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Relationship between the Hamada Grade and underlying pathological conditions in the rotator cuff and long head of biceps in symptomatic patients with rotator cuff tears

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Background: This study aimed to investigate the relationship between Hamada Grade and rotator cuff and long head of the biceps (LHB) pathologies in symptomatic patients with rotator cuff tears (RCTs).
Methods: We retrospectively reviewed 376 patients (156 men and 220 women; mean age, 68.4 years) who had undergone surgery for complete RCTs. Preoperative plain radiography, magnetic resonance imaging, and intraoperative findings were assessed. All cases were allocated to the Hamada Grade 1, 2, 3, and 4-5 groups to investigate the correlation between Hamada Grade severity and underlying rotator cuff and LHB pathologies.
Results: The rate of RCTs involving the infraspinatus was significantly higher in Grade 2 than in Grade 1 ($P < .0001$). The tear size and fatty muscle degeneration of the subscapularis in Hamada Grade 3 were significantly more severe than those in Grade 2 ($P = .01$ and $P < .0001$, respectively). The tear size and fatty muscle degeneration of the rotator cuff in Grade 4-5 were significantly more severe than those in Grade 3 (all $P < .05$). The complete LHB rupture rate was significantly higher in Hamada Grade 4-5 than in Grades 1, 2, and 3 (all $P < .001$).
Conclusion: Rotator cuff tears involving the infraspinatus were associated with Hamada Grade 2. The rate of concomitant subscapularis tears with posterosuperior RCTs was significantly higher in Hamada Grade 3 than in Hamada Grade 2. RCT enlargement, progression of fatty muscle degeneration of the subscapularis and posterosuperior rotator cuff muscles, and the increase in complete LHB rupture were associated with Hamada Grade 4-5.

Rotator cuff muscles play a major role in the dynamic stabilization of the glenohumeral joint.[22] Rotator cuff tears (RCTs) or muscle dysfunction alter the force couple of these muscles, destabilizing the glenohumeral joint. This may lead to cartilage degeneration and bony deformity, resulting in cuff tear arthropathy (CTA).[12,41] The presence of RCTs and fatty infiltration of rotator cuff muscles are suggested as risk factors for the development and progression of arthritic changes.[4,9,16] The arthritic changes following an RCT involve superior migration of the humeral head, acromial acetabulization, glenohumeral arthritis, and humeral head collapse, collectively described as CTA.[15,27]

The Hamada classification was originally developed to describe the progression of these arthritic changes in patients with massive RCTs.[14,15] Recently, preoperative radiographic evaluation according to the Hamada classification has been widely used to determine the indication for joint-preserving surgery in patients with symptomatic RCTs.[5,8,15,19,24,26,39] In addition, some studies have reported that progressed Hamada Grades worsen the clinical results of rotator cuff surgery.[8,15,29] However, the correlation between the severity of the Hamada Grade and the underlying rotator cuff and long head of the biceps (LHB) pathologies remains unclear. Previously, Hamada et al. investigated whether patient characteristics and magnetic resonance imaging (MRI) findings of the rotator cuff differed between grades. However, their study included only 75 patients: 69 patients with Hamada Grades 1 or 2 and only 6 patients with Hamada Grades 3-5.[15] To date, no study has investigated the

The study protocol was approved by the Institutional Review Board at Osaka Medical and Pharmaceutical University (#2020-076).

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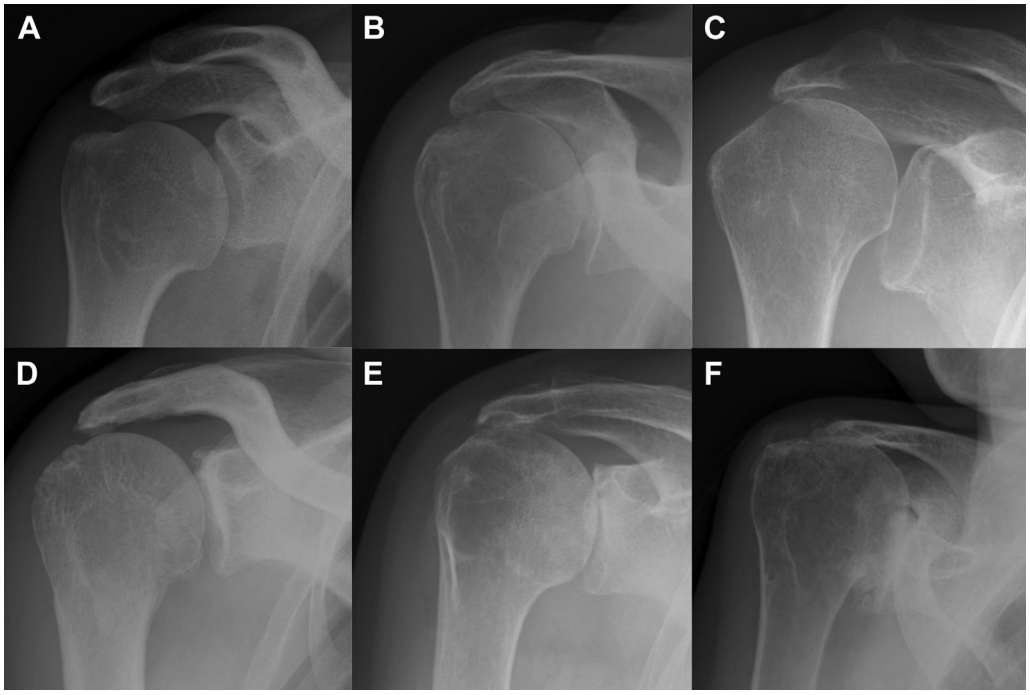

