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The Rotator Cuff Healing Index

A New Scoring System to Predict Rotator Cuff Healing After Surgical Repair

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Background: Scoring systems integrating possible prognostic factors and predicting rotator cuff healing after surgical repair could provide valuable information for clinical practice.

Purpose: To determine the prognostic factors predictive of rotator cuff healing after surgical repair and to integrate these factors into a scoring system.

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

Methods: The authors reviewed the records of 603 patients who, at least 12 months after primary rotator cuff repair by a single surgeon, had magnetic resonance imaging or computed tomographic arthrography to assess repair integrity. The mean age at the time of surgery was 60 years (range, 39-81 years), and 378 patients were women (62.7%). Previous known or suggested factors affecting cuff integrity were analyzed through univariate and multivariate analyses. Factors identified in the multivariate analysis were integrated in a scoring system based on odds ratios (ORs).

Results: The overall healing failure rate was 24%. The following independent risk factors were identified in the multivariate analysis: age >70 years at the time of surgery (P = .003, OR = 2.71), size of the tear in anteroposterior dimension (P = .033, OR = 1.94) and retraction (P = .000, OR = 4.56), fatty infiltration of infraspinatus exceeding grade 2 (P = .001, OR = 2.91), low bone mineral density (T score ≤ –2.5, P = .04, OR = 1.95), and high level of work activity (P = .036, OR = 2.18). A 15-point scoring system comprised the following: 4 points for retraction; 3 points for fatty infiltration of infraspinatus; and 2 points for anteroposterior tear size, age, bone mineral density, and work activity, weighted according to multivariate analysis ORs. Patients with ≤4 points had a 6.0% healing failure rate, and those with ≥5 and ≥10 points had 55.2% and 86.2% healing failure rates, respectively.

Conclusion: A numerical scoring system including significant clinical and radiological factors was designed to predict healing of the rotator cuff after surgical repair. This scoring system helped predict the adequacy of the repair and assist in deciding the appropriate treatment options.

Keywords: rotator cuff tear; prognostic factors; scoring system; age; tear size; fatty infiltration of infraspinatus muscle; bone mineral density; level of work activity

A rotator cuff tear is a common pathologic condition that causes pain, weakness, and disability in the shoulder joint.[17,20] Rotator cuff repair has become an increasingly popular treatment method, and surgical techniques and instruments to repair the torn rotator cuff have evolved to a remarkable level. However, the failure of rotator cuff healing after surgical repair is still an unresolved issue, and the healing failure rate has been reported as 11% to 94%.[8,24,26,30] Many studies documented factors influencing rotator cuff healing after surgical repair. Previous studies cited various prognostic factors, including age, symptom duration, tear size, fatty infiltration of the rotator cuff muscles, bone mineral density (BMD), and concomitant procedures.[3,6-8,13,18,22-24,35] However, to our knowledge, there are no scoring systems incorporating these factors and predicting the extent of recovery.

We hypothesized that patients with healing failure have distinctive characteristics as compared with patients who have successful healing. A scoring system that integrates possible prognostic factors to predict rotator cuff healing after surgical repair could provide valuable information for clinical practice, such as predicting the success of the repair and deciding appropriate treatment options.

The aims of the current study were to determine the prognostic factors that predict rotator cuff healing after surgical repair and to integrate these factors into a scoring system: the Rotator Cuff Healing Index (RoHI).

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METHODS

Cohort

Institutional review board approval was obtained for this study. Between March 2004 and December 2013, 1241 consecutive patients were surgically treated for rotator cuff disorders at the senior author's (J.H.O.) institution. We included patients who had (1) a full-thickness rotator cuff tear confirmed by arthroscopy, (2) an anatomic outcome measurement on magnetic resonance imaging (MRI) or computed tomographic arthrography (CTA) at least 1 year after surgery, and (3) a functional outcome measurement at least 1 year after surgery. We excluded patients who had (1) a partial-thickness rotator cuff tear (n = 288), (2) an isolated subscapularis tear (n = 18), or (3) previous surgery on the same shoulder (n = 15).

After the exclusion of 321 patients who met the exclusion criteria and 317 patients who did not have postoperative imaging, data from 603 patients were analyzed. Their mean age at the time of surgery was 60 years (range, 39-81 years). The mean follow-up period was 34 months (range, 12-119 months).

