.
Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Retear after arthroscopic rotator cuff repair; combination of risk factors; decision tree analysis; predictive retear factors; preoperative factors; prediction probability

A large number of studies have reported the risk factors for postoperative retear after arthroscopic rotator cuff repair (ARCR). Diebold et al[10] showed a close relationship between age and retear, the rate of which was relatively low in patients in their 50s to 60s but increased linearly in patients in their 70s. Le et al[20] demonstrated that anteroposterior (AP) tear length, tear area, and tear thickness were strongly related to postoperative retear. In a report by Jeong et al,[17] postoperative retear was shown to be affected by supraspinatus muscle atrophy with an occupation ratio of <43% atrophy or infraspinatus and fatty infiltration stage 2 or higher by the Goutallier classification.

Recently, Garcia et al[12] described the relationship between the critical shoulder angle (CSA) and postoperative retear, with an increased odds ratio of 14.8 for a CSA of >38°. As mentioned above, it is considered that the condition of the preoperative tear obtained from the image findings has a great effect on postoperative retear.

Other than the structural factors mentioned above, systemic factors have been found to be involved in retear after surgery. Chung et al[8] reported that the bone mineral density is one of the independent factors affecting postoperative retear. Cho et al[6] reported that diabetic patients have a significantly high retear rate and that effective glycemic control is associated with a better rate of healing after rotator cuff repair. Garcia et al[13] reported that hyperlipidemia has a significantly high retear rate, with an odds ratio of 6.5. These studies report the importance of confirming the presence and status of preoperative systemic factors.

In actual clinical practice, patients who develop postoperative retear have various combinations of risk factors described above. Therefore, predicting the probability of retear in patients with these factors is of great importance before surgery. The purpose of this study was to investigate the combination of risk factors that most affect postoperative retear, using a combination model for a decision tree analysis.

Materials and methods

Subjects

Between 2011 and 2017, a total of 321 patients underwent ARCR at our hospital. Of these, 25 patients were excluded because of irreparable rotator cuff tendons. Consequently, a total of 286 patients who underwent magnetic resonance (MR) imaging to assess the repair integrity at 6 months after surgery were included in this study. The patients were then divided into a healed group (intact tendon, 254 patients) and a retear group (retear tendon, 32 patients).

Surgical procedure

All the operations were performed by a single senior surgeon. Under general anesthesia, each patient was placed in a beach-chair position. In the respective healed and retear groups, the surgical repair procedure was single row in 35 and 7 patients, double row in 54 and 6 patients, and suture bridging in 197 and 19 patients. Acromioplasty, tenotomy, and mobilization, including capsulotomy, were performed as necessary.

All patients underwent a standard postoperative rehabilitation program. Passive exercises were started within a few days, and assistive self-assisted exercises were started after 3 weeks. Active exercise was permitted at 5 weeks for patients with small/medium tears, or 9 weeks for patients with large/massive tears. Isometric training was started at 9 weeks, and isotonic strength training was started at 4 months.

Outcome measures

We investigated the following 11 variables that have been previously reported: age[8,21]; AP tear width and mediolateral tear length[2,8,14,16,18,20,21]; fatty infiltration of the rotator cuff muscles (ie, supraspinatus, infraspinatus, and subscapularis) and global fatty degeneration index[2,8,17,21]; CSA[12,22]; hyperlipidemia,[13] cholesterol level, diabetes mellitus,[8] and smoking[26]; and surgical technique (ie, single-row, double-row, and suture bridging).[4,6,15,27,30] Hyperlipidemia and diabetes mellitus were defined by the primary care physician who treated the patient at the time of evaluation. The cholesterol and glycated hemoglobin (HbA1c) levels were based on preoperative blood test data. The smoking status (ie, average number per day) was directly asked and confirmed from each patient at the time of admission.