Figure 1 Classification of Hamada Grade. (**A**) Grade 1, the acromiohumeral interval is 6 mm or more. (**B**) Grade 2, the acromiohumeral interval is less than 6 mm (**C**) Grade 3, the acromiohumeral interval is less than 6 mm with acetabulization of the acromion. (**D**) Grade 4A, narrowing of the glenohumeral joint without acetabulization of the acromion. (**E**) Grade 4B, narrowing of the glenohumeral joint with acetabulization of the acromion. (**F**) Grade 5, an instance of humeral head collapse.

correlation between the severity of the Hamada Grade and the underlying rotator cuff and LHB pathologies using large sample sets. A better understanding of the correlation between Hamada Grades and underlying soft tissue conditions may improve treatment strategies for patients with degenerative RCTs. Therefore, this study aimed to investigate the relationship between Hamada Grade severity and rotator cuff and LHB pathologies in a large sample set comprising a consecutive series of symptomatic patients with RCTs. We hypothesized that there were significant correlations between the Hamada Grade and the RCT size, grade of fatty infiltration of the rotator cuff muscles, and rate of LHB lesions.

Materials and methods

Patient selection

The study protocol was approved by the Institutional Review Board of our university (No. 2020-076). We retrospectively reviewed our database of patients with RCTs. We initially included 445 consecutive patients with RCTs who had undergone surgery at our institute between January 2014 and June 2020. The inclusion criteria of this study were as follows: clinical diagnosis of symptomatic complete RCTs, having undergone surgery at our institute, and completion of preoperative radiographic assessments, including plain radiography and MRI. Exclusion criteria were patients with partial-thickness RCTs, incomplete preoperative and/or intraoperative evaluations, a history of shoulder dislocation on the affected shoulder, a history of any fracture in the affected shoulder girdle, and a prior surgical procedure on the affected shoulder. We excluded thirty-eight patients with partial-thickness RCTs, ten with incomplete evaluations, nine with a history of shoulder dislocation, six with fracture, and six with prior surgery. Consequently, we enrolled 376 patients with symptomatic complete RCTs in this study. The study population comprised 156 males and 220 females. The mean age was 68.4 years (range, 39-90 years).

Radiographic assessments

All patients underwent preoperative radiographic assessment of the conventional anteroposterior radiographs with the X-ray beam angled 20° caudally.[28,32] All radiographs were taken under magnification control with the arm in neutral rotation, and the patient relaxed. Two fellowship-trained shoulder surgeons (AH and AU) independently evaluated all preoperative plain radiographs and assigned the grade of arthritis according to the Hamada classification.[15] Briefly, in Grade 1, the acromiohumeral interval (AHI) is 6 mm or more; Grade 2, the AHI is less than 6 mm; Grade 3, acetabulization, which is characterized by excavating deformity of the acromion or excessive spur along the coracoacromial ligament, is added to the Grade 2 characteristics; Grade 4, narrowing of the glenohumeral joint is added to the Grade 2 or 3 features (Grade 4A, glenohumeral arthritis without acetabulization and Grade 4B, glenohumeral arthritis with acetabulization); and Grade 5, comprises instances of humeral head collapse (Fig. 1).[14,15,38] After a one-month interval, the shoulder surgeons were asked to evaluate each of the same plain radiographs in a different random order as second evaluations. The surgeons did not have access to the clinical data, patient information, or prior evaluations before radiographic evaluation. If the assigned grade differed between observers, a final assignment was determined by consensus. All 376 cases were allocated to four groups according to the Hamada classification: Grade 1, Grade 2, Grade 3, and Grade 4-5. In this study, Grades 4A, 4B, and 5 were grouped together as Grade 4-5 because these grades are characterized by glenohumeral arthritis with massive RCT, which is often used as an exclusion criterion for joint-preserving surgery and a good indication for reverse shoulder arthroplasty.[3,10,24]

MRI evaluations

MRI was performed using a 3.0T closed-type scanner (Discovery MR750 3.0T; GE Healthcare, Milwaukee, WI, USA). Oblique coronal,