Clinical Variables

We recorded patient variables, including age, sex, body mass index, arm dominance, involved arm, symptom duration, traumatic events, level of sports activity, level of work activity, history of steroid injections, history of smoking, preoperative visual analog scale (VAS) score for pain, preoperative range of motion, and BMD. Systemic disorders, such as diabetes mellitus and dyslipidemia, were also included. Using preoperative radiographic images, we measured the type of acromion, presence of spurs, preoperative acromiohumeral distance, anteroposterior (AP) tear size, tear retraction, and fatty infiltration of the rotator cuff muscles (supraspinatus, infraspinatus, subscapularis). Intraoperative findings were also identified, including repair technique (single or double row), biceps procedure, and acromioplasty (Table 1).

The levels of sports activity and work activity were classified as high, medium, and low. A high level of sports activity was defined as participation in contact sports (eg, basketball, football, tennis, volleyball) or martial arts. A medium level of sports activity was defined as participating in static sports (eg, running, bicycling, golf, yoga). A low level of activity was defined as rarely participating in sports activities. High levels of work activity included heavy manual labor; medium levels, manual labor with less activity; and low levels, sedentary work.[9,14,27]

Range of motion measurements were performed by a trained researcher via a standardized method with a goniometer. Forward flexion was measured as the angle between the arm and the thorax with the elbow fully extended. Internal rotation at the back was measured according to the vertebral level that the patient could reach with the thumb, with serial numbering from 1 to 12 for the 1st to 12th thoracic vertebrae, 13 to 17 for the 1st to 5th lumbar vertebrae, and 18 for any level below the sacral vertebrae. The inferior pole of the scapula was referenced as the seventh thoracic vertebra and the iliac crest as the fourth lumbar vertebra.[8,35]

The BMD was measured during preoperative assessments with dual-energy x-ray absorptiometry (DEXA; Lunar Prodigy enCORE, v 8.8; GE Medical Systems). The same DEXA machine was used throughout the study, and a calibration was performed before each session. The lowest T score of the proximal femur or lumbar spine was used for analysis, excluding the value of the ward area of the proximal femur. For patients without preoperative DEXA results, postoperative results were used if the DEXA was performed for other reasons within 1 year after surgery. Overall, BMD could be measured for 516 patients, and univariate analysis of BMD was conducted with these complete data sets.

The type of acromion, according to the classification of Bigliani,[2] was recorded as flat, curved, or hooked. The acromiohumeral distance was measured from the dense cortical bone at the inferior aspect of the acromion to the subchondral lamina of the humeral head on a conventional radiograph in a neutral AP view.[36] Fatty infiltration of the rotator cuff muscles was measured according to the Goutallier classification[16,19,32] on preoperative MRI (Magnetom Avanto 1.5-T System, Siemens; Gyroscan Intera 1.5-T System and Achieva 3.0-T System, Philips Medical Systems). The AP tear size was measured at the lateral edge of the footprint, and the tear retraction was measured intraoperatively as the distance from the lateral margin of the cuff tendon to the lateral end of the footprint.[8]

Surgical Procedure and Postoperative Care

All surgical procedures were performed by the senior author. If a patient had a stiff shoulder, manipulation under anesthesia was performed with arthroscopic capsular release in conjunction with rotator cuff repair. In the glenohumeral joint, synovectomy, biceps procedures, and debridement for torn labrums were performed. After the glenohumeral procedures, subacromial decompression was

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TABLE 1
Patient and Clinical Characteristics[a]

	Mean ± SD or n
Age, y	60.5 ± 8.2
Sex, men:women	225:378
Body mass index, kg/m^2	24.8 ± 3.4
Arm dominance, right:left	432:171
Involved arm, right:left	424:179
Symptom duration, mo	29.5 ± 47.3
Trauma, +:–	205:398
Level of sports activity, high:medium or low	88:515
Level of work activity, high:medium of low	96:507
Steroid injection, n	1.1 ± 0.9
Smoking, +:–	90:513
Preoperative VAS score for pain	6.9 ± 2.0
Forward flexion, deg	147.5 ± 30.2
Internal rotation at back,[b] deg	9.9 ± 4.3
External rotation, deg	54.4 ± 18.6
Bone mineral density	–1.3 ± 1.2
Diabetes mellitus, +:–	67:536
Dyslipidemia, +:–	43:560
Preoperative type of acromion, flat:curved:hooked	348:238:17
Preoperative subacromial spur, +:–	466:137
Preoperative acromiohumeral distance, mm	9.6 ± 2.2
AP tear size, cm	1.9 ± 1.0
Tear retraction, cm	1.9 ± 1.0
Fatty infiltration,[c] grade <2 : ≥2	
Supraspinatus	180:423
Infraspinatus	489:114
Subscapularis	514:89
Repair technique, single:double row	233:370
Biceps procedure, +:–	351:252
Acromioplasty, +:–	573:30

