A Comprehensive Evaluation of Factors Affecting Healing, Range of Motion, Strength, and Patient-Reported Outcomes After Arthroscopic Rotator Cuff Repair

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Background: Rotator cuff repair (RCR) leads to improved patient outcomes, which may or may not coincide with biological healing of the tendon. Many patient factors may play a role in subjective and objective patient outcomes of surgery.

Purpose: To evaluate the effect of various patient factors and tendon healing on range of motion, strength, and functional outcomes after arthroscopic RCR.

Study Design: Case-control study; Level of evidence, 3.

Methods: We reviewed patients who underwent arthroscopic RCR. Postoperative endpoints included physical examination, repeat magnetic resonance imaging (MRI), and patient-reported outcome measures. The Short Form–36 (SF-36) was also completed at enrollment. Physical examination included range of motion and strength testing. Preoperative tear characteristics and postoperative healing on MRI were recorded. Associations between these characteristics and rotator cuff healing were determined. Multivariate models investigated factors affecting healing and final outcomes.

Results: A total of 81 patients had MRI before and a minimum of 1 year after RCR. Patient-reported outcomes were available for all patients at mean 2.7 years (range, 1-7.7 years) after RCR. Seventy-five patients had physical examination data. Patients were less likely to heal if they had tears involving multiple tendons ($P = .037$), tears >2.2 cm ($P = .037$), tears retracted >2.0 cm ($P = .006$), and tears with cumulative Goutallier grade ≥ 3 ($P = .003$). Patients who healed were stronger on manual muscle testing in forward elevation ($P < .001$) and external rotation ($P = .005$) and on forward elevation isometric testing ($P = .033$), and they reported better patient-reported outcomes ($P \leq .01$) at final follow-up. In multivariate models, tendon healing was associated with less pain ($P = .019$) and better patient-reported outcomes (all $P \leq .006$). Lower SF-36 mental component summary (MCS) score was associated with increased pain ($P = .025$) and lower final American Shoulder and Elbow Surgeons score ($P = .035$), independent of healing status.

Conclusion: Larger, more retracted tears with greater fatty infiltration are less likely to heal per MRI. Patients who do not heal are weaker and have worse patient-reported outcome measures. Lower SF-36 MCS score was associated with poorer patient-reported outcomes independent of tendon healing.

Keywords: rotator cuff repair; healing; patient-reported outcome; strength; range of motion; mental health

Rotator cuff tears are a common etiology of patient-reported shoulder pain and dysfunction.[11,26] These can lead to patient pain, loss of shoulder function, and decreased quality of life.[26] For these reasons, many patients elect to undergo rotator cuff repair (RCR), with >250,000 RCRs performed per year in the United States.[7] Most patients experience improvements in pain and function after repair.[14] However, most patients do not undergo follow-up imaging of their repair unless they continue to be symptomatic or have a repeat injury. Therefore, the morphologic status of their RCR is often unknown. Some reports have shown that healing of the rotator cuff leads to decreased pain and increased function, while other groups have reported no association between tendon healing and patient improvement after surgery.[2,8,13-15] A recent study of long-term outcomes showed higher Constant total and Constant strength scores among those with tendon healing.[10]

Most outcomes studies involving the RCR have reported patient-reported outcome measures related to pain and shoulder function, such as the American Shoulder and Elbow Surgeons (ASES) score, the Constant score, the

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visual analog scale (VAS) for shoulder pain, and the Simple Shoulder Test (SST), among others.[12,29] Actual tendon healing was evaluated in 65% of studies, with magnetic resonance imaging (MRI) being used in 38% of studies and ultrasound in 31%.[12] Physical examination data, including range of motion and strength, are not commonly reported. Some degree of range of motion data was reported by 63% of studies, and 38% cited at least 1 strength measure at follow-up.[12] Comprehensive reporting of strength, range of motion, healing, and validated patient-reported outcome measures after RCR is relatively uncommon, and reporting of at least 1 measure from each of these categories occurred in only 21% of rotator cuff outcomes studies.[12]

The purpose of our study was (1) to report on patients with a comprehensive evaluation after arthroscopic RCR, including MRI evaluation of tendon healing, patient-reported outcome measures for the shoulder, and physical examination data, including strength and range of motion, and (2) to determine the preoperative MRI findings predictive of repair failure and the effect of repair failure on patient shoulder range of motion, strength, and patient-reported shoulder outcome measures. In addition, we sought to determine whether patient mental health or other patient factors had an effect on final patient-reported outcome measures. We hypothesized that patients with tendon healing would have improved strength and patient-reported outcome measures compared with those who did not heal.