The preoperative tear size was measured, with reference to the report of Davidson et al.[9] The maximum AP tear width was measured on T2-weighted sagittal MR images. The maximum mediolateral tear length was measured on T2-weighted oblique-coronal MR images. Based on the report of Fukuta et al,[11] and using Y-shaped MR images with 2 slices inside (1 slice: 3 mm), the preoperative fatty infiltration of the rotator cuff muscles was measured according to the Goutallier classification. As defined by Moor et al,[25] the preoperative CSA was measured using a line that connected the superior and the inferior bony margins of the glenoid and an intersecting line drawn from the inferior bony margin of the glenoid to the most lateral border of the acromion.

The postoperative integrity of the repaired tendon was assessed at 6 months after surgery. A diagnosis of retear was made when a fluid-equivalent signal was found or when the rotator cuff tendon was not visualized on more than 1 T2-weighted image (referent).[28] Functional outcomes were evaluated by shoulder scoring, using the Japanese Orthopedic Association (JOA) and the University of California at Los Angeles (UCLA) systems. These functional outcome assessments were performed preoperatively and postoperatively.

Statistical analysis

The primary objective of the data analyses was to construct clinically interpretable risk profiles. To this end, 11 risk factors for retear after surgery were identified through previously reported researches. These risk factors were used in a classification and regression tree model to extract the risk profiles that were defined as an asymmetric combination of risk factors. In order to ensure clinical interpretability, the maximum depth of the tree diagram was 3, the minimum number of cases in the target group (parent node) before division was 10, and the target groups after division (child nodes) were 3.

Data are presented as the mean ± standard deviation. The total JOA/UCLA score and the demographic data were compared between the healed and retear groups using the unpaired *t* test or the Mann-Whitney *U* test, as appropriate. The risk factors were compared between the 2 groups using the chi-square test or Fisher exact test. P values <.05 were considered statistically significant. All statistical analyses were performed using JMP 13 software (SAS Institute, Cary, NC, USA).

Results

The respective data for the healed and retear groups were a mean age of 64.7 ± 7.3 years and 66.8 ± 5.4 years, a male-to-female ratio of 160:126 and 22:10, a mean body mass index of 23.9 ± 0.2 and 24.6 ± 0.6, arm dominance of 70.1% and 56.5%, symptom duration of 9.3 and 12.6 months, small/medium tear in 169 and 8 patients, and large massive tear in 85 and 24 patients.

Compared with the preoperative measures, the postoperative measures significantly improved from 68.9 to 81.3 points for the total JOA score and from 16.5 to 26.4 points for the total UCLA score ($P < .001$ for both). However, there were no significant differences between the 2 groups in both scores before and after surgery (Table I). On univariate analysis, the healed and retear groups significantly differed in several variables, including AP tear width ($P < .0001$), mediolateral tear length ($P < .0001$), hyperlipidemia ($P = .0178$), global fatty degeneration index ($P < .0001$), stage of the supraspinatus ($P < .0001$), infraspinatus ($P < .0001$), subscapularis ($P < .0001$), and CSA ($P < .0015$) (Table I).

To extract the potential risk factors for retear, a decision tree analysis was performed using AP tear width; mediolateral tear length; hyperlipidemia; global fatty degeneration index; Goutallier stage of supraspinatus, infraspinatus, and subscapularis; and CSA as independent variables and retear as the dependent variable.

Five profiles were constructed using an asymmetrical combination of AP tear size, hyperlipidemia, CSA, and supraspinatus Goutallier stage based on the tree model. As depicted in Figure 1, the first profile group was defined as patients whose AP tear size was >40 mm, hyperlipidemia was positive, and CSA was ≥37°. The proportion of retear in this group was 86.2%. The other 4 patient profile groups were defined in a similar manner (Fig. 1).

