# The Subscapularis Healing Index

## A New Scoring System for Predicting Subscapularis Healing After Arthroscopic Repair

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**Background:** Previous research has emphasized the effect of prognostic factors on arthroscopic rotator cuff repair (ARCR) success, but a specific focus on subscapularis (SSC) tendon repair healing is lacking.

**Purpose:** To identify prognostic factors for SSC healing after ARCR and develop the Subscapularis Healing Index (SSC-HI) by incorporating these factors.

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

**Methods:** This was a retrospective study using prospectively maintained data collected from patients with isolated or combined SSC tears who underwent ARCR between 2011 and 2021 at a single institution with a minimum 2-year follow-up. Functional outcomes were assessed using the American Shoulder and Elbow Surgeons (ASES) score, Subjective Shoulder Value (SSV), and visual analog scale (VAS) pain scale. SSC tendon healing was evaluated via ultrasound at the final follow-up. Multivariate logistic regression analysis was performed to determine the factors affecting SSC healing, and based on these factors, the SSC-HI, which ranges from 0 to 15 points, was developed using odds ratios (ORs).

**Results:** Among 1018 ARCR patients, 931 met the inclusion criteria; 279 returned voluntarily for postoperative SSC ultrasound assessment. The overall healing failure rate was 10.8% (30/279). Risk factors for healing failure included female sex ($P = .008$; OR, 3.119), body mass index (BMI) $\geq$30 ($P = .053$; OR, 2.323), supraspinatus fatty infiltration $\geq$3 ($P = .033$; OR, 3.211), lower SSC fatty infiltration $\geq$2 ($P = .037$; OR, 3.608), and Lafosse classification $\geq$3 ($P = .007$; OR, 3.224). A 15-point scoring system comprised the following: 3 points for female sex, 2 points for BMI $\geq$30, 3 points for supraspinatus fatty infiltration $\geq$3, 4 points for lower SSC fatty infiltration $\geq$2, and 3 points for Lafosse classification $\geq$3. Patients with $\leq$4 points had a 4% healing failure rate, while those with $\geq$9 points had a 55% rate of healing failure. Patients with a healed SSC reported significantly higher ASES (healed SSC: ΔASES, 44.7; unhealed SSC: ΔASES, 29; $P < .01$) and SSV (healed SSC: ΔSSV, 52.9; unhealed SSC: ΔSSV, 27.5; $P < .01$) and lower VAS (healed SSC: ΔVAS, –4.2; unhealed SSC: ΔVAS, –3; $P < .01$) scores compared with those with an unhealed SSC.

**Conclusion:** The SSC-HI scoring system integrates clinical and radiological factors to predict SSC healing after surgical repair. Successful SSC healing was found to be associated with enhanced functional outcomes, underscoring the clinical relevance of SSC healing prediction in the management of these tears.

**Keywords:** subscapularis tear; rotator cuff tear; prognostic factors; scoring system; sex; tear size; fatty infiltration; arthroscopic repair; healing; retear; outcomes

Subscapularis (SSC) tendon repair significantly improves rotator cuff repair outcomes by enhancing shoulder stability, function, and the successful healing of other cuff components.[9,20,41,44] While SSC tears were once thought to constitute only approximately 5% of all rotator cuff tears, advances in technology and the more widespread use of arthroscopy have revealed that SSC tears may be identified in up to 49% of cases involving arthroscopically repaired rotator cuff tears.[15,45]

SSC retear rates as high as 32% have been reported for isolated tears and combined tears.[2,18,23,34] Previous studies have cited various factors, including age, symptom duration, tear size, fatty infiltration of the rotator cuff muscles, bone mineral density, and concomitant procedures, that may influence rotator cuff healing after surgical repair.[4-6,16,32,39,42] There is limited research that specifically focuses on SSC tendon healing.[11,19,34,46] Furthermore, while Kwon et al[24] were pioneers in developing an index for assessing posterosuperior rotator cuff tear healing, to our knowledge, there is no scoring system that incorporates these factors to predict SSC healing.

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This study aimed to identify prognostic factors for SSC tendon healing after arthroscopic repair and develop the Subscapularis Healing Index (SSC-HI) by incorporating clinical and radiological factors. This approach has the potential to offer valuable insights for clinical applications, including the ability to predict the likelihood of a successful SSC repair and make informed decisions regarding appropriate treatment strategies. We hypothesized that by developing a scoring system that includes various potential prognostic factors, we can reliably predict SSC healing after arthroscopic repair.

## METHODS

### Study Design

A retrospective study was conducted using prospectively collected data from patients with isolated or combined SSC tears who underwent arthroscopic rotator cuff repair (ARCR) at a single institution between 2011 and 2021. The inclusion criteria were patients with any SSC tear who underwent ARCR, had baseline patient-reported outcomes (PROs), and had a minimum 2-year follow-up. Patients with a history of previous ipsilateral shoulder surgery, ARCR without SSC tear, proximal humeral fracture or glenoid fracture, inaccessible magnetic resonance imaging (MRI) scans or insufficient images for evaluation, inaccessible or incomplete physical examination record, or incomplete intraoperative documentation were excluded from this study. Institutional review board approval was obtained before commencing the study. No funding was received for the study.