METHODS

Study Design

This was an institutional review board–approved study at our institution. We retrospectively reviewed patients who were enrolled in a rotator cuff outcomes database. A case-control study was performed per the healing status of the rotator cuff on MRI. All patients had undergone arthroscopic RCR by a fellowship-trained shoulder surgeon (the senior author, R.Z.T.) from May 2007 to January 2015 at a tertiary care academic medical center. At a minimum follow-up of 1 year from surgery, all patients had shoulder MRI to evaluate for tendon healing. Patients were grouped as follows: nonhealed tendon on MRI (case) and healed tendon on MRI (control). Factors detailed here were then investigated regarding their association with tendon healing, range of motion and strength, and patient-reported outcome measures. Inclusion criteria included Short Form–36 (SF-36) at enrollment, preoperative shoulder MRI, postoperative shoulder MRI to evaluate for tendon healing at a minimum of 1 year from surgery, patient-reported outcome measures at a minimum of 1 year from surgery, and patient physical examination with range of motion and strength testing at a minimum of 1 year from surgery. Exclusion criteria included the index surgery being a revision surgery, the patient's undergoing revision shoulder surgery within the first year after RCR, incomplete pre- or postoperative imaging, lack of complete physical examination data at minimum of 1 year postoperatively, and a lack of patient-reported outcome measures at a minimum of 1 year postoperatively. A billing database was queried for the total number of RCRs performed by the senior surgeon during the study period.

Patient Evaluation

Patients completed the SF-36 at enrollment. At final follow-up, patients completed evaluation forms: VAS for shoulder pain and shoulder function, SST, and ASES. The SF-36 has 2 composite scores: the physical component summary and the mental component summary (MCS). The mean scores in the population are equal to 50, with a standard deviation of 10. Higher scores represent better health-related quality of life (HRQoL).[20,28] We selected the MCS as a measure of patients' mental health that could affect shoulder-specific HRQoL.

The VAS for pain quantifies pain from the involved shoulder from 0 to 10, with 0 meaning "no pain" and 10 meaning "the worst possible pain." The VAS shoulder function quantifies the function of the involved shoulder on a scale from 0 to 10, with 0 meaning "can use it easily" and 10 meaning "can't use it at all." The SST is a shoulder questionnaire that asks the patient 10 yes/no questions about the functional performance of their shoulder and activities of daily living and 2 questions about the pain level of the shoulder. Each "yes" response is given a point, with higher scores corresponding to better shoulder HRQoL.[9] The ASES score is a reliable, validated, and responsive measure of shoulder-specific HRQoL. A VAS pain score related to the affected shoulder determines half the score. The remaining half is determined by 10 questions that assess sports activity and daily activities on a Likert scale. The total score ranges from 0 to 100, with higher scores representing better shoulder HRQoL.[16]

We collected important risk adjusters, including medical comorbidity. The patients were asked a series of yes/no questions regarding the presence of medical conditions. This list of questions is included in the Musculoskeletal Outcomes Data Evaluation and Management System.[1] Patient height and weight were collected to determine body mass index (BMI). Patient sex, age, workers' compensation status, and smoking status were determined. To evaluate

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smoking status, patients were asked if they currently smoke, have smoked in the past, or never smoked. Patients were then grouped as having a smoking history if they had ever smoked.

