Original Research

Risk Factors for Rotator Cuff Repair Failure and Reliability of the Rotator Cuff Healing Index (RoHI) in Thai Patients

Comparison of the RoHI With a Modified Scoring System

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Background: The success rate of surgical treatment for rotator cuff (RC) tear ranges from 16% to 94%. The Rotator Cuff Healing Index (RoHI) is a system for predicting failure after RC repair and is based on a combined score of factors, including age, anteroposterior (AP) tear size, tendon retraction, fatty infiltration of the infraspinatus muscle, bone mineral density (BMD), and level of work activity.

Purpose: To determine the factors leading to RC repair failure in a Thai population, to test the reliability of the RoHI in this population, and to compare the RoHI with a modified RoHI (m-RoHI) based on the factors for repair failure as determined.

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

Methods: This study included 133 Thai patients who underwent arthroscopic RC repair between February 2012 and February 2021. Postoperative magnetic resonance imaging was performed at 6 to 24 months to evaluate RC healing. Variables that might affect failure rates were evaluated, including demographic characteristics, AP tear size and retraction, radiographic measurements, and magnetic resonance imaging findings. The m-RoHI was created using factors that significantly predicted repair failure on multivariate analysis. The area under the receiver operating characteristic curve was calculated to determine the reliability of the RoHI and to compare the reliability of the RoHI and m-RoHI to predict failure rates.

Results: Multivariate logistic regression analysis revealed that body mass index $\geq$23 (adjusted odds ratio [OR], 9.02; $P = .034$), high work activity (adjusted OR, 19.53; $P = .008$), AP tear size $\geq$2.5 cm (adjusted OR, 19.04; $P = .001$), and a retraction size of 2 to $<$3 cm (adjusted OR, 20.36; $P = .013$) were the independent factors that predicted repair failure in our population. BMD was not independently predictive of repair failure. We used these 4 significant independent factors to generate the m-RoHI. The area under the curve of the final adjusted m-RoHI was slightly improved as compared with the original RoHI, but this difference was not significant (0.827 [95% CI, 0.741-0.913] vs 0.780 [95% CI, 0.686-0.875], respectively; $P = .447$).

Conclusion: The m-RoHI had a similar predictive value for repair failure to the original RoHI in our study population, but it did not require obtaining BMD. The m-RoHI may be useful in populations where BMD is not routinely obtained.

Keywords: rotator cuff surgery; rotator cuff tear; repair failure; rotator cuff healing index

Rotator cuff (RC)–related shoulder pain is a common problem in >70% of patients with shoulder pain.[11,20] Of patients with RC-related pain, 85% are found to have an RC tear on magnetic resonance imaging (MRI).[16] These tears cause pain, weakness, and disability and are frequently treated with RC repair.

The success rate of surgical treatment of a torn RC ranges from 16% to 94% depending on various factors,[1,4,9,10] among which are patient characteristics, such as age, congenital disease, occupation, and daily activities; disease factors, such as quality of tendons and time from injury to surgery; and surgical factors, including surgical technique and surgeon experience.[17] There are several studies on factors that affect healing after RC repair, such as age,[16,17,21] body mass index (BMI),[17] subscapularis and infraspinatus (ISP) fatty infiltration,[16,21] bone mineral density (BMD),[16] tear length,[16,17] tear width,[16,21] tear size area,[16,17,21] and amount of retraction.[13,15,16,19,21]

In 2019, Kwon et al[16] published a scoring system called the Rotator Cuff Healing Index (RoHI) to predict failure

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Rotator cuff Healing Index Scoring System

Factors	Point
Age	
≤ 70 y	0
> 70 y	2
Anteroposterior tear size, cm	
≤ 2.5	0
> 2.5	2
Retraction, cm	
< 1	0
1 to <2	1
2 to <3	2
≥ 3	4
Infraspinatus fatty infiltration, grade	
< 2	0
≥ 2	3
Bone mineral density	
> -2.5	0
≤ -2.5	2
Level of work activity	
low and medium	0
high	2