Patients who met the inclusion criteria were contacted for a follow-up ultrasound assessment of SSC tendon healing. The assessment was performed by an independent orthopaedic surgeon blinded to tear size and repair technique (A.I.K.). During this visit, patients filled out questionnaires including American Shoulder and Elbow Surgeons (ASES) score, Subjective Shoulder Value, and visual analog scale (VAS) for pain, as well as information about their return to activity and postoperative satisfaction. During the clinical evaluation, range of motion (ROM) was assessed using a goniometer and isometric strength was assessed using a handheld dynamometer.

### Study Variables

Patient characteristics including age, sex, tobacco use, and length of follow-up were collected. The Charlson Comorbidity Index, which includes 17 different comorbidities associated with mortality and assigns weights ranging from 1 to 6 points (0-29, points), was used to standardize comorbidities, and the Charlson Comorbidity Index score was calculated by dividing the patient's score by 29 (score received/29 = percentage).[33] Active ROM and PROs were documented at baseline and postoperatively at a minimum 2-year follow-up. Baseline ROM measurements, including forward flexion, external rotation at the side, and internal rotation, were recorded preoperatively by the treating surgeon (P.J.D.) or a physician assistant, while the follow-up measurements were assessed by an independent orthopaedic surgeon (A.I.K.). Internal rotation was numerically scaled based on the nearest spinal level achieved with the thumb (ie, T10 = 10, T12 = 12, L2 = 14, L4 = 16, S1 = 18, hip = 20). PROs included ASES score, VAS for pain score, and Subjective Shoulder Value. Complications, revision surgeries, and satisfaction were all recorded for analysis.

### Preoperative MRI Evaluation

All MRI scans were performed at a single institution with a 1.5-T magnet and with the arm in a neutral position. No intra-articular or intravenous gadolinium was administered. The Goutallier classification was assessed and documented by 1 high-volume fellowship-trained shoulder surgeon (P.J.D.) preoperatively for each rotator cuff muscle on T1-weighted sagittal MRI scans using the most lateral image where the scapular spine connects with the body of the scapula.[7,48] This classification system consists of 5 grades, scored from 0 to 4. Grade 0 indicates the absence of fat, grade 1 indicates the presence of some fatty streaks, grade 2 indicates a higher proportion of muscle compared with fat, grade 3 indicates an equal presence of fat and muscle, and grade 4 indicates a higher proportion of fat compared with muscle. The SSC was also divided into upper and lower halves for grading based on the division described by Lädermann et al.[25]

The coracohumeral distance was evaluated by measuring the narrowest distance between the cortical border of the coracoid and the cortical border of the humeral head on T2-weighted axial images obtained from MRI scans, following the criteria established by previous studies.[27,36] The axial images were set at the point where the subcoracoid space was at its narrowest. Measurements were made by an independent orthopaedic surgeon (A.I.K.). Three measurements were recorded, and the mean was taken for analysis.

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**Figure 1.** Isometric strength measurements were conducted utilizing a manual muscle testing dynamometer with the patient positioned in a standing posture. The specific measurements included (A) belly press strength measurement, (B) external rotation strength measurement, and (C) constant strength measurement.

## Isometric Muscle Strength Measures

Isometric strength measurements were conducted by the same surgeon who performed the ultrasound evaluation using a manual muscle testing dynamometer with the patient in the standing position. The strength of the SSC muscle was evaluated using the belly press test. During the test, the patient was instructed to press the hand dynamometer between the palm and abdomen (Figure 1A). To assess external rotation strength, the participants' elbows were flexed at a 90° angle, and their arms were positioned at the side. External rotation strength was measured with the hand dynamometer placed on the dorsal aspect of the forearm, 2 cm proximal to the ulnar styloid process (Figure 1B). To determine the constant strength, the patient's arms were positioned at 90° of forward flexion in the plane of the scapula, with the elbows fully extended and the forearms in a half pronation position. The hand dynamometer was placed on the dorsal aspect of the forearm, approximately 2 cm proximal to the ulnar styloid process (Figure 1C). For each participant, the mean of the 3 independent measurements was taken.

## Ultrasound Examination

SSC tendon healing was graded using the Barth modification of the Sugaya classification for ultrasound assessment of rotator cuff repair.[1] Grade 1 designates tendons with sufficient thickness and normal structure. Grade 2 indicates sufficient thickness with partial hypoechogenicity. Grade 3 indicates insufficient thickness without discontinuity. Grade 4 repairs demonstrate minor discontinuity in the tendon. Grade V repairs demonstrate major discontinuity. Repairs graded 1, 2, and 3 were considered healed.[1,18]

## Surgical Technique and Arthroscopic Findings

All arthroscopic procedures were performed by a single surgeon (P.J.D.). Patients were positioned in the lateral decubitus position, and conventional portals were used (ie, posterior, anterosuperior, and lateral). SSC tendon integrity was evaluated from the posterior viewing portal with 30° and 70° arthroscopes. Intraoperatively, SSC tear type was documented according to the Lafosse classification[26,40] (ie, types 1-5) and SSC tear size as a percentage (ie, cephalad to caudal percentage). In addition, long head biceps tendon integrity (ie, intact, subluxation, partial tear, or complete tear), supraspinatus (SS) tear (ie, intact, partial tear, or complete tear), and infraspinatus tear (ie, intact, partial tear, or complete tear) were reported.[26,40]

After arthroscopic examination of the joint, high bicipital groove onlay biceps tenodesis was performed on patients with impaired biceps sling, or biceps pathology on physical examination or imaging. The width of the subcoracoid space was evaluated. Coracoplasty was performed if there was a narrowed subcoracoid space (<7 mm) or if a coracoid spur was present. SSC repair was performed with a single-row or double-row technique based on the tear pattern and tendon mobility. After repair of the SSC, the posterosuperior cuff was evaluated. A double-row repair was the preferred choice based on the tear pattern unless it was under excessive tension or there was tendon loss. In such cases, a single-row repair or a single-row repair with ripstop technique was performed instead. A limited acromioplasty with preservation of the coracoacromial ligament was routinely conducted. All tears were fully repairable at the time of surgery.