The first profile group's retear proportion was 100%, indicating this as the highest-risk group. To examine the risk of retear between the 5 profiles, odds ratio was estimated. To this end, we combined the first and second group because the proportion of retear in the first group was 100%. Then, logistic regression model was fitted using 4 groups, and the high-risk group had ① to ②, middle-risk group had ③ to ④, and the low-risk group had ⑤, which were defined by comparing the odds ratio obtained from the model (Fig. 2). The total prediction probability rate (① and ②) for the high-risk group was significantly higher than that for the low-risk group (50.8% [8/15] vs. 4.3% [9/213]), with an odds ratio of 25.9 ($P < .0001$). Similarly, the results of the odds ratio of the middle-risk vs. low-risk and of the high-risk vs. low-risk groups are shown in Table II.

Discussion

In most previous studies in which the risk factors for retear after ARCR were examined, multivariate logistic regression analyses were used.[7,10,14,17,18,21,26] Although such analysis can extract significant and independent explanatory variables, evaluation of the correlations among these variables may be difficult. In contrast, a decision tree analysis is a useful method that can construct predictions in a tree diagram for the analysis of multiple combination effects of these risk factors. The present study successfully used this analysis to demonstrate that AP tear size, hyperlipidemia, and CSA are the factors that most affect postoperative retear. Specifically, AP tear size of ≥40 mm, hyperlipidemia, and CSA of ≥37° increased the prediction probability for retear to 86.2%.

Kwon et al[19] developed a scoring system as an index to predict healing after ARCR. In their report, the significant independent variable among age, AP and mediolateral tear size, fatty infiltration of the infraspinatus, low bone mineral density, and high activity level of work was extracted by logistic regression analysis and used as the scoring variable. Their total score was calculated using the odds ratio as weighting (eg, the predicted retear rate was 86.2% when the score was ≥10 out of the maximum possible of 15 points).

Table I Combination variables between the healed and retear outcome groups.

	Total (n = 286)	Healed (n = 254)	Retear (n = 32)	*P* value
Age, yr	64.9 ± 7.1	64.7 ± 7.3	66.8 ± 5.4	.1144
Sex, male/female, n	160/126	138/116	22/10	.1215
Body mass index	24.0 ± 0.2	23.9 ± 0.2	24.6 ± 0.6	.2865
Arm dominance, right:left	68.6	70.1	56.5	.0622
Symptom duration, mo	9.7 ± 11.6	9.3 ± 9.9	12.6 ± 18.8	.0778
Tear size				
Medium	177	169	8	
Large	84	70	14	
Massive	25	15	10	
Surgical technique, n				.3401
Single row	38	31	7	
Double row	54	48	6	
Brigding suture	194	175	19	
LHB, tenotomy	27	21	6	
Subscapularis tear	23	15	8	
ASD	267	236	31	
Mobilization	83	71	12	
Medialization	44	36	8	
Smokers, n (%)	41 (14.3)	37 (14.6)	4 (12.5)	.7532
Times smoked per day, mean	17.4	17.3	18.5	
Hyperlipidemia, n (%)	61 (21.3)	49 (19.3)	12 (37.5)	.0178*
Cholesterol level, mg/dL	209 ± 34.7	198.1 ± 42.8	210.6 ± 33.5	.0594
Diabetes mellitus, n (%)	42 (14.7)	36 (14.2)	6 (18.8)	.4906
HbA1c, %	6.5	6.5	6.7	
Tear width, mm	27.8 ± 11.4	26.4 ± 10.4	38.4 ± 13.2	<.0001†
Tear length, mm	27.6 ± 9.8	26.7 ± 9.3	34.7 ± 10.5	<.0001†
GFDI	1.00 ± 0.68	0.93 ± 0.64	1.63 ± 0.71	<.0001†
Goutallier stage				
Supraspinatus	1.56 ± 0.98	1.47 ± 0.96	2.25 ± 0.92	<.0001†
Infraspinatus	0.88 ± 0.86	0.81 ± 0.83	1.43 ± 0.91	<.0001†
Subscapularis	0.57 ± 0.85	0.49 ± 0.74	1.19 ± 1.31	<.0001†
Critical shoulder angle	33.7 ± 3.61	33.5 ± 3.54	35.7 ± 3.72	.0015†
JOA score				
Preoperative	68.9 ± 13.7	69.4 ± 1.2	65.6 ± 3.4	.2968
Postoperative	81.3 ± 9.6	81.8 ± 0.9	77.7 ± 2.4	.1121
UCLA score				
Preoperative	16.5 ± 3.6	16.6 ± 0.3	15.8 ± 0.9	.3574
Postoperative	26.4 ± 5.7	26.7 ± 0.5	24.3 ± 1.4	.1114