[a]AP, anteroposterior; VAS, visual analog scale; +:–, yes:no.
[b]Measured by vertebral level that the patient was able to reach with the thumb and numbered serially as follows: 1 to 12 for the 1st to 12th thoracic vertebrae, 13 to 17 for the 1st to 5th lumbar vertebrae, and 18 for any level below the sacral region.
[c]Graded according to the system by Goutallier et al.[19]

conducted to remove pathologic bursal tissue, and acromioplasty was performed in almost all patients (572 of 603) in the presence of a meaningful spur of >7 mm thickness of the anterior of acromion.[31] The footprint preparation was performed with a ring curette, rasp, and shaver to expose the bleeding surface. The repair technique, single or double row, was decided in consideration of the tear size, configuration, and reparability. All sutures were tied securely with an SMC knot (Samsung Medical Center). After the subacromial procedures, the glenohumeral joint was reevaluated to confirm cuff integrity and anchor pullout.

Immobilization after surgery was maintained with an abduction brace. Duration was determined by tear size: 4 weeks for small-sized tears (<1 cm), 5 weeks for medium-sized tears (1-3 cm), and 6 weeks for large-sized or massive tears (>3 cm or involving 2 tendons). Shrugging of the shoulders and active elbow, forearm, hand, and wrist motions were encouraged immediately after surgery. Passive shoulder motion was also recommended immediately after surgery but only for patients with small- to medium-sized tears. After weaning off the brace, active-assisted range of motion exercises were encouraged. Muscle-strengthening exercises were started after full passive range of motion was achieved, and all sports activities were permitted by 6 months after surgery. The patients who underwent rotator cuff repair surgery had preoperative education for postoperative rehabilitation. All rehabilitation was conducted with the cooperation of, and under the supervision of, a team in the Department of Rehabilitation at the senior author's institution.

Outcome Assessment

Postoperative cuff healing was evaluated with MRI or CTA at least 1 year after surgery. All patients who underwent rotator cuff repair at the senior author's institution were recommended to undergo MRI for evaluation of cuff integrity at 1 year after surgery. Patients who declined MRI because of cost underwent CTA instead of MRI. An experienced musculoskeletal radiologist interpreted the MRI or CTA findings and confirmed cuff healing success or failure. On the basis of the MRI findings, Sugaya classification[39] type IV or V was regarded as healing failure. Based on the CTA findings, contrast leakage through the footprint with rotator cuff discontinuity was considered healing failure.[8] Of the total patients undergoing the postoperative imaging study, 258 were examined with CTA, and the remaining 345 underwent MRI. The mean time for conducting the postoperative imaging study was 14.6 months (range, 12–39 months).

Functional outcomes were evaluated with VAS score for pain, the American Shoulder and Elbow Surgeons (ASES) score, the Simple Shoulder Test, and the Constant-Murley score. The VAS was scaled from 0 to 10, with 10 being the worst pain. The ASES score had a total of 100 points, including 50 points for daily function and 50 points for pain. The Simple Shoulder Test had a total score of 12 positive answers. The functional outcome assessment was performed at the time of the preoperative admission and at regular postoperative follow-up visits.

Statistical Analysis

All statistical analyses were performed with SPSS (v 20.0; IBM), and P values <.05 were considered statistically significant. In the univariate analysis, the Student t test was used for comparison of the mean values; the paired t test or the Mann-Whitney U test was used for the continuous variables; and the chi-square test or Fisher exact test was used for the categorical variables. In the multivariate analysis, logistic regression with a forward stepwise technique was used to determine the independent variables associated with cuff healing after rotator cuff repair and to estimate the odds ratios (ORs). The estimated ORs from the logistic regression were used to represent the scores for independent risk factors. The paired t test was used to compare pre- and postoperative functional scores. Some missing values of BMD were handled with a pairwise deletion method in the analysis, and the values derived from multiple imputation were used when the scoring system was applied to the study cohort to confirm the sensitivity and specificity of this system.[21]

TABLE 2
Functional Outcomes 1 Year After Rotator Cuff Repair Surgery[a]

	Healed (n = 458)	Healing Failure (n = 145)	*P* Value
VAS for pain	1.1 ± 6.5	1.9 ± 2.7	.546
ASES score	93.6 ± 8.6	91.3 ± 10.1	.159
SST	11.9 ± 7.8	9.2 ± 3.6	.264
Constant-Murley score	78.1 ± 11.9	74.2 ± 14.0	.148

[a]Results are expressed as mean ± SD. ASES, American Shoulder and Elbow Surgeons; SST, Simple Shoulder Test; VAS, visual analog scale.

