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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A R T I C L E   I N F O

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Level of evidence: Level IV; Case Series; Prognosis Study

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.

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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.3,10,16 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.5,8,15,19,24,26,28 In addition, some studies have reported that progressed Hamada Grades worsen the clinical results of rotator cuff surgery.3,15,29 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...
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 (where surgery had been performed), 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. 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. 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). 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.

MRI evaluations

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

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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.
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.
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 < 0.01; 0.021, 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).

The rate of normal LHBs decreased significantly with increasing Hamada Grade 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).

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).

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### Table II

| Number of Torn Tendons | Grade 1 n = 210 | Grade 2 n = 96 | Grade 3 n = 40 | Grade 4-5 n = 30 |
|------------------------|----------------|---------------|---------------|----------------|
| 1.6 ± 0.6              | 2.2 ± 0.5*     | 2.5 ± 0.6*    | 3.0 ± 0.7**   |
| 2.0 ± 0.9              | 3.3 ± 0.9*     | 3.8 ± 1.0*    | 5.2 ± 1.3**   |
| 1.9 ± 0.7              | 3.0 ± 0.7*     | 3.3 ± 0.7*    | 3.9 ± 0.9**   |
| 0.1 ± 0.4              | 0.2 ± 0.5      | 0.6 ± 0.8**   | 1.4 ± 0.9**   |

### Table III

| Characteristics of RCT 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 (79.5)         | 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 2 (P = .0002). |
| **Significantly higher than values in Grade 2 (P < .0001). |
Values are presented as means ± standard deviations. *Significantly higher than values in Grade 1 (P < .0001).
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*Significantly higher than values 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.18,19,26 However, Walsh et al. reported that arthroscopic biceps tenotomy without rotator cuff repair did not show immediate superior migration of the humeral head on postoperative radiographs.36 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, 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.14 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.

### Table V
Reductibility of rotator cuff tears.

| Treatment | 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).
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*Significantly lower than values 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.18,19,26 However, Walsh et al. reported that arthroscopic biceps tenotomy without rotator cuff repair did not show immediate superior migration of the humeral head on postoperative radiographs.36 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,
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, the Favard classification and/or Walch classification based on computed tomography evaluation may be more useful.13,17 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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