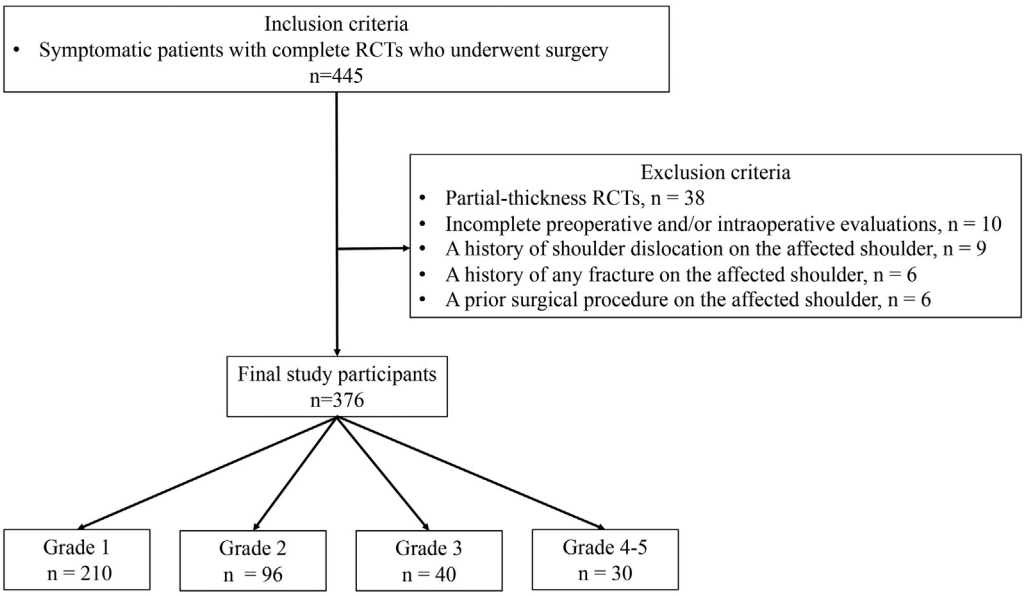

Figure 2 Flowchart of patient inclusion. *RCTs*, rotator cuff tears.

Table I
Patient demographics.

	Grade 1	Grade 2	Grade 3	Grade 4-5
Number of patients	210	96	40	30
Sex	75 M, 135 F	49 M, 47 F	20 M, 20 F	12 M, 18 F
Age (y)*	66.3 ± 10.2	69.7 ± 8.2†	70.9 ± 6.9†	75.5 ± 7.2‡
Duration of symptoms (mo)*	10.6 ± 17.0	14.9 ± 24.6	20.0 ± 30.9	41.9 ± 40.4§,‖,¶

M, male; *F*, female.
P values were calculated by Tukey's post hoc test.
*Values are presented as means ± standard deviations.
†Significantly older than Grade 1 ($P < .05$).
‡Significantly older than Grade 1 ($P < .0001$).
§Significantly longer than Grade 1 ($P < .0001$).
‖Significantly longer than Grade 2 ($P < .0001$).
¶Significantly longer than Grade 3 ($P = .001$).

oblique sagittal, and axial T1- and T2-weighted images were acquired for semi-qualitative assessment of fatty muscle degeneration of the rotator cuff muscles. Two fellowship-trained shoulder surgeons (AH and AU) independently evaluated all preoperative MR images and assigned the stage of fatty muscle degeneration according to the Goutallier classification.[11,13] The surgeons were blinded as described for the radiographic evaluations. If the stage assigned was different between observers, a final diagnosis was determined by consensus for the following correlation analysis between the severity of the Hamada Grade and fatty muscle degeneration of the RCTs.

Intraoperative assessments

Rotator cuff tears were confirmed intraoperatively by a senior surgeon (TM). The torn tendons and sizes of the RCTs (anterior-posterior direction) were evaluated intraoperatively with a measuring probe. The LHB findings were recorded as normal, partial rupture, or complete rupture. In addition, the reducibility of torn rotator cuff tendons was assessed during surgery. An RCT was defined as irreparable when the torn rotator cuff tendons could not cover the original footprint on the greater or lesser tuberosity at 30° of shoulder abduction during surgery.[8,25]

Statistical analyses

Descriptive statistics were used to report basic measures. Values are presented as mean ± standard deviation. To investigate the correlation between Hamada Grade severity and RCT and LHB pathologies, we compared the number of torn tendons, tear size of rotator cuff tendons, stage of fatty muscle degeneration of rotator cuff muscles, and concomitant LHB pathologies among the four groups. For the comparison of continuous values, a one-way analysis of variance (ANOVA) followed by Tukey's post hoc test was used. Statistical significance was set at $P < .05$. For the comparison of categorical values among the four groups, Fisher's exact test was used, and $P < .0083$ was considered statistically significant after Bonferroni correction. All statistical analyses were performed using JMP Pro 14.0 software (SAS Institute Inc., Cary, NC, USA).

Cohen's kappa coefficient was used to report the intrarater and inter-rater agreements for the assessment of the Hamada Grade and Goutallier classification stages. Kappa values were calculated using SPSS software, version 22.0 (IBM Corp., Armonk, NY, USA). The kappa values were interpreted according to guidelines adapted from the work of Landis and Koch.[21] 'Almost perfect' agreement occurred when the kappa value was between 0.81 and 1.00; 'substantial', between 0.61 and 0.80; 'moderate', between 0.41 and 0.60; 'fair', between 0.21 and 0.40; and 'poor', 0.20 or less.

Table II
Number of torn tendons and rotator cuff tear size.

	Grade 1 n = 210	Grade 2 n = 96	Grade 3 n = 40	Grade 4-5 n = 30
Number of torn tendons	1.6 ± 0.6	2.2 ± 0.5*	2.5 ± 0.6*	3.0 ± 0.7*,†,‡
RCT size, cm	2.0 ± 0.9	3.3 ± 0.9*	3.8 ± 1.0*,§	5.2 ± 1.3*,†,‖
Posterosuperior RCT size, cm	1.9 ± 0.7	3.0 ± 0.7*	3.3 ± 0.7*	3.9 ± 0.9*,†,‡
Subscapularis tear size, cm	0.1 ± 0.4	0.2 ± 0.5	0.6 ± 0.8*,§	1.4 ± 0.9*,†,‖

RCT, rotator cuff tear.
Values are presented as means ± standard deviations.
P values were calculated by Tukey's post hoc test.
*Significantly larger than values in Grade 1 ($P < .0001$).
†Significantly larger than values in Grade 2 ($P < .0001$).
‡Significantly larger than values in Grade 3 ($P < .01$).
§Significantly larger than values in Grade 2 ($P < .05$).
‖Significantly larger than values in Grade 3 ($P < .0001$).