LHB, long head of biceps; *ASD*, arthroscopic subacromial decompression; *HbA1c*, glycated hemoglobin; *GFDI*, global fatty degeneration index; *JOA*, Japanese Orthpaedic Association; *UCLA*, University of California at Los Angeles shoulder score.
Unless otherwise noted, values are mean ± standard deviation.
* Statistically significant ($P < .05$) among the 2 groups with the chi-square test or Fisher exact test.
† Statistically significant ($P < .05$) among the 2 groups with the unpaired *t* test or the Mann-Whitney *U* test.

Thus, compared with multivariate analysis that independently extracts significant variables in a sample population, the decision tree analysis is relatively suitable for predicting retear because this analysis can directly identify patients who are likely to retear and it can clearly anticipate its probability in these patients.

Previous studies have emphasized the importance of tear size as a risk factor for postoperative retear.[2,14,21] Tear size affected tendon healing rates, but this effect was more pronounced when evaluated on the sagittal plane rather than the coronal plane.[5] Le et al[20] concluded that AP tear size was the most important independent risk factor for postoperative retear in 1000 patients with ARCR. Consistently, in the decision tree analysis, AP tear size was chosen as the best bifurcation variable, with a cutoff value of 40 mm. Given the fact that the mean maximum length of the supraspinatus and infraspinatus footprints was 12.6 and 32.7 mm, respectively,[24] this cutoff value may be valid.

An experimental animal study demonstrated the deleterious effects of hypercholesterolemia on tendon-to-bone healing, and decreasing hypercholesterolemia improved the

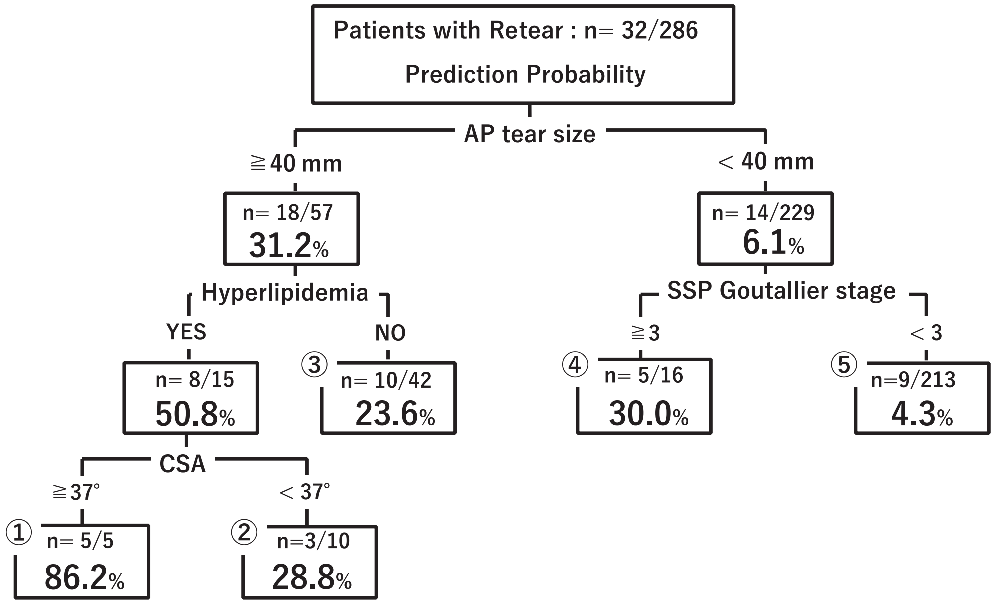

Figure 1 Decision tree model for the prediction of retear. *AP*, anteroposterior; *SSP*, supraspinatus; *CSA*, critical shoulder angle.