Shoulder MRI was performed as part of pre- and postoperative evaluations. MRI was done on a Siemens 1.5-T Avanto system with a shoulder-specific protocol. Two study authors (R.Z.T. and J.D.W.) interpreted the shoulder MRI, blinded from other patient factors. Tear characteristics were determined, including anterior-to-posterior tear size, medial tear retraction, Goutallier classification of fatty atrophy of the musculature, and number of tendons involved in the tear. Tear size was measured in centimeters on T2 sagittal images as the anterior-to-posterior distance of the area on the lesser and greater tuberosity footprints that did not have tendon attached. Tear retraction was determined as the maximum distance of the tendon edge of the supraspinatus to the lateral aspect of the greater tuberosity tendon footprint or the maximum distance from the tendon edge of the subscapularis to the lesser tuberosity on T2 coronal images. The number of torn tendons was determined by adding each tendon (subscapularis, supraspinatus, infraspinatus) involved in the full-thickness aspect of the tear; partial thickness tearing of tendons was not included. A tear size >2.5 cm in the anterior-to-posterior dimension was determined to include the infraspinatus tendon. Goutallier classification of fatty infiltration was measured for each muscle belly on a scale of 0 to 4. Each patient then received a score by the sum of the 4 muscles, representing their cumulative Goutallier score. On postoperative MRI evaluation, tendons were recorded as healed or not healed by the senior author. A tendon was considered healed if there was a continuous sheet of tissue extending from the muscle to the bone on all coronal images. If there was discontinuity on even a single coronal image, it was recorded as not healed.[24,25]

Postoperative endpoints included physical examination, repeat MRI, and patient-reported outcomes—VAS for pain and shoulder function, SST, and ASES scores. Physical examinations were performed by 1 of the authors (E.K.G.) blinded to the repair status (healed vs not) and not involved in the patients' clinical care. Examination data included passive and active forward elevation (FE) and external range of motion, as well as manual muscle testing (MMT) and isometer testing of strength in FE and external rotation (ER). A single examiner measured patient range of motion in active and passive FE and ER with the arm in adduction. MMT was performed in FE with the arm forward flexed 80° to 90° and in ER with the arm adducted on a scale from 1 to 5, with 3 representing strength against gravity and 5 representing full strength. Isometric strength testing was performed with an isometer (Innovative Design Orthopaedics) in the same arm positions for FE and ER. Each test was performed twice, and the mean of these 2 measures was recorded.

Statistical Methods

Receiver operator characteristic curves were calculated to determine cutoffs for dichotomizing patient variables when appropriate. Differences in continuous variables between groups were calculated by Student *t* test. The difference in proportions of categorical variables between groups was determined by Pearson chi-square test. Bivariate correlations were investigated by Pearson correlation coefficients. Multivariate regression models were built with categorical variables as dummy variables (ie, for sex; 0 = male, 1 = female). Logistic regression models predicting tear healing included patient age, sex, BMI, number of medical comorbidities, smoking status, SF-36 MCS, and preoperative tear characteristics. Linear regression models included patient age, sex, BMI, number of medical comorbidities, smoking status, SF-36 MCS, and tendon healing as variables predictive of outcome measures. VAS shoulder pain, VAS shoulder function, SST, and ASES scores were the dependent variables in investigation of the effect of healing and patient factors on HRQoL outcomes. Final analysis used multivariate linear or logistic regression modeling with entry of all predictor variables. Odds ratios (ORs) and regression coefficients are reported when appropriate. *P* values <.05 were considered significant.

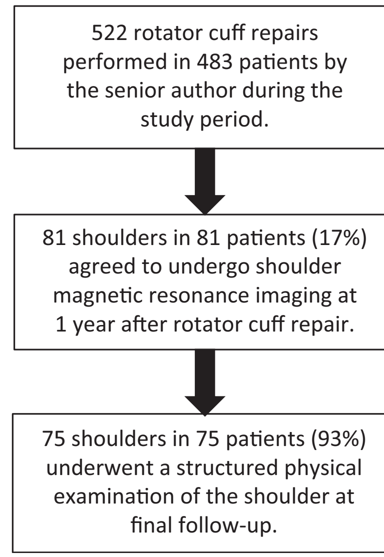

Figure 1. Flow diagram of patients who were operated on during the study period by the senior author.

RESULTS

Patient Cohort

Eighty-one patients had MRI before and a minimum of 1 year after RCR. The senior surgeon performed 522 RCRs in 483 patients during the study period; therefore, the series represented 17% of the patients who underwent RCR (Figure 1). Patient-reported outcomes were available for all patients at mean 2.7 years (range, 1.0-7.7 years) after RCR. Sixty-four (79%) patients had a minimum 2-year follow-up (range, 2.0-7.7 years), while 17 (21%) patients had between 1 and 2 years of follow-up.