Table III
Characteristics of rotator cuff tear involvement.

	Grade 1 n = 210 (%)	Grade 2 n = 96 (%)	Grade 3 n = 40 (%)	Grade 4-5 n = 30 (%)
Isolated SSP tear	112 (53.3)*	4 (4.2)*	1 (2.5)*	0 (0)*
Multiple tendon tear involving ISP	93 (44.3)	91 (94.8)†	39 (97.5)†	30 (100)†
Multiple tendon tear involving SSc	27 (12.9)	21 (21.9)	22 (55.0)†,‡	23 (76.7)†,§
Multiple tendon tear involving TM	2 (1.0)	6 (6.3)	2 (5.0)	7 (23.3)†

SSP, supraspinatus; *ISP*, infraspinatus; *SSc*, subscapularis; *TM*, teres minor.
Values are presented as number of shoulders, with the percentage in parentheses.
*Significantly lower than values in Grade 1 ($P < .0001$).
†Significantly higher than values in Grade 1 ($P < .0001$).
‡Significantly higher than values in Grade 2 ($P = .0002$).
§Significantly higher than values in Grade 2 ($P < .0001$).

We used the G*Power package (version 3; UCLA Statistical Consulting Group) to perform power analysis after data collection. We calculated the power (1-β) of comparison among the four groups by defining the sample sizes as 210, 96, 40, and 30 for Grades 1, 2, 3, and 4-5, respectively; the threshold of significance (α) as 0.05; and the effect size as 0.29 for the patients' age, 0.34 for the duration of symptoms, 0.59 for the number of torn tendons, 0.72 for the RCT size, 0.61 for subscapularis tear size, and 0.67, 0.69, 0.58, and 0.41 for the severity of Goutallier classification of the supraspinatus, infraspinatus, subscapularis, and teres minor, respectively.

Results

In the power analysis, the comparison among the four groups demonstrated the power of 0.75 for the patients' age; 0.88 for the duration of symptoms; 0.99 for the number of torn tendons; 0.99 for the RCT size; 0.99 for subscapularis tear size; and 0.95, 0.99, 0.99, and 0.97 for the severity of Goutallier classification of the supraspinatus, infraspinatus, subscapularis, and teres minor, respectively.

The intrarater and inter-rater agreement kappa values for the modified Hamada classification grading (Grades 1, 2, 3, and 4-5) in the radiographic analysis were 0.894-0.903 and 0.813-0.851, respectively. The intrarater and inter-rater agreement kappa values for the Goutallier classification grading in the MRI analysis were 0.694-0.734 and 0.613-0.648, respectively. These results suggest that radiographic evaluations were reliable.

Of the 376 shoulders, 210, 96, 40, and 30 (18, Grade 4A; 8, Grade 4B; and 4, Grade 5) were classified as Hamada Grades 1, 2, 3, and 4-5, respectively (Fig. 2). Patients in Hamada Grades 2, 3, and 4-5 were significantly older than those in Grade 1 ($P = .013$, $P = .021$, and $P < .0001$, respectively; Table I). The duration of symptoms in Hamada Grade 4-5 was significantly longer than that in Grades 1, 2, and 3 ($P < .0001$, $P < .0001$, and $P = .001$, respectively).

Both the number of torn tendons and RCT size significantly increased with increasing Hamada Grade (number of torn tendons, 1.6 ± 0.6, 2.2 ± 0.5, 2.5 ± 0.6, and 3.0 ± 0.7 in Grades 1, 2, 3, and 4-5, respectively; RCT size, 2.0 ± 0.9 cm, 3.3 ± 0.9 cm, 3.8 ± 1.0 cm, and 5.2 ± 1.3 cm in Grades 1, 2, 3, and 4-5, respectively; both $P < .0001$ by one-way ANOVA; Table II).

The characteristics of RCT involvement are presented in Table III. The rate of RCTs involving the infraspinatus was significantly higher in Grades 2 (94.8%), 3 (97.5%), and 4-5 (100%) than in Grade 1 (44.3%) (all $P < .0001$; Table III). The rate of RCTs involving the subscapularis was significantly higher in Grades 3 (55.0%) and 4-5 (76.7%) than in Grades 1 (12.9%) and 2 (21.9%) (all $P < .001$).

The grade of fatty muscle degeneration of all rotator cuff muscles increased significantly with increasing Hamada Grade ($P < .0001$ by one-way ANOVA; Table IV). The fatty muscle degeneration of the subscapularis in Grade 3 (1.5 ± 1.4) was significantly more severe than that in Grades 1 (0.3 ± 0.7) and 2 (0.6 ± 0.8) (both $P < .0001$). Hamada Grade 4-5 shoulders had significantly more severe fatty muscle degeneration in the subscapularis, infraspinatus, and teres minor than that in Grade 3 ($P < .0001$, $P = .008$, and $P = .03$, respectively).