Postoperatively, patients were immobilized in a sling for 4 weeks for SSC tears ≤50% of the footprint and for 6 weeks for tears >50% of the footprint. After sling discontinuation, patients were permitted to engage in passive external rotation and forward flexion. Strengthening exercises and passive internal rotation began 3 months postoperatively, with full return to activity, including sports, at 6 months.

## New Scoring Design

The SSC healing scoring system was developed primarily using patients' baseline characteristics and MRI and

intraoperative findings. Receiver operating characteristic (ROC) analysis was employed to establish clinical thresholds for baseline and intraoperative, continuous, and nominal categorical data, based on whether the SSC healed or not. Cutoff values were determined using the Youden index. Subsequently, a multivariate logistic regression model (backward logistic regression) was utilized to calculate the odds ratio (OR) for SSC healing. Point values were assigned to each category based on the likelihood ratios of the data associated with SSC healing, resulting in the creation of the SSC-HI.

### Statistical Analysis

Categorical variables were characterized using absolute and proportional frequencies, whereas continuous variables were described by means and standard deviations. The statistical analysis included the chi-square test to assess associations among categorical variables, and the *t* test was used to compare means among continuous variables. The Shapiro-Wilk test was used to assess the normality of the numerical data distribution. Parametric tests were used to compare groups when data were normally distributed, and nonparametric tests were used when data were not normally distributed. The assessment of SSC healing with ultrasound was considered the gold standard, and clinical threshold values for baseline and intraoperative data were determined accordingly. ROC analysis was conducted for baseline characteristics and intraoperative data to establish clinical threshold values. For each data set, an ROC curve was plotted, and optimal cutoff values (clinical thresholds) were determined by calculating the Youden index. The cutoff value associated with the highest Youden index was selected as the optimal threshold. Multivariate logistic regression analysis was used to identify the variables that influenced SSC healing, and a scoring system was created based on the magnitude of the ORs. The SPSS Version 25 (IBM Corp) program and MedCalc 20 were used to evaluate the data. A threshold of $P < .05$ was used to denote statistical significance.

## RESULTS

A total of 1018 patients were identified from the database of patients who underwent ARCR for isolated or combined SSC tendon tears during the study period. Of these, 931 patients met the study inclusion criteria. A total of 231 participants could not be reached, but access was successfully achieved with 700 patients. Within this group, 272 individuals reported being out of state and 149 declined to participate in the study. Consequently, 279 voluntarily returned to the clinic for assessment of postoperative SSC integrity using ultrasound (Figure 2). Baseline characteristics are summarized in Table 1. There was a male predominance (60.9%; n = 170). The mean follow-up period was 72.6 ± 30.3 months (range, 23-138 months). The dominant side was involved in 195 cases (70%). Isolated SSC tears

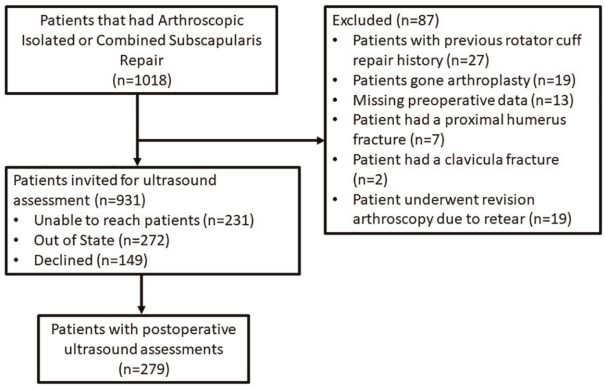


**Figure 2.** A total of 1018 patients were identified from a registry of individuals who underwent arthroscopic rotator cuff repair (ARCR) for isolated or combined subscapularis tears at a single institution between 2011 and 2021. Among these, 931 patients met the study's inclusion criteria. Postoperative ultrasound assessments for subscapularis repair integrity were conducted for 279 of these patients.

accounted for 15% (n = 42) of the cases, anterosuperior tears (SSC with SS tendon tears) constituted 60% (n = 167) of the cases, and 3-tendon tears made up 25% (n = 70) of the cases. SSC tears were categorized as type 1, type 2, type 3, type 4, and type 5, accounting for 123 (44.1%), 80 (28.7%), 45 (16.1%), 31 (11.1%), and 0 (0%) cases, respectively.