Figure 1. The score distribution for the RoHI.[16] Factors include age (≤70 or >70 years), anteroposterior tear size (≤2.5 or >2.5 cm), amount of retraction (<1, 1 to <2, 2 to <3, or ≥3 cm), infraspinatus fatty infiltration according to Goutallier classification[8] (grade <2 or ≥2), bone mineral density (>–2.5 or ≤–2.5), and level of work activity (low and medium or high). RoHI, Rotator Cuff Healing Index.

after RC repair. This 15-point scoring system consists of 4 points for retraction; 3 points for fatty infiltration of the ISP; and 2 points each for anteroposterior (AP) tear size, patient age, BMD, and work activity (Figure 1). In a Korean population, patients with a score ≤4 had a 6.0% failure rate, and those with scores ≥5 and ≥10 had failure rates of 55.2% and 86.2%, respectively.[16] However, the RoHI has not been independently validated.

The purposes of this study were to determine the factors leading to RC repair failure in a Thai population, test the reliability of the RoHI in this population, and compare the reliability of a modified RoHI (m-RoHI) against the original RoHI based on the factors for repair failure as determined.

METHODS

After receiving ethics committee approval, we conducted a case-control study of patients who had undergone arthroscopic RC repair between February 2012 to February 2021 at a single institution. The inclusion criteria were full-thickness RC tear confirmed by arthroscopy and postoperative MRI ≥6 months after surgery. The exclusion criteria were a partial-thickness RC tear, an isolated subscapularis tear, or previous surgery on the same shoulder. Of the 547 initial patients, 133 were ultimately included in this study. A diagram of the study flow is shown in Figure 2.

Surgical Procedure

All of the arthroscopic RC repair procedures were performed by a fellowship-trained sports medicine surgeon (B.C.) with patients in a beach-chair position. The operation started in the glenohumeral articulation where concomitant procedures were performed, such as biceps tenotomy or tenodesis, synovectomy, or capsular release. The subacromial bursectomy was routinely performed and potentially accompanied by an acromioplasty in patients with significant subacromial impingement (fraying of the coracoacromial ligament) or a pathologic spur. All RC repair techniques used the transosseous-equivalent repair technique. The repair techniques and the number of anchors depended on the tear size and tear characteristics. Before anchor placement, the RC footprint was prepared to create adequate biologic healing using a shaver, curette, or microfracture awl.

Postoperative Rehabilitation

The patients' shoulders were immobilized with an abduction sling for 4 to 6 weeks. Active elbow, wrist, and hand motion was encouraged immediately after surgery. Passive shoulder motion was allowed after 2 weeks postoperatively. Active shoulder motion was allowed after 6 weeks postoperatively. Return-to-sport activities were allowed after 6 months postoperatively.

Clinical and Radiological Assessment

We collected baseline patient characteristics (age, sex, BMI), side affected, date of operation, work activity, sports

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Ethical approval for this study was obtained from Thammasat University (No. MTU-EC-OT-0-209/64).