Of the 81 patients, 75 had physical examination data at final follow-up. Forty-nine of 81 (60%) had evidence of

TABLE 1
Tendon Healing by Number and Specific Tendons Torn

No. of Tendons Torn: Tear Type	Patients No.	Patients Healed	Healing Rate, %
1 tendon: supraspinatus	47	33	70
2 tendons	25	12	48
Supraspinatus/infraspinatus	17	9	53
Supraspinatus/subscapularis	8	3	38
3 tendons	8	4	50
Supraspinatus/infraspinatus/subscapularis	7	3	43
Supraspinatus/infraspinatus/teres minor	1	1	100
All 4 tendons	1	0	0
Total	81	49	60

tendon healing on follow-up MRI, while 32 (40%) had evidence of tendon-healing failure. There was no difference in mean follow-up comparing those who healed and those who did not—2.2 and 2.6 years, respectively ($P = .15$). Mean tear size was 2.6 cm (range, 0.75-6.1 cm), and mean tear retraction was 2.3 cm (range, 0.0-6.0 cm). Sixty-five patients were male, and 16 were female. Forty-three patients had no medical comorbidities; 14, 15, and 9 had 1, 2, and $\geq$3 comorbidities, respectively. Forty-seven patients had never smoked, and 34 had a history of smoking or were current smokers.

Effect of Tear Severity and Patient Factors on Tendon Healing

The mean age of patients with healed tears was 60.1 years, and the mean age of those with tears that did not heal was 60.2 years ($P = .941$). The mean BMI of patients with healed tears was 33.9, and the BMI among those with tears that did not heal was 30.9 ($P = .531$). Sixty-five patients were male, of which 40 healed (61.5%); 16 patients were female, of which 9 healed (56.3%) ($\chi^2 = 0.15$, $P = .698$). There was no difference in mean SF-36 MCS scores between the patients who healed and those who did not ($P = .463$).

Receiver operator characteristic curves calculated the cutoffs maximizing the sensitivity and specificity of preoperative MRI characteristics: >1 tendon involved in the tear, a tear >2.2 cm or in the anterior-to-posterior direction, a tear with >2 cm of retraction, and a cumulative Goutallier score $\geq$3. Patients with tears involving >1 tendon were less likely to heal ($\chi^2 = 4.4$, $P = .037$). Table 1 shows the healing rate as stratified by number and type of tendons torn. A tear >2.2 cm in size had a healing rate of 49% (19 of 39 tears), as compared with 71% (30 of 42 tears) for patents with a tear $\leq$2.2 cm in size ($\chi^2 = 4.4$, $P = .037$). Tear retraction >2.0 cm had a healing rate of 47% (20 of 43 tears), as opposed to 76% (29 of 38 tears) among patients with retraction $\leq$2.0 cm ($\chi^2 = 7.5$, $P = .006$). Similarly, cumulative Goutallier grade $\geq$3 had a healing rate of 33% (7 of 21 tears) versus 70% (42 of 60) for a grade of 0 to 2 ($\chi^2 = 8.75$, $P = .003$) on preoperative MRI. In multivariate logistic regression models, when controlling for other patient factors (age, sex, BMI, medical comorbidity, smoking, and patient mental health), tear size >2.2 cm (OR = 0.35, $P = .039$), tear retraction >2 cm (OR = 0.24, $P = .006$), and cumulative Goutallier grade >3 (OR = 0.21, $P = .007$) were all significant predictors of the tendon's not healing per MRI. There was no effect of age, sex, BMI, medical comorbidity, smoking, or patient mental health on tendon healing (all $P > .05$ in all models).

TABLE 2
Physical Examination Testing Comparing Range of Motion and Strength in Rotator Cuff Tendons Based on Healing[a]

	Healed (n = 47)	Not Healed (n = 28)	*P* Value
Range of motion			
Active FE	163 (2.3)	159 (5.4)	.386
Passive FE	174 (2.1)	172 (3.4)	.701
Active ER	48 (2.5)	42 (2.6)	.120
Passive ER	54 (2.1)	49 (2.6)	.088
Strength			
FE MMT	4.4 (0.1)	3.6 (0.2)	<.001
ER MMT	4.6 (0.1)	4.0 (0.2)	.005
FE isometer, lb	16.3 (1.4)	11.7 (1.5)	.033
ER isometer, lb	15.4 (0.9)	13.3 (1.3)	.165

[a]Values are presented as mean (SEM). ER, external rotation; FE, forward elevation; MMT, manual muscle testing.