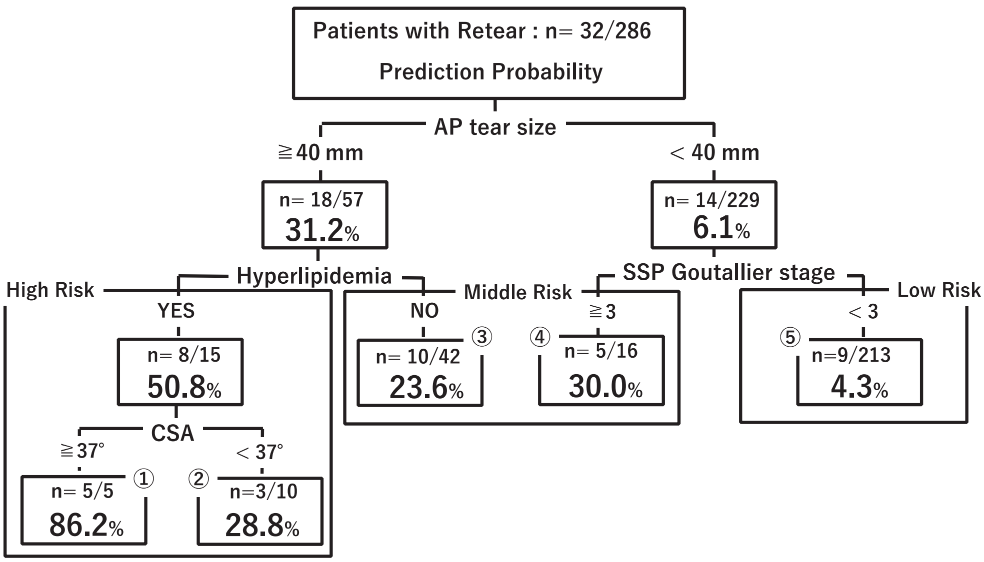

Figure 2 Risk group classification by decesion tree model. *AP*, anteroposterior; *SSP*, supraspinatus; *CSA*, critical shoulder angle.

negative effects.[3,7] Abbound et al[1] reported that compared with controls, patients with rotator cuff tears had significantly more severe hypercholesterolemia, with significantly higher total cholesterol and triglyceride levels and lower low-density lipoprotein levels. Garcia et al[13] reported that hyperlipidemia contributed to postoperative retear, with an odds ratio of 6.5. In this study, the coexistence of hyperlipidemia further increased retear probability when AP tear size significantly indicated retear at risk (AP size of ≥40 mm: 31.2%; AP size of ≥40 mm + hyperlipidemia: 50.8%).

CSA of ≥35° was an indicator of the risk for developing rotator cuff tear.[25] Using a finite element analysis, Viehofer et al[29] showed that the joint shear force was significantly higher at a CSA of 38° than at a CSA of 33°, implying that the biomechanical stress to the rotator cuff increased as the CSA increased. Garcia et al[12] showed that preoperative CSA was significantly higher in the postoperative retear group (38.6°, odds ratio: 14.8) than in the healed and partial repair groups. In the present study, CSA is also considered to be an important risk factor for retear. When CSA

Table II Retear odds ratio for each profiles.

Profiles	Odds ratio	95% confidence interval	*P* value
High risk vs. low risk	25.9	7.69, 87.2	<.0001
Middle risk vs. low risk	7.91	3.25, 19.2	<.0001
High risk vs. middle risk	3.28	1.01, 10.6	.0473

combined with AP tear size and the presence of hyperlipidemia reached significance of retear at risk, the prediction probability for retear further increased (AP size of ≥40 mm + hyperlipidemia + CSA of ≥37°: 86.2%).