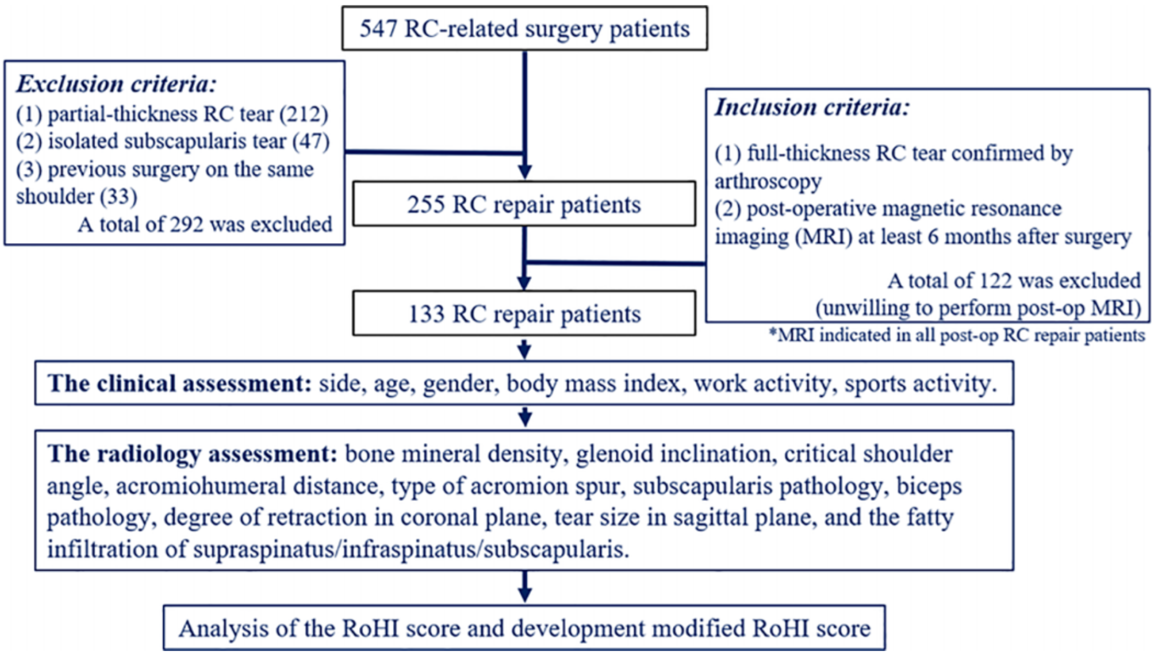

Figure 2. Flowchart of study procedure. MRI, magnetic resonance imaging; RC, rotator cuff; RoHI, Rotator Cuff Healing Index .

activity, and preoperative visual analog scale score for pain (0-10 points). Work activity and sports activity were classified according to Kwon et al[16] as follows:

- *Sports activity*: low (rarely participating in sports activities), medium (participation in static sports; eg, running, bicycling, golf, yoga), or high (participation in contact sports; eg, basketball, football, tennis, volleyball)
- *Work activity*: low (sedentary work), medium (manual labor with less activity), or high (heavy manual labor)

In addition, patients underwent BMD testing before the surgery or <1 year after the RC repair. The BMD was measured with dual-energy x-ray absorptiometry (Hologic Horizon W). The lowest T score of the femoral neck or lumbar spine was recorded.

We used preoperative plain radiographs to evaluate the type of acromion and the presence of an acromial spur, as well as measure the acromiohumeral interval, critical shoulder angle, and glenoid inclination. We classified types of acromion in 2 categories: (1) the classification of Bigliani et al[3] was recorded as flat, curved, or hooked, and (2) the classification of "at-risk spur"[13] was recorded as nonpathologic spur and pathologic spur (heel, keel, and irregular spur). The acromiohumeral interval was measured from the dense cortical bone by marking the inferior aspect of the acromion at a point directly above the head of the humerus and recording the smallest distance between this point and the articular cortex of the head of the humerus.[23] The glenoid inclination angle was measured by creating a line between the superior and inferior rims of the glenoid and a line between the spinoglenoid notch and the intersection of the scapular spine and medial border.[26] The critical shoulder angle was measured by creating a line from the supraglenoid tubercle to the infraglenoid tubercle and a line from the infraglenoid tubercle to the lateral-most aspect of the acromion.[22]

Tear retraction, AP tear size, presence of biceps pathology (contour irregularity, subluxation, and alteration of signal intensity), and fatty infiltration were assessed by preoperative MRI. Categorical parameters were matched to those used in the original RoHI.[16] Tear size was categorized as <2.5 or ≥2.5 cm. Tear retraction was measured in centimeters[6] and classified into 4 groups (<1, 1 to <2, 2 to <3, and ≥3).[16] Fatty infiltration was classified using the Goutallier classification.[5,7,8,16,25,27]

All MRI parameters were measured by an orthopaedic surgeon (P.M.) and a musculoskeletal radiologist (W.P.). Interrater reliability was calculated with the kappa coefficient (κ)[18] for categorical variables (AP tear size, fatty infiltration classification, tear retraction classification), in which $\kappa < 0.00$ was considered poor strength of agreement; 0.00 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; and 0.81 to 1.00, almost perfect. The interrater reliability of the continuous variable (amount of tear retraction) was evaluated with the intraclass correlation coefficient (ICC) using a 2-way random effects model, in which values <0.5, 0.5 to 0.74, 0.75 to 0.9, and >0.90 were indicative of poor, moderate, good, and excellent reliability, respectively.[14]