The reducibility of the RCTs is presented in Table V. The rates of irreparable posterosuperior tears in Grades 2 (84.4%), 3 (90.0%), and 4-5 (100%) were significantly higher than those in Grade 1 (22.9%) (all $P < .0001$). The rate of irreparable subscapularis tears in Grade 4-5 (20.0%) was significantly higher than that in Grades 1 (1.4%) and 2 (2.0%) ($P = .0002$ and $P = .002$, respectively; Table V).

The rate of normal LHBs decreased significantly with increasing Hamada Grade (67.6%, 31.3%, 17.5%, and 10.0% in Grades 1, 2, 3, and 4-5, respectively; $P < .0001$ by one-way ANOVA; Table VI). In contrast, the rate of complete LHB rupture increased significantly with increasing Hamada Grade ($P < .0001$ by one-way ANOVA). The rate of complete LHB rupture was significantly higher in Grades 2 (24.0%), 3 (25.0%), and 4-5 (66.7%) than in Grade 1 (5.7%) ($P < .0001$, $P = .0006$, and $P < .0001$, respectively).

Table IV
Grade of fatty muscle degeneration of rotator cuff muscles.

	Grade 1 n = 210	Grade 2 n = 96	Grade 3 n = 40	Grade 4-5 n = 30
SSP	2.0 ± 0.9	3.4 ± 0.8*	3.6 ± 0.6*	3.9 ± 0.3*,†
ISP	0.6 ± 0.8	2.2 ± 1.3*	2.6 ± 1.4*	3.4 ± 0.9*,†,§
SSc	0.3 ± 0.7	0.6 ± 0.8	1.5 ± 1.4*,†	2.4 ± 1.3*,†,‡
TM	0.1 ± 0.3	0.4 ± 0.9*	0.7 ± 1.1*	1.2 ± 1.4*,‖

SSP, supraspinatus; *ISP*, infraspinatus; *SSc*, subscapularis; *TM*, teres minor.
Values are presented as means ± standard deviations.
*Significantly higher than values in Grade 1 ($P < .0001$).
†Significantly higher than values in Grade 2 ($P < .0001$).
‡Significantly higher than values in Grade 3 ($P < .0001$).
§Significantly higher than values in Grade 3 ($P = .008$).
‖Significantly higher than values in Grade 3 ($P = .03$).

Discussion

The primary finding of this study was that there were significant correlations between the Hamada Grade and the number of torn tendons, RCT size, grade of fatty infiltration of rotator cuff muscles, and rate of LHB lesions. These findings support the hypothesis of the authors.

A notable finding of this study was that most of the patients with Hamada Grade 2 or higher had RCTs involving the infraspinatus. In addition, the grade of fatty muscle degeneration in the supraspinatus and infraspinatus in patients with Hamada Grade 2 or higher was significantly more severe than that in those with Grade 1. These results are consistent with those of previous studies that reported that multiple-tendon RCTs involving the infraspinatus and the degree of fatty degeneration of the infraspinatus muscle influence the acromiohumeral interval.[28,32] The initial radiographic change following an RCT is the narrowing of the AHI caused by the superior migration of the humeral head, which corresponds to Hamada Grade 2. These findings suggest that large RCTs involving the infraspinatus contribute to superior migration of the humeral head and subsequent progression of CTA.

Another notable finding of this study was that the rate of RCTs involving the subscapularis in Hamada Grade 3 was significantly higher than that in Grade 2. In addition, the fatty muscle degeneration of the subscapularis in Hamada Grade 3 was significantly more severe than that in Grade 2. However, the posterosuperior RCT tear size and fatty muscle degeneration of other rotator cuff muscles showed no significant difference between Grades 2 and 3. These results suggest that concomitant subscapularis tears with posterosuperior RCTs might promote the progression of Hamada Grade 2 to 3. The subscapularis is essential for maintaining normal glenohumeral biomechanics.[22,31,36] A subscapularis tendon tear combined with a posterosuperior RCT can decrease glenohumeral stability and reduce force coupling in the glenohumeral joint.[2,7,34] Nové-Josserand et al. measured the coracohumeral interval in 206 shoulders with full-thickness RCTs using computed tomography. They found that an abnormal coracohumeral interval was associated with a combined tear of the supraspinatus and subscapularis and fatty degeneration of the infraspinatus or subscapularis.[28] A cadaveric study on the cumulative effect of sequential disruption of the subscapularis tendon demonstrated that detachment of the superior half or more of the subscapularis tendon in anterosuperior RCTs leads to increased anterosuperior glenohumeral translation.[34] Based on these biomechanical and clinical studies, the subscapularis muscle is essential for providing a stable fulcrum for glenohumeral motion and for preserving the balanced force couple of the rotator cuff. The increased anterosuperior translation of the humeral head due to a subscapularis tear combined with a posterosuperior RCT might produce an excessive force on the undersurface of the acromion and coracoacromial ligament. This may lead to a Hamada Grade 3 deformity characterized by an excavating deformity of the acromion and excessive spur along the coracoacromial ligament.