TABLE 3
Mean Differences in Patient-Reported Outcomes in Rotator Cuff Tendons Based on Healing[a]

Score	Healed (n = 49)	Not Healed (n = 32)	*P* Value
VAS			
Pain	1.0 (0.29)	2.3 (0.46)	.013
Function	0.9 (0.21)	2.3 (0.39)	.001
SST	10.7 (0.33)	8.9 (0.55)	.004
ASES	89.7 (2.2)	73.9 (4.6)	.001

[a]Values are presented as mean (SEM). ASES, American Shoulder and Elbow Surgeons; SST, Simple Shoulder Test; VAS, visual analog scale.

Effect of Tendon Healing on Patient Objective Physical Examination Outcomes

Seventy-five patients returned for physical examination of their repaired shoulders at final follow-up. There was no difference in range of motion between patients whose tears did and did not heal (all $P > .088$) (Table 2). Patients who healed were stronger on MMT in FE and ER, with nonhealed rotator cuffs exhibiting strength more than half a grade lower than those who healed per MRI. In addition, isometric strength testing showed that shoulders with healed tendons were stronger in FE isometer testing but not ER testing (Table 2).

Effect of Tendon Healing on Patient-Reported Outcome Measures

There was no difference in any patient-reported outcome measure between patients with $\leq$2 and >2 years of follow-

TABLE 4
Multivariate Models Reporting Predictors of Patient-Reported Outcome Measures at Final Follow-up[a]

	β (*P* Value)						
Score	Age	Male	BMI	Medical Comorbidity	Smoking	SF-36 MCS	Tendon Healing
VAS							
Pain	0.02 (.533)	–0.16 (.809)	0.01 (.704)	–0.12 (.625)	0.48 (.377)	–0.06 (.025)	–1.26 (.019)
Function	0.01 (.310)	0.13 (.803)	–0.01 (.567)	0.03 (.882)	–0.15 (.740)	–0.03 (.123)	–1.39 (.002)
SST	–0.03 (.409)	0.743 (.340)	0.01 (.748)	–0.13 (.660)	–0.69 (.280)	0.04 (.231)	1.74 (.006)
ASES	–0.07 (.792)	7.67 (.183)	0.02 (.780)	–1.45 (.496)	–4.36 (.355)	0.46 (.035)	15.5 (.001)

[a]ASES, American Shoulder and Elbow Surgeons; BMI, body mass index; SF-36 MCS, Short Form–36 mental component summary; SST, Simple Shoulder Test; VAS, visual analog scale.

up (all $P > .45$). Patients who healed per MRI had less patient-reported pain, better shoulder function, and higher SST and ASES scores at final follow-up (Table 3). In multivariate models, tendon healing was associated with less pain, better shoulder function, and higher SST and ASES scores. Lower SF-36 MCS was associated with increased VAS pain and lower final ASES score, independent of healing status (Table 4).

DISCUSSION

This study yielded multiple important findings regarding factors affecting tendon healing after RCR, as well as the effect of RCR healing on strength and outcomes. Our data indicate discrete preoperative MRI findings associated with a lack of tendon healing after repair: a tear >2.2 cm in the anterior-to-posterior dimension, a tear retracted from the footprint >2.0 cm, and a cumulative Goutallier grade ≥3. There was no difference in range of motion between patients whose rotator cuff tears did and did not heal at final follow-up. However, patients who had rotator cuffs that did not heal were weaker in MMT of FE and ER and isometric testing in FE. In addition, patients who healed had less pain, better shoulder function, and improved patient-reported shoulder outcomes at follow-up as compared with those who did not heal. At final follow-up, worse patient mental health, as measured by the SF-36 MCS, was associated with worse patient-reported outcome measures independent of tendon healing.