Outcome Assessment

The assessment of retears was conducted on minimum 6-month postoperative MRI by the same 2 reviewers who measured the other MRI parameters. We used an MRI evaluation of 6 months instead of 1 year because we believed the "critical period" for healing after RC repair, during which

TABLE 1
Baseline Characteristics Between the Healed and Failure Groups (N = 133)[a]

	Healed (n = 106)	Failure (n = 27)	*P*
Sex			.963
Female	82 (77.4)	21 (77.8)	
Male	24 (22.6)	6 (22.2)	
Weight, kg	61.92 ± 10.34	66.57 ± 12.59	**.048**
Height, m	1.56 ± 0.08	1.56 ± 0.09	.694
Body mass index	25.29 ± 3.63	27.38 ± 4.09	**.010**
Body mass index group			**.035**
<23	28 (26.4)	2 (7.4)	
≥23	78 (73.6)	25 (92.6)	
Affected side			**.019**
Left	41 (38.7)	4 (14.8)	
Right	65 (61.3)	23 (85.2)	
Age, y	63.72 ± 8.05	62.63 ± 7.75	.529
Age group, y			.527
<70	88 (83)	21 (77.8)	
≥70	18 (17)	6 (22.2)	
Work activity			**.004**
Low and medium	104 (98.1)	23 (85.2)	
High	2 (1.9)	4 (14.8)	
Sports activity			.400
Low	97 (91.5)	26 (96.3)	
Moderate	9 (8.5)	1 (3.7)	
High	0 (0)	0 (0)	
Bone mineral density			.598
Normal	38 (35.8)	7 (25.9)	
Osteopenia	53 (50)	15 (55.6)	
Osteoporosis	15 (14.2)	5 (18.5)	

[a]Data are presented as No. (%) or mean ± SD. Bold *P* values indicate statistically significant differences between groups ($P < .05$).

TABLE 2
Radiologic Parameters Between the Healed and Failure Groups (N = 133)[a]

	Healed (n = 106)	Failure (n = 27)	*P*
AP tear size, cm			**<.001**
<2.5	101 (95.3)	16 (59.3)	
≥2.5	5 (4.7)	11 (40.7)	
Retraction, cm	1.75 ± 1.04	2.52 ± 1.1	**.001**
Retraction group, cm			**.007**
<1	31 (29.2)	1 (3.7)	
1 to <2	42 (39.6)	9 (33.3)	
2 to <3	19 (17.9)	9 (33.3)	
≥3	14 (13.2)	8 (29.6)	
Glenoid inclination, deg	18.07 ± 7.57	18.11 ± 7.12	.978
Critical shoulder angle, deg	37.89 ± 5.4	38.78 ± 6.58	.466
Acromiohumeral interval, mm	8.79 ± 2.1	8.73 ± 2.02	.895
Acromion type			.413
AP view			
Flat	39 (36.8)	13 (48.1)	
Curved	62 (58.5)	12 (44.4)	
Hooked	5 (4.7)	2 (7.4)	
Rockwood view			.826
No spur	33 (31.1)	9 (33.3)	
At-risk spur	73 (68.9)	18 (66.7)	
Biceps pathology			**.023**
No	30 (28.3)	2 (7.4)	
Yes	76 (71.7)	25 (92.6)	
Fatty infiltration grade			
Supraspinatus			**.001**
<2	72 (67.9)	9 (33.3)	
≥2	34 (32.1)	18 (66.7)	
ISP			**.001**
<2	84 (79.2)	13 (48.1)	
≥2	22 (20.8)	14 (51.9)	
SSC			.827
<2	92 (86.8)	23 (85.2)	
≥2	14 (13.2)	4 (14.8)	
SSC pathology			**.014**
No	74 (69.8)	12 (44.4)	
Yes	32 (30.2)	15 (55.6)	