Furthermore, we found that the size of the subscapularis tear in Hamada Grade 4-5 was significantly larger than that in Grade 3. The subscapularis fatty muscle degeneration stage in Hamada Grade 4-5 was also significantly more severe than that in Grade 3. Moreover, the presence of irreparable subscapularis tears in Hamada Grade 4-5 was significantly higher than that in Grades 1 and 2. Previous studies have reported that a concomitant subscapularis tear is a predictive factor of inferior functional outcomes after latissimus dorsi tendon transfer for irreparable posterosuperior RCTs.[17] In addition, an irreparable subscapularis tear has been reported as a risk factor for retear after rotator cuff repair and inferior clinical outcomes after arthroscopic superior capsular reconstruction.[23,25,30,35] Therefore, surgeons need to pay more attention to the status of the subscapularis when they consider joint-preserving treatments for patients with Hamada Grade 3 or higher.

Regarding the LHB, previous studies reported that the LHB functions as a humeral head depressor, compressor, anterior stabilizer, and posterior stabilizer.[1,18,38,40] However, Walch et al. reported that arthroscopic biceps tenotomy without rotator cuff repair did not show immediate superior migration of the humeral head on postoperative radiographs.[38] In this study, we found that the rate of normal LHBs decreased with Hamada Grade progression. In Hamada Grade 1, 67.6% of patients had normal LHBs. However,

Table V
Reducibility of rotator cuff tears.

	Grade 1 n = 210 (%)	Grade 2 n = 96 (%)	Grade 3 n = 40 (%)	Grade 4-5 n = 30 (%)
Posterosuperior RCT (SSP/ISP/TM)				
Reparable	162 (77.1)	15 (15.6)*	4 (10.0)*	0 (0.0)*
Irreparable	48 (22.9)	81 (84.4)†	36 (90.0)†	30 (100)†
SSc				
Intact	183 (87.1)	74 (77.0)	18 (45.0)‡,§	7 (23.3)‡,‖
Reparable	24 (11.4)	20 (20.8)	18 (45.0)	17 (56.7)
Irreparable	3 (1.4)	2 (2.0)	4 (10.0)	6 (20.0)**,††

RCT, rotator cuff tear; *SSP*, supraspinatus; *ISP*, infraspinatus; *TM*, teres minor; *SSc*, subscapularis.
Values are presented as number of shoulders, with the percentage in parentheses.
*Significantly lower than values in Grade 1 ($P < .0001$).
†Significantly higher than values in Grade 1 ($P < .0001$).
‡Significantly lower than values in Grade 1 ($P < .0001$).
§Significantly lower than values in Grade 2 ($P = .0002$).
‖Significantly lower than values in Grade 2 ($P < .0001$).
**Significantly higher than values in Grade 1 ($P = .0002$).
††Significantly higher than values in Grade 2 ($P = .002$).

Table VI
Condition of the long head of the biceps.

	Grade 1 n = 210 (%)	Grade 2 n = 96 (%)	Grade 3 n = 40 (%)	Grade 4-5 n = 30 (%)
Normal	142 (67.6)	30 (31.3)*	7 (17.5)*	3 (10.0)*
Partial LHB rupture	56 (26.7)	43 (44.8)†	23 (57.5)‡	7 (23.3)
Complete LHB rupture	12 (5.7)	23 (24.0)§	10 (25.0)‖	20 (66.7)§,**,††

LHB, long head of biceps.
Values are presented as the number of shoulders, with the percentage in parentheses.
P values were calculated by Fisher's exact test.
*Significantly lower than values in Grade 1 ($P < .0001$).
†Significantly higher than values in Grade 1 ($P = .002$).
‡Significantly higher than values in Grade 1 ($P = .0003$).
§Significantly higher than values in Grade 1 ($P < .0001$).
‖Significantly higher than values in Grade 1 ($P = .0006$).
**Significantly higher than values in Grade 2 ($P < .0001$).
††Significantly higher than values in Grade 3 ($P = .0007$).

the rate of normal LHBs decreased to 31.3%, 17.5%, and 10.0% in Grades 2, 3, and 4-5, respectively. In contrast, the rate of complete rupture of the LHB increased significantly with increasing Hamada Grade (5.7%, 24.0%, 25.0%, and 66.7% in Grades 1, 2, 3, and 4-5, respectively). These results suggest that most of the LHB ruptures occur following the superior migration of the humeral head due to multiple-tendon RCTs. Increased stress across the LHB, along with mechanical friction between the humeral head and acromial undersurface, with increasing Hamada Grade might lead to the rupture of the LHB. Recently, several surgical techniques have been proposed to use the LHB for the augmentation of rotator cuff repairs or superior capsule reconstruction.[6,20] We believe that the status of the LHB is important for these techniques. Therefore, this information might be helpful when surgeons consider these techniques for patients with Hamada Grade 2 or higher.

This study had several limitations. First, the onset of symptoms was defined based on the patient's report at the initial visit to our clinic. Therefore, there is a possibility of recall bias. Second, the Hamada classification does not address morphological changes in the glenoid. If surgeons consider arthroplasty, such as reverse shoulder arthroplasty, the Favard classification and/or Walch classification based on computed tomography evaluation may be more useful.[33,37] Third, this was a retrospective cross-sectional study. Thus, the effect of the severity of the Hamada Grade on the clinical and structural outcomes after surgery remains unclear. Fourth, there were differences in patients' age and duration of symptoms among the groups, which might have affected the Hamada Grades.