### Functional Outcomes

The failure rate of SSC healing was 10.8% (30/279 patients). The SSC healing rates for isolated SSC, anterosuperior tears (SSC with SS tendon tears), and 3-tendon tears were 88.1% (37/42), 91.6% (153/167), and 84.3% (59/70), respectively, ($P > .05$). Overall, PROs and ROM improved significantly from baseline to final follow-up ($P < .01$) (Table 2). In the unhealed SSC group (30 patients), there was a statistically significant improvement in pre- to postoperative change in PROs ($P < .01$). Improvement in ROM did not reach statistical significance ($P > .05$). When comparing pre- and postoperative changes in PROs and ROM, the healed group (249 patients) demonstrated greater improvement overall ($P < .01$) aside from forward flexion, which was not significantly different between groups ($P = .31$). The self-reported patient satisfaction rate for the healed group was 87.6% (218/249), compared with 30% (9/30) for the unhealed SSC group ($P < .01$). Return to activity was reported in 94.8% (236/249) of the healed group, compared with 53% (16/30) of the unhealed SSC group ($P < .01$).

### Subscapularis Healing Index

A summary of the ROC curves used to determine the clinical threshold values for factors predictive of SSC healing

TABLE 1
Baseline Characteristics of Arthroscopic Subscapularis Repair (N = 279)[a]

| Variable | Value |
|---|---|
| Patient characteristics | |
| Age, y | 61.9 ± 9.1 |
| Male sex* | 170 (60.9) |
| BMI | 29.1 ± 5.5 |
| Follow-up, mo** | 72.6 ± 30.3 |
| Duration of symptoms, mo | 17.1 ± 24.1 |
| Tobacco use: yes | 39 (14.0) |
| Workers' compensation: yes** | 44 (15.8) |
| Charlson Comorbidity Index score, % | 2.5 ± 3.6 |
| Dominant arm: yes | 195 (69.9) |
| Contralateral shoulder cuff surgery history: yes | 32 (11.5) |
| MRI findings | |
| Goutullier grade 0/1/2/3/4, n | |
| Supraspinatus fatty infiltration* | 121/52/84/18/4 |
| Infraspinatus fatty infiltration | 137/77/54/9/2 |
| Subscapularis upper-part fatty infiltration** | 112/66/61/26/14 |
| Subscapularis lower-part fatty infiltration** | 221/40/10/6/2 |
| Axial image of CHD on MRI, mm | 6.6 ± 1.8 |
| Intraoperative findings | |
| Size of the torn SSC tendon, cephalad to caudal, %** | 48.2 ± 25.9 |
| Lafosse type** | |
| 1 | 123 (44.1) |
| 2 | 80 (28.7) |
| 3 | 45 (16.1) |
| 4 | 31 (11.1) |
| 5 | 0 (0.0) |
| Cuff tear type | |
| Isolated subscapularis tears | 42 (15.1) |
| Anterosuperior tears | 167 (59.9) |
| Subscapularis with posterosuperior tears | 70 (25.1) |
| Long head biceps tendon | |
| Intact | 72 (25.8) |
| Subluxation or dislocation | 67 (24.0) |
| Partial tear | 100 (35.8) |
| Complete or retracted tear | 40 (14.3) |
| Concomitant procedures | |
| Biceps tenodesis: yes | 214 (76.7) |
| Biceps left alone: yes | 25 (9.0) |
| Acromioplasty: yes | 270 (96.8) |
| Coracoplasty: yes | 92 (33.0) |
| Fixation construct* | |
| Single-row knotted | 47 (16.8) |
| Single-row knotless | 161 (57.7) |
| Double-row knotless | 71 (25.4) |
| Total No. of anchors | 3.6 ± 1.8 |

[a]Values are shown as n (%) or mean ± SD unless otherwise indicated. Comparison between subscapularis healed and unhealed: *$P < .05$; **$P < .01$. BMI, body mass index; CHD, coracohumeral distance; MRI, magnetic resonance imaging; SSC, subscapularis. *P* values show a comparison between healed and unhealed subscapularis tears which was conducted using the chi-square test to evaluate relationships between categorical variables and the t-test to compare means between continuous variables.

is provided in Table 3. In multivariate analysis with logistic regression, prognostic factors for SSC healing included female sex ($P = .008$), SS muscle fatty infiltration ($P = .033$), lower SSC muscle fatty infiltration ($P = .037$), and the Lafosse classification ($P = .007$). Body mass index (BMI) showed borderline significance ($P = .053$) (Table 4). The SSC-HI scores were determined based on the ORs reflecting the influence of these parameters on SSC healing. For BMI ≥30, where the OR was found to be 2.3, 2 points were assigned to SSC-HI. Similarly, for female sex, with an OR of 3.1, 3 points were assigned to SSC-HI. SS muscle fatty infiltration grade ≥3, with an OR of 3.2, also contributed 3 points to SSC-HI. Lower SSC muscle fatty infiltration grade ≥2, having an OR of 3.6, was