[a]Data are presented as No. (%) or mean ± SD. Bold *P* values indicate statistically significant differences between groups ($P < .05$). AP, anteroposterior; ISP, infraspinatus; SSC, subscapularis.

risks of retears are high, extends to the first 6 months and should be sufficient to predict repair failure.[2] The repair integrity on postoperative MRI was classified according to the Sugaya classification,[24] in which Sugaya grades 0 to 3 were considered healed RC repairs and Sugaya grades 4 and 5 were considered repairs that failed to heal. The study patients were grouped according to those with healed repairs and those with repairs that failed to heal.

Statistical Analysis

The sample size was calculated by using the infinite proportion formula with the variables including an RoHI cutoff score of 5, error (d) of 0.0841, alpha of .05, and power of 80%. The calculated sample size was 73. The cutoff score of 5 was chosen because Kwon et al[16] showed that at an RoHI score of 5, the probability of repair failure was 55.2%. Thus, the true sample size would equal 73/55.2% = 133.

Patient baseline characteristics and radiologic and imaging outcomes were compared between the healed repair group and the repair failure group. Outcome data were compared via the chi-square test for qualitative variables and independent *t* tests for quantitative variables, where appropriate. We then identified the independent factors for repair failure in our study population, and we generated the m-RoHI based on these factors. The reliability of the original RoHI in our study sample was calculated with the area under the receiver operating characteristic curve (AUC), and the AUCs of the RoHI and m-RoHI were then compared. The Youden index was used to identify the cutoff value of the m-RoHI for achieving >50% ability to detect repair failure. The significance of statistics was established at $P < .05$, and all statistical analyses were performed with STATA software for Windows (Version 17; Stata Corp LP).

RESULTS

A total of 133 patients, 103 female (77%) and 30 male (23%), were included with a mean age of 63.5 years (range, 43-83

TABLE 3
Multivariate Logistic Regression and Proposed m-RoHI[a]

	Beta	Adjusted OR (95% CI)	*P*	m-RoHI Score (Total 11)	
				Unadjusted	Adjusted
Body mass index					
<23	Reference	Reference		0	0
≥23	2.200	9.02 (1.18-68.99)	**.034**	2	2
Work activity					
Low and medium	Reference	Reference		0	0
High	2.972	19.53 (2.20-173.60)	**.008**	3	3
AP tear size, cm					
<2.5	Reference	Reference		0	0
≥2.5	2.947	19.04 (3.56-101.73)	**.001**	3	3
Retraction, cm					
<1	Reference	Reference		0	0
1 to <2	1.877	6.53 (0.64-66.61)	.113	2	2
2 to <3	3.014	20.36 (1.88-220.91)	**.013**	3	3
≥3	0.931	2.54 (0.18-35.27)	.488	1	3[b]

[a]Bold *P* values indicate statistical significance vs reference value ($P < .05$). AP, anteroposterior; m-RoHI, modified Rotator Cuff Healing Index; OR, odds ratio.

[b]Adjusted by clinical importance.

years). According to the Sugaya classification, a healed RC repair was found in 106 (79.7%), while repair failure occurred in 27 (20.3%). From the univariable analysis of patient characteristics, weight ($P = .048$), BMI ($P = .010$), BMI group ($P = .035$), affected side ($P = .019$), and work activity ($P = .004$) were significantly different between the healed and failure groups (Table 1).

The interrater reliability of the MRI measurements indicated moderate agreement for AP tear size ($\kappa = 0.526$) and ISP fatty infiltration grade ($\kappa = 0.510$) and substantial agreement for retraction grading ($\kappa = 0.660$). The ICC value of the retraction measurement revealed good reliability (ICC = 0.841).

Based on the univariable analysis of radiographic parameters, AP tear size ($P < .001$), amount of retraction ($P = .001$), retraction classification ($P = .007$), biceps pathology ($P = .023$), supraspinatus fatty infiltration grade ($P = .001$), ISP fatty infiltration grade ($P = .001$), and subscapularis pathology ($P = .014$) were significantly different between the healed and failure groups (Table 2).