Scoring System Design

To develop a new scoring system that integrated the identified factors to predict rotator cuff healing, an evidence-based categorization needed to be conducted preferentially. In the cases with variables that had clinical cutoff values, categorization was based on these values. Meanwhile, receiver operating characteristic (ROC) curves were used to predict cutoff values for variables without clinical cutoff values. Cutoff values were determined according to a specificity of 90% on ROC curves. When the ROC curve was difficult to apply because variables had a linear correlation with a healing failure rate, the categorization had to be subdivided discretionally. In this case, the effect of this variable on healing failure could have been overestimated because the baseline was lower. Therefore, the score given to this variable was based on the OR value derived from categorization into 2 groups. Finally, these factors were integrated in a scoring system and were basically weighted according to their ORs in the multivariate analysis.

RESULTS

The overall failure rate for cuff healing was 24.0% (145 of 603 patients). All postoperative functional scores, including the VAS for pain, ASES, Simple Shoulder Test, and Constant-Murley, were significantly improved. There were no significant differences in the functional outcomes of healed cuffs versus unhealed cuffs (Table 2).

In the univariate analysis (Appendix Table A1, available in the online version of this article), rotator cuff healing was affected by age ($P < .001$), symptom duration ($P = .004$), level of work activity ($P = .010$), BMD ($P = .042$), preoperative acromiohumeral distance ($P < .001$), AP tear size ($P < .001$), tear retraction ($P < .001$), fatty infiltration of rotator cuff muscles (supraspinatus, $P < .001$; infraspinatus, $P < .001$; subscapularis, $P < .001$), and concomitant biceps procedure ($P = .016$). In the multivariate analysis with logistic regression, the following independent factors were identified: age, AP tear size, tear retraction, fatty infiltration of infraspinatus muscle, BMD, and level of work activity.

To develop a new scoring system that integrated the identified factors to predict rotator cuff healing, an evidence-based categorization was conducted with clinical cutoff values or ROC curves. In the cases of age and AP

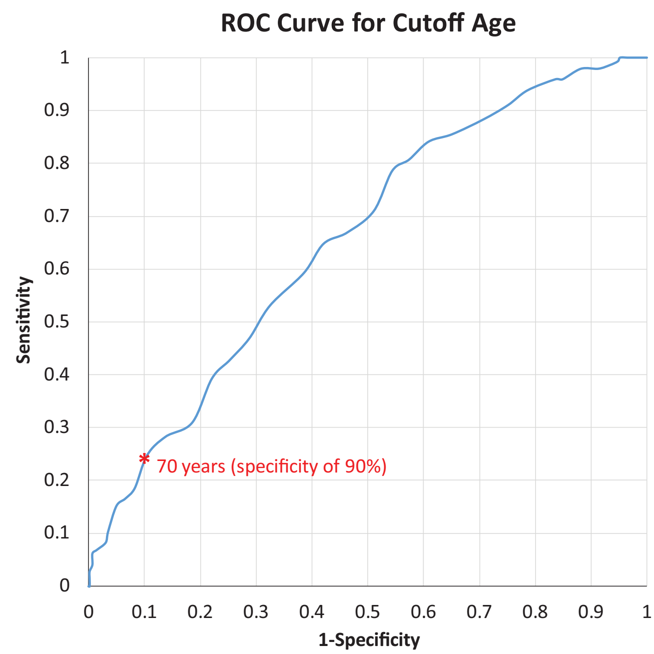

Figure 1. The receiver operating characteristic (ROC) curve for the cutoff age for successful cuff healing: <70 years was significant with a specificity of 90%.

tear size, no clinical cutoff values were investigated in previous studies. Therefore, ROC curves were calculated to predict cutoff values for the oldest age and largest AP tear size for successful rotator cuff healing. Cutoff values were determined according to a specificity of 90% on ROC curves. Age <70 years was significant, and the critical AP tear size was 2.5 cm for successful cuff healing (Figures 1 and 2).