TABLE 2
Comparison of Pre- and Postoperative Changes Between Healed (n = 249) and Unhealed (n = 30) Subscapularis Groups[a]

| | Mean ± SD | | Improvement | | | |
|---|---|---|---|---|---|---|
| | Preoperative | Postoperative | Mean | 95% CI | *P* | *P*[b] |
| PROs | | | | | | |
| VAS pain | | | | | | |
| Healed | 5.3 ± 1.9 | 1.1 ± 1.7 | –4.2 | –4.5 to −4 | <.01 | <.01 |
| Unhealed | 6.4 ± 2 | 3.4 ± 2.1 | –3 | –3.9 to −2.1 | <.01 | |
| Total | 5.4 ± 2 | 1.3 ± 1.9 | –4.6 | –4.4 to −3.8 | <.01 | |
| ASES | | | | | | |
| Healed | 45.3 ± 14.9 | 89.9 ± 12.6 | 44.7 | 42.7 to 46.7 | <.01 | <.01 |
| Unhealed | 33.7 ± 13.6 | 62.7 ± 17.7 | 29 | 22.5 to 35.7 | <.01 | |
| Total | 44.1 ± 15.2 | 87.1 ± 15.7 | 43 | 41 to 45 | <.01 | |
| SSV | | | | | | |
| Healed | 37.8 ± 19.3 | 90.6 ± 12.6 | 52.9 | 50.1 to 55.8 | <.01 | <.01 |
| Unhealed | 30.5 ± 16.7 | 58 ± 22.8 | 27.5 | 19.3 to 35.7 | <.01 | |
| Total | 36.9 ± 19.1 | 87 ± 17.3 | 50.2 | 47.4 to 53.1 | <.01 | |
| ROM | | | | | | |
| Active FF, deg | | | | | | |
| Healed | 140 ± 35 | 159 ± 12 | 19 | 15 to 23 | <.01 | .31 |
| Unhealed | 120 ± 49 | 132 ± 31 | 12 | –7 to 31 | .22 | |
| Total | 138 ± 37 | 156 ± 18 | 18 | 14 to 22 | <.01 | |
| Active ER at side, deg | | | | | | |
| Healed | 55 ± 16 | 70 ± 13 | 14 | 13 to 17 | <.01 | <.01 |
| Unhealed | 49 ± 22 | 49 ± 21 | –1 | –9 to 8 | .91 | |
| Total | 54 ± 17 | 68 ± 5 | 13 | 11 to 16 | <.01 | |
| Active IR: spinal level | | | | | | |
| Healed | L3 ± 3 | T11 ± 3 | 5 | 4 to 5 | <.01 | <.01 |
| Unhealed | L4 ± 3 | L3 ± 3 | 1 | 0 to 3 | .06 | |
| Total | L4 ± 3 | T11 ± 3 | 4 | 3 to 5 | <.01 | |
| Strength, lb | | | Mean Difference | 95% CI | | |
| ER strength at side | | | | | | |
| Healed | | 20.4 ± 7.1 | 8.8 | 6.2 to 11.4 | <.01 | |
| Unhealed | | 11.6 ± 3.9 | | | | |
| Total | | 20.2 ± 8.3 | | | | |
| BP strength | | | | | | |
| Healed | | 20.6 ± 7.6 | 8.5 | 5.7 to 11.3 | <.01 | |
| Unhealed | | 12.1 ± 5 | | | | |
| Total | | 19.5 ± 8.1 | | | | |
| Constant strength | | | | | | |
| Healed | | 14.6 ± 6.2 | 9.1 | 6.9 to 11.4 | <.01 | |
| Unhealed | | 5.4 ± 3.6 | | | | |
| Total | | 14.9 ± 6.9 | | | | |
| Status | | % (n) | | | | |
| Return to activity | | | | | | |
| Healed | | 87.6 (218) | | | <.01 | |
| Unhealed | | 30.0 (9) | | | | |
| Total | | 81.4 (227) | | | | |
| Satisfaction | | | | | | |
| Healed | | 94.8 (236) | | | <.01 | |
| Unhealed | | 53.3 (16) | | | | |
| Total | | 90.3 (252) | | | | |

[a]ASES, American Shoulder and Elbow Surgeons; BP, belly press; ER, external rotation; FF, forward flexion; IR, internal rotation; PRO, patient-reported outcome; ROM, range of motion; SSV, Subjective Shoulder Value; VAS, visual analog scale.
[b]Comparison of pre- and postoperative changes between healed and unhealed subscapularis groups.

associated with 4 points on the SSC-HI scale. Last, the Lafosse classification, with an OR of 3.2, was linked to 3 points on SSC-HI. The scoring system ranged from a minimum of 0 points to a maximum of 15 points, indicating a decreasing probability of healing as the score increased from 0 to 15 (Table 4). The mean SSC-HI score for the SSC healed group was 3 ± 2.5, while it was 6 ± 2.9 for the unhealed group.

TABLE 3
Determination of Cutoff Values for Preoperative and Intraoperative Continuous and Multiple Category Data Using the Youden Index Through ROC Analysis[a]

| | Cutoff Value | Youden Index J | Sensitivity | Specificity | AUC |
|---|---|---|---|---|---|
| Age | ≥70 | 0.7380 | 20.1 | 76.7 | 0.541 |
| BMI | ≥30 | 0.2028 | 70.3 | 50 | 0.537 |
| Duration of symptoms, mo | ≥6 | 0.1225 | 62.5 | 50 | 0.515 |
| Charlson Comorbidity Index, % | ≥3.4 | 0.0631 | 43 | 63.3 | 0.517 |
| SSC tear, % | ≥50 | 0.2884 | 53.3 | 75.5 | 0.645 |
| Lafosse classification | ≥3 | 0.2924 | 53.3 | 75.9 | 0.674 |
| Supraspinatus fatty infiltration | ≥3 | 0.1731 | 23.3 | 93.9 | 0.560 |
| Infraspinatus fatty infiltration | ≥1 | 0.1394 | 63.3 | 50.6 | 0.583 |
| SSC upper-part fatty infiltration | ≥3 | 0.2129 | 33.3 | 87.9 | 0.613 |
| SSC lower-part fatty infiltration | ≥2 | 0.1518 | 20 | 95.2 | 0.566 |

[a]AUC, area under the curve; BMI, body mass index; ROC, receiver operating characteristic; SSC, subscapularis.