In the multivariate logistic regression analysis, the significant independent factors were BMI ≥23, high work activity level, AP tear ≥2.5 cm, and retraction between 2 and <3 cm (Table 3). We used these factors in generating the m-RoHI. However, we adjusted the scoring of tear retraction ≥3 cm from 1 to 3 points, as we felt that this amount of retraction would likely affect retear rates, but the small number of study patients with this amount of retraction did not show a significant effect.[12,16] The maximum possible score for the adjusted m-RoHI was 11.

By applying the RoHI scoring system to our study population, the mean score for the healed group was 2.7 (range, 0-11), and the mean score for the failure group was 5.7 (range, 1-13). Patients who scored <5 had a repair failure rate of 33.3%, while those with a score ≥5 had a failure rate of 66.7%. By applying the adjusted m-RoHI scoring system, the mean score for the healed group was 3.1 (range, 0-6), and the mean score for the failure group was 5.5 (range, 2-9). Patients who scored <5 had a repair failure rate of 8.3%, while those with a score ≥5 had a failure rate of 51.4%. According to the Youden index, an adjusted m-RoHI score of 5 had a >50% risk of repair failure, with a sensitivity of 70.4%, specificity of 83.0%, and accuracy of 80.5% (Table 4).

The AUC for reliability of the RoHI to predict RC healing in our patient population was 0.780 (95% CI, 0.686-0.875), indicating fair reliability. The AUC of the adjusted m-RoHI was 0.827 (95% CI, 0.8-0.9), indicating good reliability. The comparison of AUC values among the RoHI, m-RoHI, and adjusted m-RoHI revealed no statistically significant differences ($P = .447$) (Figure 3).

DISCUSSION

From our study, we found that the ability of the RoHI to predict RC repair failure in our population was fair (AUC, 0.780; 95% CI, 0.685-0.875) and the corresponding ability of the adjusted m-RoHI was good (AUC, 0.827; 95% CI, 0.741-0.913). Interestingly, we found that BMI was also an independent risk factor for failure after RC repair. After the multivariate logistic regression analysis, the significant independent risk factors for repair failure were BMI ≥23, high level of work activity (ie, manual labor), AP tear ≥2.5 cm, and tear retraction from 2 to <3 cm. BMD, ISP fatty infiltration grade, and age at the time of surgery were not independent risk factors in our study population. The 11-point adjusted m-RoHI created with these significant independent factors revealed a mean score of 3.1 (range, 0-6) for the healed group and 5.5 (range, 2-9) for the failure group. Patients who scored <5 had a failure rate of 8.3%, whereas those with a score ≥5

TABLE 4
Cutoff Scores and Diagnostic Accuracy for the Adjusted Modified Rotator Cuff Healing Index[a]

Cutoff Score	Failure, n	Healed, n	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Accuracy, %
0	0	8	100.0	0.0	20.3	NA	26.3
1	0	2	100.0	7.5	21.6	100.0	26.3
2	1	32	100.0	9.4	22.0	100.0	27.8
3	2	14	96.3	39.6	28.9	97.7	51.1
4	5	32	88.9	52.8	32.4	94.9	60.2
5[b]	6	12	70.4	83.0	51.4	91.7	80.5
6	5	6	48.1	94.3	68.4	87.7	85.0
7	5	0	29.6	100.0	100.0	84.8	85.7
8	2	0	11.1	100.0	100.0	81.5	82.0
9	1	0	3.7	100.0	100.0	80.3	80.5

[a]NA, not applicable; NPV, negative predictive value; PPV, positive predictive value.
[b]Cutoff score for repair failure >50%.