With regard to tear retraction, more subdivisions were performed because of stronger correlations with healing failure than other factors. In the cases of fatty infiltration of the infraspinatus muscle and BMD, the clinical cutoff value in previous studies (fatty infiltration of the infraspinatus muscle grade ≥2) and the criteria of osteoporosis (T score ≤–2.5) were applied.[8]

Finally, these factors were integrated into a 15-point scoring system: 4 points for retraction (<1 cm, 0 point; 1 to <2 cm, 1 point; 2 to <3 cm, 2 points; ≥3 cm, 4 points), 3 points for fatty infiltration of the infraspinatus muscle; and 2 points for age, AP tear size, BMD, and work activity, which were weighted according to their ORs in the multivariate analysis. The maximum value of tear retraction in the scoring system was given per the OR value obtained when the retraction was divided into ≥3 cm and <3 cm (OR, 4.56; 95% CI, 2.34-8.86) (Table 3).

When this scoring system was applied to the study population, the mean score for the healing failure group was 8.0 points (range, 1–15 points), and the mean score for the healing group was 3.0 points (range, 0–13 points). Patients with ≤4 points accounted for 6.0% of the identified healing failure rate, and those with ≥5 and ≥10 points accounted for 55.2% and 86.2% of the identified healing failure rate, respectively (Table 4).

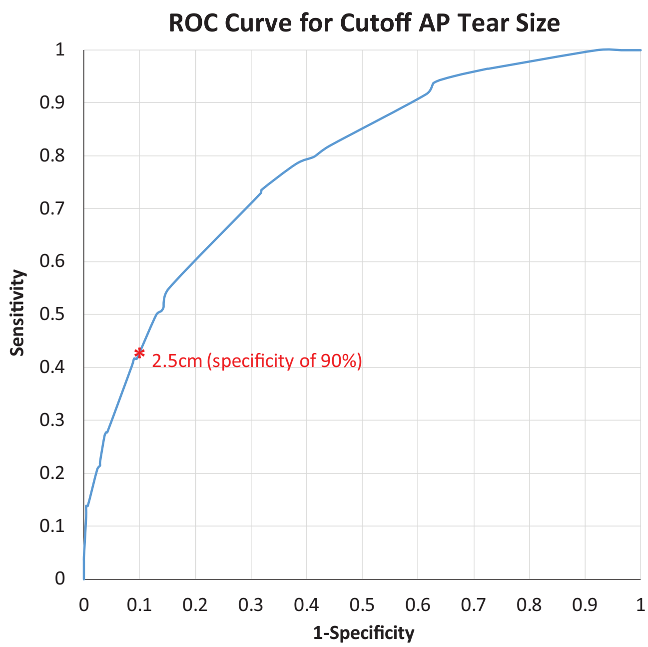

Figure 2. The receiver operating characteristic (ROC) curve for the cutoff anteroposterior tear size for successful cuff healing: 2.5 cm was the critical anteroposterior tear size with a specificity of 90%.

TABLE 3
Prognostic Factors Associated With Rotator Cuff Healing in the Multivariate Analysis (Stepwise Forward: Conditional)[a]

	P Value	OR	95% CI	Points in RoHI
Age >70 y	.003	2.71	1.39-5.27	2
AP tear size >2.5 cm	.033	1.94	1.06-3.58	2
Retraction, cm	<.001			
<1				0
1 to <2	.528	1.64	0.35-7.62	1
2 to <3	.065	4.40	0.91-21.02	2
≥3	.02	12.90	2.48-66.69	4
Infraspinatus fatty infiltration, grade ≥2	.001	2.91	1.58-5.34	3
BMD, ≤ –2.5	.040	1.95	1.03-3.68	2
Level of work activity, high	.036	2.18	1.05-4.50	2

[a]AP, anteroposterior; BMD, bone mineral density; OR, odds ratio; RoHI, Rotator Cuff Healing Index.