TABLE 4
Prognostic Factors Associated With Subscapularis Healing in the Multivariate Logistic Regression Analysis (Backward Stepwise Likelihood Ratio Test at Last Step)[a]

| | *P* | OR | 95% CI | Points of each parameter in SSC-HI |
|---|---|---|---|---|
| Body mass index ≥30 | .053 | 2.323 | 0.988-5.462 | 2 |
| Female sex | .008 | 3.119 | 1.341-7.250 | 3 |
| Supraspinatus fatty infiltration ≥3 | .033 | 3.211 | 1.098-9.389 | 3 |
| Subscapularis lower-part fatty infiltration ≥2 | .037 | 3.608 | 1.098-9.389 | 4 |
| Lafosse classification ≥3 | .007 | 3.224 | 1.370-7.588 | 3 |
| Total | | | | 15 |

[a]OR, odds ratio; SSC-HI, Subscapularis Healing Index.

When applying this scoring system to the study population, the ROC analysis yielded an area under the curve (AUC) of 0.78, and based on the Youden index, a cutoff value ≤4 was determined (sensitivity, 72%; specificity, 73%) (Figure 3). Among the patients, those with ≤4 points had a healing failure rate of 4%, those with 5 to 8 points had a healing failure rate of 20%, and those with ≥9 points had a healing failure rate of 55% (Table 5).

## DISCUSSION

The main finding of this study was the demonstration of prognostic factors associated with SSC healing after ARCR. These factors include female sex, SS muscle fatty infiltration grade, lower SSC muscle fatty infiltration, and Lafosse classification. Additionally, BMI showed borderline significance as a prognostic factor. These factors were used to develop the SSC-HI, a scoring system ranging from 0 to 15 points. Patients with a score ≤4 points had a 4% healing failure rate, while those scoring ≥9 points showed a notable 55% rate of healing failure. Improvement in PROs was observed for SSC healed as well as unhealed groups compared with preoperative values. However, while the SSC healed group showed enhanced ROM values, no improvement was observed in the unhealed group. The healed group showed significantly higher external rotation strength, belly press strength, and constant strength compared with the unhealed group ($P < .01$). These findings offer valuable insights into predicting SSC healing outcomes in patients undergoing ARCR, while providing clinicians with a practical tool to assist in treatment decision making.

SSC repair significantly improves rotator cuff repair outcomes by enhancing shoulder stability, function, and the successful healing of superior cuff components.[9,20,41,44] In this study, the overall SSC healing failure rate was 10.8%, and individuals with successful SSC healing demonstrated improved clinical outcomes compared with those with unhealed (retear) SSC tears in terms of PROs and ROM ($P < .01$). Shibayama et al[43] reported a 5% healing failure rate in a case series of 101 arthroscopic SSC repairs with a minimum 2-year follow-up. The healing failure group had inferior PROs compared with the intact group (ASES; 81 vs 93; $P = .003$). In a retrospective study of 20 patients who underwent ARCR conducted by Ide et al,[17] significant improvements were observed in University of California, Los Angeles, scores (from 14.9 to 31.1) and Japanese Orthopaedic Association scores (from 55.7 to 91). Postoperative follow-up MRI revealed that 7 patients had recurrent tears and scored lower than those with intact repairs. Similar to our study, the functional scores of

TABLE 5
Implementation of the New Scoring System in the Study Cohort[a]

| | Subscapularis Assessment, n[b] | | | | | | |
|---|---|---|---|---|---|---|---|
| Score | Unhealed | Healed | Total | Healing Failure Rate, % | Sensitivity, % | Specificity, % | PPV, % |
| 0 | 0 | 65 | 65 | 0 | 100 | 0 | 10.8 |
| 2 | 4 | 45 | 49 | 8.2 | 100 | 26.1 | 14 |
| 3 | 4 | 68 | 72 | 5.6 | 86.7 | 44.2 | 15.8 |
| 4 | 0 | 1 | 1 | 0 | 73.3 | 71.5 | 23.7 |
| 5 | 7 | 34 | 41 | 17.1 | 73.3 | 71.9 | 23.9 |
| 6 | 4 | 12 | 16 | 25 | 50 | 85.5 | 29.4 |
| 7 | 1 | 6 | 7 | 14.3 | 36.7 | 90.4 | 31.4 |
| 8 | 4 | 13 | 17 | 23.5 | 33.3 | 92.8 | 35.7 |
| 9 | 0 | 1 | 1 | 0 | 20 | 98 | 54.5 |
| 10 | 4 | 2 | 6 | 66.7 | 20 | 98.4 | 60 |
| 11 | 1 | 1 | 2 | 50 | 6.7 | 99.2 | 50 |
| 12 | 1 | 1 | 2 | 50 | 3.3 | 99.6 | 50 |

[a]PPV, positive predictive value.
[b]Distribution of patients across the new scoring system.