We found multiple preoperative imaging factors associated with failure to heal per MRI—most notably, the size and retraction of the tear and the degree of fatty infiltration. Park et al[19] found, in a large cohort of patients with small- to medium-sized tears, that tear size and tendon retraction >2 cm were associated with repair failure. Our study found similar numbers, with tears >2.2 cm in the anterior-to-posterior direction or with >2 cm of retraction from the tuberosity less likely to heal. Similarly, if the tear involved a single tendon, it was significantly more likely to heal than those involving multiple tendons. Others have postulated that when tear size exceeds 2 cm, there starts to be significant involvement of the infraspinatus, which alters humeral head kinematics by generating unbalance force coupling and may put the tear at increased risk of repair failure.[17,19] In addition, we found that a cumulative Goutallier score ≥3 was associated with failure to heal after repair. Park et al[19] found that infraspinatus atrophy was associated with healing failure in small to medium tears. Similarly, for massive tears, Chung et al[6] showed that fatty infiltration of the infraspinatus was the only independent predictor of failure to heal. In addition, authors using the global fatty infiltration index found that among all patients with a score >2, all repairs failed.[5]

The effect of tendon healing on patient-reported outcome after RCR is controversial. Even with repair failure, many patients have significant improvement in shoulder pain and function and patient-reported outcome measures. Patients with large tears and early structural failure can have continued clinical improvement and pain relief at long-term follow-up.[21] Multiple studies have found no difference in outcome between patients with tendons that healed and those that failed.[13,18,27] This finding may be due to the outcome measure used. Assessments based on objective measurements of patient strength or function—such as the Constant score and the University of California, Los Angeles (UCLA), scoring system—seem to be more likely to show a difference between patients who healed and those who did not.[13] In a recent long-term study, at 10-year follow-up, patients with tendon healing had higher total Constant scores and Constant strength scores.[10] In the current study, we found that repair failure led to statistically and clinically significant decreased ASES and SST scores and worse shoulder pain and function on VAS scales at final follow-up, even when controlling for other patient factors in multivariate models.

When investigating more objective measures of patient outcome, we found no association between tendon healing and patient range of motion. Most studies have reported similar findings, indicating that the healing status of the rotator cuff does not have a significant effect on final range of motion after repair.[5,13] However, we found improved objective strength testing among patients with healed tendons on MRI. Specifically, these patients were stronger on MMT in FE and ER and isometric strength testing in FE versus patients with no tendon healing. Others have investigated strength after RCR and its relation to healing. Cho and Rhee[5] found that elevation strength was significantly higher for patients with tendon healing. Other authors have shown increased strength in healed rotator cuff tears when compared with those that failed to heal.[3,13] Heuberer et al[10] reported improved Constant strength scores when comparing those with tendon healing with retears at long-term follow-up; however, most patients reported improved shoulder pain and function in both groups.

One additional interesting finding from this study is the effect of patient mental health on outcome after RCR. Prior studies have shown that worse mental health correlates with lower shoulder scores preoperatively.[23,30] However, some groups demonstrated that these patients obtain similar outcomes postoperatively.[4,22] Here we find that, independent of healing status, lower SF-36 MCS scores correlate with lower ASES scores and higher VAS pain scores at final follow-up. The discrepancy in these findings may be due to the fact that we looked at final follow-up scores and not the change in scores over time. Patients with poorer mental health may see similar improvements but start and finish at a lower ASES or higher VAS pain score. In addition, this finding suggests that other factors targeting patient mental health may improve reported outcomes of shoulder surgery. This could be an area of future intervention to improve outcomes.

There are limitations of this study. Only patients willing to come back for repeat evaluation with MRI at >1 year after surgery were included. Given this restriction, it is a small percentage of patients who underwent surgery with the principal investigator during the period and who were included in the study. This potentially created a selection bias toward the patients who were included. Our follow-up period was relatively short: a mean of 2.8 years with a minimum 1-year follow-up. However, while clinical outcomes may change over time, 1-year follow-up with MRI is likely sufficient to judge the morphologic healing of the rotator cuff after arthroscopic repair. Iannotti et al[11] recently published a prospective study finding that almost all retears, or failure to heal, happened within the first 26 weeks after surgery. Therefore, they were likely captured in this cohort of patients. Finally, we looked only at final functional outcome scores and not a change in outcomes. Consequently, some patients whom we might consider worse than others, based on their final outcome, may have had similar improvement in outcome from baseline.

In conclusion, patients with larger, more retracted tears and greater fatty infiltration are less likely to heal on MRI. Patients whose RCR does not heal are weaker, and they have worse patient-reported outcomes than do those with healed tendons per MRI. Worse mental health correlates with worse functional outcomes and increased pain, independent of healing status.

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