TABLE 4
Application of the New Scoring System in the Study Cohort

Score	Healing Failure[a]	Healed[a]	Sensitivity, %[b]	Specificity, %[c]	Positive Predictive Value, %[d]
0	0	43			
1	1	137	100	9.4	26.0
2	5	37	99.3	39.3	34.1
3	7	81	95.9	47.4	36.1
4	10	61	91.0	65.1	45.2
5	14	32	84.1	78.4	55.2
6	18	35	74.5	85.4	61.7
7	8	5	62.1	93.6	73.8
8	18	7	56.6	94.1	75.2
9	14	12	44.1	95.6	76.2
10	8	3	34.5	98.3	86.2
11	24	3	29.0	98.9	89.4
12	2	0	12.4	99.6	90.0
13	10	2	11.0	99.6	88.9
15	6	0	4.1	100	100

[a]Number of patients at each point in the new scoring system.
[b]The sensitivity of the new scoring system when each point is set as a critical point to predict healing failure.
[c]The specificity of the new scoring system when each point is set as a critical point to predict healing failure.
[d]The positive predictive value of the new scoring system when each point is set as a critical point to predict healing failure.

DISCUSSION

The present study demonstrated that age, AP tear size, tear retraction, fatty infiltration of the infraspinatus muscle, BMD, and level of work activity were significant prognostic factors influencing rotator cuff healing after surgical repair. Moreover, these factors were integrated into the RoHI and were verified in the study population retrospectively.

Several previous studies identified some of the prognostic factors affecting cuff healing after rotator cuff repair.[8,33-35] One study reported that the amount of retraction, fatty infiltration of the infraspinatus, and BMD were independent prognostic factors for the failure of cuff healing after repair of full-thickness rotator cuff tears.[8] Another study confined the cohort to only massive rotator cuff tears and revealed that only fatty infiltration of the infraspinatus was an independent prognostic factor that negatively influenced structural integrity.[6] More recent studies demonstrated that age, AP tear size, and fatty infiltration of the infraspinatus were significant prognostic factors for small- to medium-sized rotator cuff tears.[35] The current study evaluated the prognostic factors more thoroughly with a much larger cohort and incorporated the findings of previous studies.

Age as a prognostic factor for tendon healing is debatable. Several previous studies suggested that age did not influence the results of rotator cuff healing.[4,6,8,11] However, more recent studies that performed meta-analyses with high levels of evidence determined that retears were associated with advanced age. McElvany et al[26] collected data from 108 articles reporting 8011 shoulders and revealed that retears were more frequent among older patients. Saccomanno et al[37] performed a meta-analysis of 7 studies that had high quality methodologically and found that older age was associated with a lower rate of rotator cuff healing. The present study identified results comparable with these statistically powerful studies. The effect of age as a prognostic factor might be underestimated in a small or confined cohort; however, previous meta-analyses and the present study found that age is significant in terms of rotator cuff healing.

It is generally accepted that larger tear sizes have negative effects on tendon healing.[28,29] Cofield et al[10] classified rotator cuff tears based on tear size and reported that larger tear sizes were associated with unsatisfactory results. In the study of Cho and Rhee,[5] rotator cuff healing at least 2 years after surgery was 96.7% for patients with small-sized tears, as compared with 87.3% and 58.8% for the patients with medium or large/massive tears, respectively. Recently published meta-analyses also showed that larger tear sizes were associated with higher retear rates.[26,37] Although the original classification by Cofield et al[10] categorized rotator cuff tears based on tear size measured in the AP dimension, different measurements were used in several studies (length in coronal and sagittal planes or measurement in square millimeters).[28,29] Several confounding studies reported that either AP tear size or tear retraction was associated with rotator cuff healing.[14,24,26,35,37] In general, it is believed that AP tear size and tear retraction are correlated; therefore, we considered choosing either of these parameters but decided to include both for 3 reasons. First, both parameters identified independent prognostic factors associated with rotator cuff healing in the multivariate analysis. This result might be attributed to the significance of the tear configuration. Ellman and Gartsman[12] categorized full-thickness rotator cuff tears according to tear configuration and emphasized an understanding of these patterns with regard to repair surgery. Several studies published afterward supported the premise that tear configuration was correlated with cuff mobility and reparability.[38] Although AP tear size was commonly increased with tear retraction, excluding either or aggregating them might lead to underestimating the significance of tear configuration. Also, we believe that these 2 factors have different implications such that larger AP tear sizes may represent multiple-tendon involvement and larger tear retractions may reflect tear chronicity. Mochizuki et al[28] demonstrated that the supraspinatus footprint on the greater tuberosity was much smaller than previously believed, with a mean maximum AP length of 12.6 mm and a mean maximum AP length of the infraspinatus of 32.7 mm. Park et al[35] reported that the predictive cutoff value for the largest tear size associated with successful healing was calculated to be 2 cm in small- to medium-sized cuff tears. They concluded that anatomic outcomes might be better if the repair is performed before the tear size exceeds 2 cm. In the present study, the critical AP tear size was 2.5 cm. Note, however, that even though the value of the critical endpoint was different, because the current study included large to massive cuff tears, the conclusions obtained were ultimately similar to those of the previous study. Regarding the actual AP length of the supraspinatus and the infraspinatus footprints, AP tear sizes >2.5 cm were likely ruptures involving more than half of the infraspinatus muscle insertion, which suggests that the healing potential is significantly reduced in such cases. Finally, we included both AP tear size and tear retraction because tear retraction had a stronger correlation with tendon healing than any of the other factors. More subdivisions for retraction were needed to develop the scoring system because of its strong correlation. Moreover, adding the AP tear size or multiplying by it might undermine its effects on rotator cuff healing.