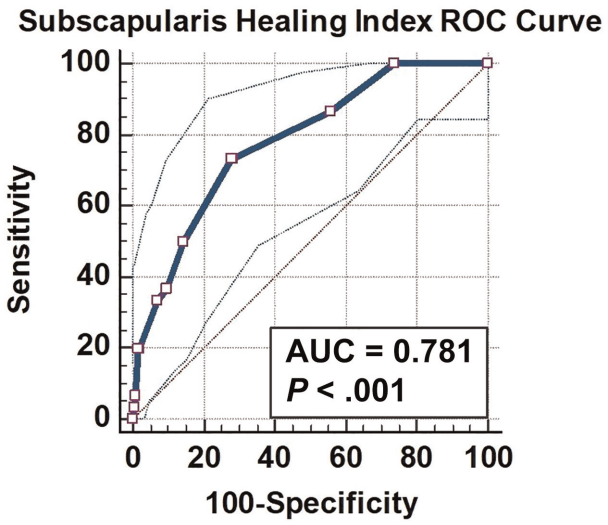


**Figure 3.** The receiver operating characteristic (ROC) analysis in the study population for the new subscapularis scoring system resulted in an area under the curve (AUC) of 0.781 ($P < .001$), with a determined cutoff value $\leq 4$, achieving a sensitivity of 71.9% and specificity of 73.3%.

individuals who did not heal after SSC repair were lower than those who healed. However, both groups showed improved scores compared with their preoperative status, indicating reduced pain and improved function. Importantly, patient satisfaction was 87.6% in the healed group compared with only 30% in the failed to heal group. Likewise, return to activity was more likely in the healed group (95% vs 53%). These results demonstrate that SSC healing plays a critical role in overall rotator cuff repair outcomes, and they are consistent with those in previous studies that have highlighted the importance of SSC integrity in achieving optimal shoulder function and stability after ARCR. This also underscores that patient satisfaction is influenced not only by pain relief and functional improvement, but also by the success of specific repair procedures, particularly the SSC repair.

While several previous studies have explored prognostic factors influencing rotator cuff healing after posterosuperior ARCR, there are no studies in the literature specifically addressing factors affecting SSC healing.[6,37-39] Previous research has consistently highlighted several determinants affecting healing after posterosuperior ARCR, with notable factors including age,[32,39,42] tear size or amount of retraction,[6,39] grade of fatty infiltration infraspinatus muscle,[4-6,16,39] and bone mineral density.[6,24] These factors have been identified as independent prognostic indicators for the likelihood of achieving postoperative healing. Within our research, we identified several significant prognostic factors affecting SSC tear healing, including BMI, female sex, fatty infiltration in both the SS and the SSC muscles, and the Lafosse classification. Notably, Kwon et al[24] were pioneers in developing an index for assessing rotator cuff tear healing. Given the importance of SSC healing for functional outcomes, one of the primary contributions of our study is the introduction of the SSC-HI scoring system. This scoring system enables clinicians to evaluate the likelihood of successful SSC healing in their patients, thereby facilitating individualized and patient-specific treatment decisions. The SSC-HI scoring system represents a promising approach to optimizing patient outcomes and tailoring surgical interventions based on the patients' specific risk profiles.

Many studies have demonstrated the negative correlation fatty infiltration has with rotator cuff healing, especially after the introduction of the Goutallier grading system.[4-6,14,16] Fatty infiltration, particularly of the infraspinatus muscle, also influences outcomes of ARCR.[5,16,22] However, there has been limited research addressing the effect that SSC muscle fatty infiltration has on healing after repair. In a retrospective review of 32 patients, Fandridis et al[11] evaluated the

effect of SSC fatty infiltration on retear rate. Repair integrity was assessed via ultrasound at 6 and 12 months postoperatively. In their series 33% (3/9) of patients with grade 2 fatty infiltration failed to heal, while 57.1% (4/7) of those with grade 3 fatty infiltration failed to heal. Complete healing was observed in all patients with grade 0 or 1 fatty infiltration. Yoon et al[47] reported a retear rate of 79% in a consecutive case series of 28 patients with isolated SSC repairs and Goutallier grade 3 or 4 fatty infiltration. Similarly, our study observed the negative effect that SSC fatty infiltration has on healing. In particular, fatty infiltration of the lower portion of the SSC (lower SSC fatty infiltration $\geq$2; OR, 3.608; $P$ = .037) had a significant negative effect on SSC healing. Additionally, we found that fatty infiltration of the SS also significantly affected SSC healing (SS fat infiltration $\geq$3; OR, 3.211; $P$ = .033). An associated SS tear and infraspinatus tear alone did not significantly influence SSC healing in logistic regression analysis. This is most likely explained by the fact that chronic tears with fatty infiltration of the SS have poorer biology.

Previous research has demonstrated that the risk of SSC healing failure increases as tear size enlarges.[4,6,19,34,39] For instance, Kamijo et al[19] conducted a study comparing small SSC tears (n = 35; classified as Lafosse type 1, 2, or 3) with larger tears (n = 11; classified as Lafosse type 4 or 5). For larger tears, the failure of healing was notably elevated (7/11; 64%) compared with small tears (2/35; 6%) ($P < .001$). In a study by Meshram et al[34] that compared isolated SSC tears and combined tears (30 vs 100, respectively), several factors were associated with SSC retear risk. These factors included SSC tear retraction (OR, 1.1; $P$ = .16), the cephalocaudal tear dimension of the SSC (OR, 1.1; $P$ = .14), and the presence of Lafosse type 4 tears (OR, 5.1; $P$ = .009). In our study, larger tears were also less likely to heal, with Lafosse type 3 and higher having a higher risk of failure (OR, 3.224; $P$ = .007).