This study had some limitations. First, it was a retrospective cohort study with a small number of samples. Second, postoperative retear was evaluated at 6 months after surgery; notably, the validity of our data was supported because most cases of retear occur within 3 months after surgery.[23] Third, a single surgeon performed the surgeries, but multiple different techniques were used. Fourth, several other risk factors, such as osteoporosis, were not included in this study, and this may have affected our data. On the other hand, the strength of this study lay in its use of a decision tree analysis, which enabled us to successfully demonstrate the combination of risk factors in a step-by-step manner.

Conclusions

Based on the decision tree analysis, the risk factors that affect retear after ARCR the most were an AP tear size of ≥40 mm, hyperlipidemia, and a CSA of ≥37°. Moreover, the coexistence of these factors increased the prediction probability for retear to 86.2%.

Disclaimer

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References

1. Abboud JA, Kim JS. The effect of hypercholesterolemia on rotator cuff disease. Clin Orthop Relat Res 2010;468:1493-7. https://doi.org/10.1007/s11999-009-1151-9
2. Barth J, Andrieu K, Fotiadis E, Hannink G, Barthelemy R, Saffarini M. Critical period and risk factors for retear following arthroscopic repair of the rotator cuff. Knee Surgery. Sport Traumatol Arthrosc 2017;25:2196-204. https://doi.org/10.1007/s00167-016-4276-x
3. Beason DP, Tucker JJ, Lee CS, Edelstein L, Abboud JA, Soslowsky LJ. Rat rotator cuff tendon-to-bone healing properties are adversely affected by hypercholesterolemia. J Shoulder Elbow Surg 2014;23:867-72. https://doi.org/10.1016/j.jse.2013.08.018
4. Bedeir YH, Schumaier AP, Abu-Sheasha G, Grawe BM. Type 2 retear after arthroscopic single-row, double-row and suture bridge rotator cuff repair: a systematic review. Eur J Orthop Surg Traumatol 2018;29:373-82. https://doi.org/10.1007/s00590-018-2306-8
5. Boileau P, Brassart N, Watkinson DJ, Caries M, Hatzidakis AM, Krishnan SG. Arthoroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 2005;87:1229-40. https://doi.org/10.2106/JBJS.D.02035
6. Cho NS, Moon SC, Jeon JW, Rhee YG. The influence of diabetes mellitus on clinical and structural outcomes after arthroscopic rotator cuff repair. Am J Sports Med 2015;43:991-7. https://doi.org/10.1177/0363546514565097
7. Chung SW, Park H, Kwon J, Choe GY, Kim SH, Oh JH. Effect of hypercholesterolemia on fatty infiltration and quality of tendon-to-bone healing in a rabbit model of a chronic rotator cuff tear: electrophysiological, biomechanical, and histological analyses. Am J Sports Med 2016;44:1153-64. https://doi.org/10.1177/0363546515627816
8. Chung SW, Oh JH, Gong HS, Kim JY, Kim SH. Factors affecting rotator cuff healing after arthroscopic repair. Am J Sports Med 2011;39:2099-107. https://doi.org/10.1177/0363546511415659
9. Davidson J, Burkhart SS. The geometric classification of rotator cuff tears: a system linking tear pattern to treatment and prognosis. Arthroscopy 2010;26:417-24. https://doi.org/10.1016/j.arthro.2009.07.009
10. Diebold G, Lam P, Walton J, Murrell GAC. Relationship between age and rotator cuff repair: a study of 1,600 consecutive cuff repairs. J Bone Joint Surg Am 2017;99:1198-205. https://doi.org/10.2106/JBJS.16.00770
11. Fukuta S, Tsutsui T, Amari R, Wada K, Sairyo K. Tendon retraction with rotator cuff tear causes a decrease in cross-sectional area of the supraspinatus muscle on magnetic resonance imaging. J Shoulder Elbow Surg 2016;25:1069-75. https://doi.org/10.1016/j.jse.2015.11.008
12. Garcia GH, Liu JN, Degen RM, Johnson CC, Wong AC, Dines DM, et al. Higher critical shoulder angle increases the risk of retear after rotator cuff repair. J Shoulder Elbow Surg 2017;26:241-5. https://doi.org/10.1016/j.jse.2016.07.009
13. 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
14. Gwark JY, Sung CM, Na JB, Park HB. Outcomes of arthroscopic rotator cuff repair in patients who are 70 years of age or older versus under 70 years of age: a sex- and tear size-matched case-control study. Arthroscopy 2018;34:2045-53. https://doi.org/10.1016/j.arthro.2018.02.047
15. Hashiguchi H, Iwashita S, Sonoki K, Abe K, Yoneda M, Takai S. Clinical outcomes and structural integrity of arthroscopic double-row versus suture-bridge repair for rotator cuff tears. J Orthop 2018;15:396-400. https://doi.org/10.1016/j.jor.2018.03.012
16. Hein J, Reilly JM, Chae J, Maerz T, Anderson K. Retear rates after arthroscopic single-row, double-row, and suture bridge rotator cuff repair at a minimum of 1 year of imaging follow-up: a systematic review. Arthroscopy 2015;31:2274-81. https://doi.org/10.1016/j.arthro.2015.06.004
17. 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
18. Kim YK, Jung KH, Kim JW, Kim US, Hwang DH. Factors affecting rotator cuff integrity after arthroscopic repair for medium-sized or larger or cuff tears. J Shoulder Elbow Surg 2018;27:1012-20. https://doi.org/10.1016/j.jse.2017.11.016
19. 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