Fatty infiltration of the infraspinatus muscle has been regarded as an important factor affecting cuff healing since Goutallier introduced his scoring system in 1994.[5,6,8,14,19,22] Goutallier et al[19] reported that infraspinatus degeneration had a highly negative influence on the outcome of cuff repairs. Chung et al[6] confirmed that higher fatty infiltration of the infraspinatus was the most important factor negatively affecting cuff healing in cases of massive rotator cuff repair (OR, 11.25 for grade 3 and 4 fatty infiltration).[14] A recent systematic review[22] included 11 studies reporting on 925 shoulders, and it concluded that rotator cuffs with moderate or significant preoperative fatty infiltration (grades 2-4) had a significantly higher retear rate than those with no or minimal fatty infiltration (grades 0-1) (59% vs 25%, P = .045). The result of the current study was consistent with those of previous studies in which preoperative grade $\geq$2 fatty infiltration of the infraspinatus muscle was associated with poor outcomes (OR, 2.91; 95% CI, 1.58-5.34). We believe that fatty infiltration of the infraspinatus muscle reflects muscle and tendon quality—a significant factor affecting reparability.

Bone density as an independent factor influencing rotator cuff healing in the current study exposed the effect of osteoporosis on rotator cuff healing failures. As reported by Chung et al,[8] bone quality is considered to have its role in rotator cuff healing. We believe that no other studies have reported BMD as a prognostic factor for tendon healing, as DEXA is usually not performed before rotator cuff repair surgery in most clinics. This could be a missing parameter to aid in enhancing healing of rotator cuff muscles.

The significance of the level of work activity in cuff healing after repair surgery has been overlooked in the orthopaedic fields. Occupational environmental medicine has been actively studied to determine the effects of work-related factors on the incidence of shoulder pain and rotator cuff disorders. One longitudinally designed study showed that physical work involving a heavy load and awkward work posture were risk factors of persistent shoulder pain.[27] A recent meta-analysis study, including 27 studies with 2,413,772 workers, revealed moderate associations between shoulder disorders and arm-hand elevation (OR, 1.9; 95% CI, 1.47-2.47) and shoulder load (OR, 2.0; 95% CI, 1.90-2.1).[40] In the orthopaedic field, Abate et al[1] reported that heavy repetitive work was independently related to a higher probability of bilateral rotator cuff tears. Furthermore, Namdari et al[30] showed that those who self-identified their occupation as being labor intensive represented a special group of patients who are at a high risk for poor outcomes after a failed rotator cuff repair. However, only a few studies evaluated the effect of level of work activity on the rotator cuff healing rate. The level of work activity, which correlated with cuff healing in the current study, has not been evaluated in previous studies. However, it seems that orthopaedic surgeons are less interested in the level of work activity, which is probably why this has not been sufficiently studied.

To the best of our knowledge, this is the first study to identify prognostic factors associated with rotator cuff healing in such a large cohort and to subsequently integrate those factors into a scoring system to predict the fate of repaired tendons. We made a conscious effort to include every known prognostic factor reported in previous studies and performed a multivariate analysis to minimize the confounding factors and determine the independent prognostic factors. Additionally, evidence-based categorization with ROC curves and a scoring system weighting according to the OR of each factor could have improved the reliability. The RoHI, a new scoring system to predict rotator cuff healing after surgical repair, demonstrated good predictive results in the study cohort. Therefore, it could provide valuable information in clinical practice.