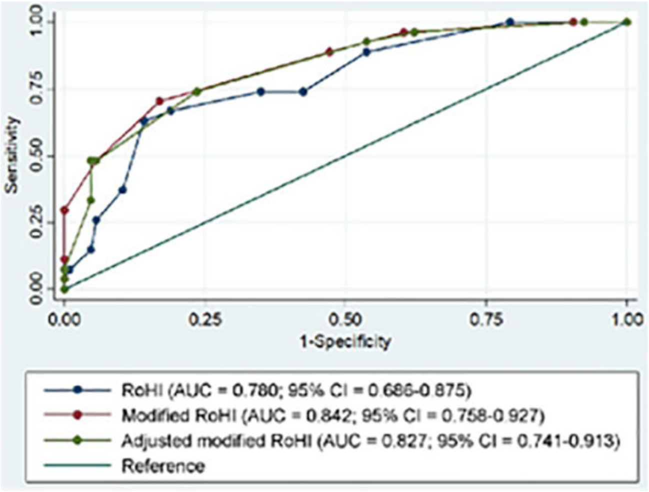

Figure 3. Receiver operating characteristic curves for the Rotator Cuff Healing Index (RoHI), the modified RoHI, and the adjusted modified RoHI in the study population. There was no significant difference in areas under the curve (AUCs) among the scoring systems (P = .447).

had a failure rate of 51.4%. An adjusted m-RoHI score of 5 predicted repair failure with a sensitivity of 70.4%, specificity of 83.0%, and accuracy of 80.5%.

The study results indicate that the RoHI may lack some information applicable to other population groups regarding possible factors affecting tendon healing after surgery.[16] In our population of Thai patients, only 4 factors (BMI, AP tear size, tear retraction, and work activity) were significantly associated with repair failure. AP tear size, tear retraction, and work activity were the same predictors as in the original RoHI, but the BMI was added to our m-RoHI scoring system. Previous studies have also shown that high BMI and obesity were related to the increasing possibility of RC retear.[5,12,27]

As shown in Table 3, the final adjusted m-RoHI score was reduced to 11 points from 15 points in the original RoHI. Because tear retraction ≥3 cm had only 1-point scoring based on the statistical analysis, this was adjusted to 3 points, as the small number of patients with this much retraction likely limited our analysis.[12,16] The adjusted m-RoHI revealed no statistically significant difference in AUC with the original RoHI (P = .447).

The factors contributing to repair failure in this study included the following. (1) Higher BMI might increase mechanical strain attributed to arm weight on the RCs and might have a negative influence on tendon healing related to metabolic factors. (2) High work activity might increase the mechanical load on the repaired site. (3) AP tear might represent multiple-tendon involvement. (4) Retraction might reflect tear chronicity that had negative effects on RC healing. BMD, ISP fatty infiltration of grade ≥2, and age ≥70 years at the time of surgery (all variables included in the original RoHI) were not independent risk factors in our study population. This finding could be due to the following. (1) BMD of the hips and spine might have no strong correlation with the bone quality of the RC footprints. (2) ISP fatty infiltration was a risk factor in univariate analysis but not in multivariate analysis, possibly because of the relationship between fatty infiltration and tear retraction. The retraction of the torn tendon may have exaggerated the amount of fatty infiltration on MRI more than the actual intramuscular fat. (3) Patient age might not determine RC quality and tear chronicity.

Limitations

There are certain limitations to our study. First, radiologic assessment is moderately subjective, and interobserver reliability resulted in moderate to substantial agreement (0.510 in ISP fatty infiltration, 0.526 in AP tear size, and 0.660 in the retraction grading). Second, we did not evaluate pre- and postoperative functional outcome scores related to the healed or failure group. Third, the results of the study were based on a short-term outcome (≥6 months); a longer outcome (>1 year) might have different results. Fourth, some factors that affect healing were not considered in this study, such as diabetes, autoimmune inflammatory disorders, smoking, and preoperative inflammatory markers. These can be a subject for future prospective study. Fifth, even though our sample size had enough power for statistical analysis, it was still less than the sample size in the original Kwon et al[16] study (N = 603). Last, this was a retrospective study with limited postoperative MRI in nearly 50% of the study population, and loss to follow-up could have introduced confounding by selection/transfer bias.

CONCLUSION

The m-RoHI, composed of BMI, activity level, tear size, and retraction, had a similar predictive value for RC repair failure to the original RoHI but did not require obtaining BMD. This modified scale may be useful in populations where BMD is not routinely obtained.

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