Our findings also suggest that female sex and increased BMI are poor prognostic factors for SSC healing. A recent systematic review involving 5693 patients reported that higher BMI was associated with an increased rate of retear after ARCR.[49] Another systematic review also indicated that obesity was linked to a higher incidence of rotator cuff tendinopathy, tears, and complications after surgery.[29] Additionally, a recent clinical study emphasized that BMI (OR, 1.15; $P$ = .02) serves as a significant independent prognostic factor for the healing of small- to medium-sized rotator cuff tears.[10] It is essential to note that while these studies generally focus on rotator cuff injuries, they do not specifically evaluate the SSC. However, although not statistically significant, our study demonstrated a negative effect on SSC healing when BMI was $\geq$30 (OR, 2.323; $P$ = .053). Furthermore, animal studies have shown that obesity is linked to poor tendon quality and elevated levels of pro-inflammatory cytokines and reactive oxygen species.[8,28] This suggests that elevated BMI hampers tendon healing by promoting inflammation. Another potential explanation is that obesity might increase mechanical load and pressure on the joint, which may lead to impaired tendon healing.[21] In a recent study conducted by Nabergoj et al,[35] 12.2% of patients experienced a poor clinical outcome despite achieving successful healing of the repaired tendon in their series. The authors reported that female sex was the only factor significantly affecting the clinical outcome among the evaluated variables. Other studies have also indicated female sex as a poor prognostic factor after ARCR.[3,14,30] In the current study, similar to reports on the posterosuperior rotator cuff,[3,14,30] female sex (OR, 3.119; $P$ = .008) was found to negatively affect SSC healing. The effect of sex differences on healing may be because of potential hormonal differences and requires further investigation.

Some precautions are essential when interpreting the results of this study and when applying them to clinical practice. In this study, postoperative anatomic outcomes were evaluated using ultrasound with Barth modification of the Sugaya classification,[1] regarding grades 4 and 5 as healing failure.[18] It is important to keep in mind that some of the cases in the study identified as unhealed or as retears might, in fact, have been instances of partially healed tendons. Furthermore, the utilization of a predictive scoring system carries the potential for negative implications. While this study could offer specific criteria that might be used to grant or deny authorization for surgery in terms of insurance coverage, it is critical to recognize that although the SSC-HI scoring system enables the prediction of postoperative outcome trends, it cannot provide accurate predictions for individual treatment outcomes. Additionally, it is imperative to remember that numerous factors beyond those considered in this study may exert varying influences on the healing process. Therefore, SSC-HI should not serve as a basis for rejecting treatment solely because of a low expected cure rate; rather, it should be used as a tool to more reliably predict the outcome of the surgical procedure and assist in making informed treatment decisions.

This study has several limitations that need to be noted. First, given the inherent constraints of a retrospective study design, many patients who underwent ARCR for isolated or combined SSC tears at our institution dropped out. Of 931 patients, an ultrasound assessment of SSC healing was performed in 279 cases. This introduces the potential for selection bias and the possibility of unanticipated confounding factors that could affect the accuracy of the results. However, it is important to note that this limitation is expected to be minimal because the study included a sufficiently large cohort. Second, the evaluation was limited to assessing postoperative SSC healing exclusively through ultrasound, without considering the status of the other superior cuff tendons. This limitation has the potential to create differences in functional outcomes and may affect the overall healing trajectory of the SSC. Also, tendon healing was assessed using only ultrasound, with no concomitant additional validation using MRI or computed tomography angiography. However, it is important to note that ultrasound has been verified to be equivalent or even superior to MRI in the evaluation of rotator cuff tears.[13,50] Additionally, the evaluation of SSC healing via ultrasound was conducted by a single observer, which may introduce possible observer bias. To reduce this potential bias, an independent orthopaedist was assigned to

assess the ultrasound scans. It is particularly important to mention that the accuracy of ultrasound assessments may vary depending on the level of the tester's experience, potentially affecting the ability to accurately differentiate between healed and unhealed cases.[12,50] Third, during the development of the new scoring system, both continuous and nominal data were dichotomized for the purpose of analysis. These variables were then subjected to multivariate analysis to calculate ORs, upon which a weighted scoring system was constructed. While the scoring system incorporated the most influential factors identified in the analysis, it is important to note that the dichotomization of continuous and nominal data can potentially exaggerate the results. However, it is crucial to emphasize that despite this potential limitation, the new scoring system exhibited robust performance in ROC analysis within this specific population, achieving an AUC of 0.781. This high AUC value indicates an almost excellent discriminatory ability for the scoring system.[31] Finally, the SSC-HI has not been tested clinically, serving as another limitation of the study. Consequently, it requires validation in another patient cohort.

## CONCLUSION

Healing of SSC tears is negatively associated with female sex, BMI $\geq$30, SS fatty infiltration $\geq$3, lower SSC fatty infiltration $\geq$2, and Lafosse classification $\geq$3. The SSC-HI scoring system integrates clinical and radiological factors to predict SSC healing after surgical repair. Successful SSC healing was found to be associated with enhanced functional outcomes, underscoring the clinical relevance of SSC healing prediction in the management of these tears.

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