This study has several limitations. First, because of the inherent limitation of a retrospective study design, some patients who underwent rotator cuff repair surgery at the institution dropped out (603 patients were enrolled among the total of 1241 patients). This could have led to selection bias and may have created an inaccurate understanding of the results because of unanticipated confounding factors. However, this limitation is expected to be minimal because this study included a sufficiently large cohort. Although the homogeneous population in this study could be another advantage, the long period over which the study spans (between 2004 and 2014) is a second limitation. The surgical techniques could have improved with time, and this could have confounded the results. Third, there was an inevitable statistical pitfall in managing large amounts of data. Some missing data in BMD (87 of 603, 14.4%) had to be handled properly, and this study used the pairwise deletion method for analysis of all cases in which the variables of interest were present.[21] It is a reasonable method of statistically handling the missing data; however, it might result in bias or distort the conclusion. Additionally, some parts reflected author subjectivity in development of the scoring system. We believe that a scoring system predicting a certain event should have the following conditions: it should include prognostic factors that are independently correlated with the event, and the effect of these factors on occurrence of the event should be analyzed and appropriately reflected. Even though 1 factor has a strong correlation with the event, the effect of other factors should not be underestimated. Tear retraction had a linear correlation with the healing failure, which indicated a stronger correlation than that with other factors. We decided to subdivide the retraction, and when this was performed, the baseline of the analysis was lower; therefore, the results might be exaggerated. The maximum value of 4 points was given per the OR obtained when the retraction was divided by 3 cm (OR, 4.56; 95% CI, 2.34-8.86). In this process, we made a subjective judgment at each stage—namely, the number of grades, the reference point used to divide into 2 groups, and the point value assigned in each grade. However, these efforts were made to reflect the results obtained from the analysis as objectively as possible, and we believe that this process was worthy enough. Fourth, the RoHI has not been verified in other cohorts. In this study cohort, the risk of healing failure after rotator cuff repair was >50% and >85% when the RoHI was ≥5 and ≥10 points, respectively. We believe that the critical point of this scoring system is 5 points because it has maximum sensitivity and specificity (sensitivity, 84.1%; specificity, 78.4%). Since the variable factors of the RoHI were those that increased the risk of rotator cuff healing failure, it is not surprising that the higher the score, the higher the probability of healing failure. However, for the RoHI to be valuable as a scoring system, a critical point should be established where sensitivity and specificity are at an appropriate level, and this should be validated in other cohorts.

Some precautions are needed in interpreting the results of this study or applying it to clinical practice. In the current study, we assessed postoperative anatomic outcomes using MRI or CTA findings. Sugaya classification of type IV or V on MRI or contrast leakage through the footprint on CTA was considered healing failure. However, the defects in the repaired cuff could also be present in partial healing or a retear because we do not know exactly when tendon healing is complete after rotator cuff repair surgery. It should be kept in mind that some of what we had identified as retears might have been partially healed cuffs. Additionally, the results of this study were based on the initial short-term outcomes, and the mid- or long-term outcomes might have different results. The cuff integrity could be influenced by subsequent mechanical loading, trauma, and aging. In addition, even short-term outcomes might have different results in institutions with different settings. Different immobilization protocols from our institution, for instance, might affect healing results. There was also a caution in interpreting functional results. In this study, there were no significant differences in the functional outcomes of healed cuffs as compared with those of unhealed cuffs 1 year after surgery. These results might suggest that rotator cuff repair surgery is not meaningful; however, it might be attributed to the evaluation of short-term functional outcomes. It is thought that healing failures are likely to develop into osteoarthritis, which would be reflected in long-term functional outcomes.[15,25] Last, we addressed the potential negative effect of a predictive scoring system. This study could provide specific criteria that might be misused to allow or deny preauthorization for surgery. However, this study was simply based on the anatomic outcomes for 1 year after surgery. It is possible to predict the tendency of postoperative outcomes with this scoring system, the RoHI, but not possible to accurately predict individual treatment results. In addition, it should never be assumed that various factors other than the variables mentioned in this study could affect the healing rate in diverse ways. Therefore, the RoHI should be used as a means to predict with some confidence what the outcome of a procedure would be and to decide a better treatment and not as a means of refusing treatment because of a low healing rate.

In conclusion, we have designed a numerical scoring system to predict the healing of rotator cuffs after surgical repair. Our scoring system accounts for significant clinical and radiologic factors, such as age, AP tear size, tear retraction, fatty infiltration of the infraspinatus muscle, BMD, and level of work activity. Thus, as this RoHI will aid in predicting the success of the repair, it could be useful in deciding appropriate treatment options.

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