20. 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
21. 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
22. Li H, Chen Y, Chen J, Hua Y, Chen S. Large critical shoulder angle has higher risk of tendon retear after arthroscopic rotator cuff repair. Am J Sports Med 2018;46:1892-900. https://doi.org/10.1177/0363546518767634
23. Miller BS, Downie BK, Kohen RB, Kijek T, Lesniak B, Jacobson JA, et al. When do you rotator cuff repairs fall? Serial ultrasound examination after arthroscopic repair of large and massive rotator cuff tears. Am J Sports Med 2011;39:2064-70. https://doi.org/10.1177/0363546511413372
24. 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. J Bone Joint Surg Am 2009;91(Suppl 2, Pt 1):1-7. https://doi.org/10.2106/JBJS.H.01426
25. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint? Bone Joint J 2013;95:935-41. https://doi.org/10.1302/0301-620X.95B7.31028
26. Park JH, Oh KS, Kim TM, Kim J, Yoon JP, Kim JY, et al. Effect of Smoking on Healing Failure After Rotator Cuff Repair. Am J Sports Med 2018;46:2960-8. https://doi.org/10.1177/0363546518789691
27. Shin YK, Ryu KN, Park JS, Jin W, Park SY, Yoon YC. Predictive factors of retear in patients with repaired rotator cuff tear on shoulder MRI. AJR Am J Roentgenol 2018;210:134-41. https://doi.org/10.2214/AJR.17.17915
28. Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repairs: single-row versus dual-row fixation. Arthroscopy 2005;21:1307-16. https://doi.org/10.1016/j.arthro.2005.08.011
29. Viehöfer AF, Gerber C, Favre P, Bachmann E, Snedeker JG. A larger critical shoulder angle requires more rotator cuff activity to preserve joint stability. J Orthop Res 2016;34:961-8. https://doi.org/10.1002/jor.23104
30. Wade R, Salgar S. Clinico-radiological evaluation of retear rate in arthroscopic double row versus single row repair technique in full thickness rotator cuff tear. J Orthop 2017;14:313-8. https://doi.org/10.1016/j.jor.2017.01.001