Despite these limitations, the strength of this study is that we included a large number of patients with Hamada Grades 3, 4, and 5 compared with those of previous studies.[14,15] To our knowledge, this is the largest cohort study that investigated the relationship between the Hamada Grade and underlying rotator cuff and LHB pathological conditions in symptomatic patients with RCTs. Therefore, we believe that the results of this study provide a better understanding of the relationship between Hamada Grades and the condition of soft tissue, including the rotator cuff and LHB.

Conclusions

Rotator cuff tears involving the infraspinatus contributed to superior migration of the humeral head and were associated with Hamada Grade 2. The rate of concomitant subscapularis tears with posterosuperior RCTs was significantly higher in patients with Hamada Grade 3 than in those with Hamada Grade 2. The enlargement of RCTs, progression of fatty muscle degeneration of the subscapularis and posterosuperior rotator cuffs, as well as the increase in complete LHB rupture, were associated with Hamada Grade 4-5.

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References

1. Blasier RB, Soslowsky LJ, Malicky DM, Palmer ML. Posterior glenohumeral subluxation: active and passive stabilization in a biomechanical model. J Bone Joint Surg Am 1997;79:433-40.
2. Bowen MK, Warren RF. Ligamentous control of shoulder stability based on selective cutting and static translation experiments. Clin Sports Med 1991;10:757-82.
3. Brolin TJ, Updegrove GF, Horneff JG. Classifications in brief: Hamada classification of massive rotator cuff tears. Clin Orthop Relat Res 2017;475:2819-23. https://doi.org/10.1007/s11999-017-5340-7.
4. Chalmers PN, Salazar DH, Steger-May K, Chamberlain AM, Stobbs-Cucchi G, Yamaguchi K, et al. Radiographic progression of arthritic changes in shoulders with degenerative rotator cuff tears. J Shoulder Elbow Surg 2016;25:1749-55. https://doi.org/10.1016/j.jse.2016.07.022.
5. Chen KH, Chiang ER, Wang HY, Ma HL. Arthroscopic partial repair of irreparable rotator cuff tears: factors related to greater degree of clinical improvement at 2 years of follow-up. Arthroscopy 2017;33:1949-55. https://doi.org/10.1016/j.arthro.2017.06.047.
6. Colbath G, Murray A, Siatkowski S, Pate T, Krussig M, Pill S, et al. Autograft long head biceps tendon can be used as a scaffold for biologically augmenting rotator cuff repairs. Arthroscopy 2022;38:38-48. https://doi.org/10.1016/j.arthro.2021.05.064.
7. Collin P, Matsumura N, Ladermann A, Denard PJ, Walch G. Relationship between massive chronic rotator cuff tear pattern and loss of active shoulder range of motion. J Shoulder Elbow Surg 2014;23:1195-202. https://doi.org/10.1016/j.jse.2013.11.019.
8. Denard PJ, Brady PC, Adams CR, Tokish JM, Burkhart SS. Preliminary results of arthroscopic superior capsule reconstruction with dermal allograft. Arthroscopy 2018;34:93-9. https://doi.org/10.1016/j.arthro.2017.08.265.
9. Flurin PH, Hardy P, Valenti P, Meyer N, Collin P, Kempf JF, et al. Osteoarthritis after rotator cuff repair: a 10-year follow-up study. Orthop Traumatol Surg Res 2017;103:477-81. https://doi.org/10.1016/j.otsr.2017.03.007.
10. Frankle M, Levy JC, Pupello D, Siegal S, Saleem A, Mighell M, et al. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. a minimum two-year follow-up study of sixty patients surgical technique. J Bone Joint Surg Am 2006;88(Suppl 1 Pt 2):178-90. https://doi.org/10.2106/JBJS.F.00123.
11. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elbow Surg 1999;8:599-605.
12. Gombera MM, Sekiya JK. Rotator cuff tear and glenohumeral instability : a systematic review. Clin Orthop Relat Res 2014;472:2448-56. https://doi.org/10.1007/s11999-013-3290-2.

13. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res 1994:78-83.
14. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res 1990:92-6.
15. Hamada K, Yamanaka K, Uchiyama Y, Mikasa T, Mikasa M. A radiographic classification of massive rotator cuff tear arthritis. Clin Orthop Relat Res 2011;469:2452-60. https://doi.org/10.1007/s11999-011-1896-9.
16. Herve A, Thomazeau H, Favard L, Colmar M, Mansat P, Walch G, et al. Clinical and radiological outcomes of osteoarthritis twenty years after rotator cuff repair. Orthop Traumatol Surg Res 2019;105:813-8. https://doi.org/10.1016/j.otsr.2019.02.013.
17. Irlenbusch U, Bracht M, Gansen HK, Lorenz U, Thiel J. Latissimus dorsi transfer for irreparable rotator cuff tears: a longitudinal study. J Shoulder Elbow Surg 2008;17:527-34. https://doi.org/10.1016/j.jse.2007.11.022.
18. Itoi E, Kuechle DK, Newman SR, Morrey BF, An KN. Stabilising function of the biceps in stable and unstable shoulders. J Bone Joint Surg Br 1993;75:546-50.
19. Kholinne E, Kwak JM, Kim H, Koh KH, Jeon IH. Arthroscopic superior capsular reconstruction with mesh augmentation for the treatment of irreparable rotator cuff tears: a comparative study of surgical outcomes. Am J Sports Med 2020;48:3328-38. https://doi.org/10.1177/0363546520958708.
20. Kim D, Um J, Lee J, Kim J. Improved clinical and radiologic outcomes seen after superior capsule reconstruction using long head biceps tendon autograft. Arthroscopy 2021;37:2756-67. https://doi.org/10.1016/j.arthro.2021.04.006.
21. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
22. Lee SB, Kim KJ, O'Driscoll SW, Morrey BF, An KN. Dynamic glenohumeral stability provided by the rotator cuff muscles in the mid-range and end-range of motion. A study in cadavera. J Bone Joint Surg Am 2000;82:849-57.
23. Lee SH, Nam DJ, Kim SJ, Kim JW. Comparison of clinical and structural outcomes by subscapularis tendon status in massive rotator cuff tear. Am J Sports Med 2017;45:2555-62. https://doi.org/10.1177/0363546517721187.
24. Luo Z, Lin J, Sun Y, Zhu K, Wang C, Chen J. Outcome comparison of latissimus dorsi transfer and pectoralis major transfer for irreparable subscapularis tendon tear: a systematic review. Am J Sports Med 2021:3635465211018216. https://doi.org/10.1177/03635465211018216.
25. Mihata T, Lee TQ, Hasegawa A, Fukunishi K, Kawakami T, Fujisawa Y, et al. Arthroscopic superior capsule reconstruction for irreparable rotator cuff tears: comparison of clinical outcomes with and without subscapularis tear. Am J Sports Med 2020;48:3429-38. https://doi.org/10.1177/0363546520965993.
26. Mihata T, Lee TQ, Hasegawa A, Fukunishi K, Kawakami T, Fujisawa Y, et al. Five-Year follow-up of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. J Bone Joint Surg Am 2019;101:1921-30. https://doi.org/10.2106/JBJS.19.00135.
27. Neer CS 2nd, Craig EV, Fukuda H. Cuff-tear arthropathy. J Bone Joint Surg Am 1983;65:1232-44.
28. Nove-Josserand L, Edwards TB, O'Connor DP, Walch G. The acromiohumeral and coracohumeral intervals are abnormal in rotator cuff tears with muscular fatty degeneration. Clin Orthop Relat Res 2005:90-6. https://doi.org/10.1097/01.blo.0000151441.05180.0e.
29. Ohta S, Komai O, Onochi Y. Outcomes of superior capsule reconstruction for massive rotator cuff tears and risk factors for postoperative retear. Arch Orthop Trauma Surg 2020;140:1319-25. https://doi.org/10.1007/s00402-019-03316-2.
30. Park JY, Chung SW, Lee SJ, Cho HW, Lee JH, Lee JH, et al. Combined subscapularis tears in massive posterosuperior rotator cuff tears: do they affect postoperative shoulder function and rotator cuff integrity? Am J Sports Med 2016;44:183-90. https://doi.org/10.1177/0363546515610552.
31. Richards DP, Burkhart SS, Campbell SE. Relation between narrowed coracohumeral distance and subscapularis tears. Arthroscopy 2005;21:1223-8. https://doi.org/10.1016/j.arthro.2005.06.015.
32. Saupe N, Pfirrmann CW, Schmid MR, Jost B, Werner CM, Zanetti M. Association between rotator cuff abnormalities and reduced acromiohumeral distance. AJR Am J Roentgenol 2006;187:376-82. https://doi.org/10.2214/AJR.05.0435.
33. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388-95. https://doi.org/10.1302/0301-620x.86b3.14024.
34. Su WR, Budoff JE, Luo ZP. The effect of anterosuperior rotator cuff tears on glenohumeral translation. Arthroscopy 2009;25:282-9. https://doi.org/10.1016/j.arthro.2008.10.005.
35. Takayama K, Yamada S, Kobori Y, Shiode H. Association between the postoperative condition of the subscapularis tendon and clinical outcomes after superior capsular reconstruction using autologous tensor fascia lata in patients with pseudoparalytic shoulder. Am J Sports Med 2020;48:1812-7. https://doi.org/10.1177/0363546520919956.
36. Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. J Bone Joint Surg Am 1981;63:1208-17.
37. Walch G, Boulahia A, Boileau P, Kempf JF. Primary glenohumeral osteoarthritis: clinical and radiographic classification. The Aequalis Group. Acta Orthop Belg 1998;64(Suppl 2):46-52.
38. Walch G, Edwards TB, Boulahia A, Nove-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. J Shoulder Elbow Surg 2005;14:238-46. https://doi.org/10.1016/j.jse.2004.07.008.
39. Waltenspul M, Jochum B, Filli L, Ernstbrunner L, Wieser K, Meyer D, et al. Midterm results of arthroscopically assisted latissimus dorsi transfer for irreparable posterosuperior rotator cuff tears. J Shoulder Elbow Surg 2021;30:e676-88. https://doi.org/10.1016/j.jse.2021.03.149.
40. Youm T, ElAttrache NS, Tibone JE, McGarry MH, Lee TQ. The effect of the long head of the biceps on glenohumeral kinematics. J Shoulder Elbow Surg 2009;18:122-9. https://doi.org/10.1016/j.jse.2008.06.003.
41. Zingman A, Li H, Sundem L, DeHority B, Geary M, Fussel T, et al. Shoulder arthritis secondary to rotator cuff tear: a reproducible murine model and histopathologic scoring system. J Orthop Res 2017;35:506-14. https://doi.org/10.1002/jor.23383.