



Are scapular morphologic characteristics or rotator cuff tear patterns associated with acetabularization of the coracoacromial arch?

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Purpose: To determine whether rotator cuff tear (RCT) patterns and scapular morphologic characteristics are associated with acetabularization of the coracoacromial arch when the remaining rotator cuff cannot stabilize the humeral head centered on the glenoid.

Methods: Thirty-two consecutive patients incapable of stabilizing the humeral head within the native glenoid were included and divided into 2 groups: unstable glenohumeral fulcrum kinematics (GHFK) group (n = 16; absence of acetabularization of the coracoacromial arch) and captured GHFK group (n = 16; the presence of acetabularization of the coracoacromial arch). Magnetic resonance imaging (MRI) analysis included tear locations, tear extensions (anterior, posterior, and global), and fatty infiltration of the rotator cuff muscles. Plain radiographic and computed tomography image measurements included acromioclavicular distance, critical shoulder angle, lateral acromial angle, acromial index, acromial tilt, acromial slope angle, anterior and posterior acromial coverage, and coracoacromial ligament coverage.

Results: Patient demographic characteristics did not differ significantly ($P > .05$). No differences in tear patterns were found between patients with unstable GHFK and those with captured GHFK on MRI ($P > .05$). Scapular morphologic parameter measurements showed significant differences between the unstable and captured GHFK groups: anterior acromial coverage ($-5.8 \pm 13.8^\circ$ vs. $13.8 \pm 11.3^\circ$, $P < .001$), acromial tilt ($34.9 \pm 8.9^\circ$ vs. $26.7 \pm 6.2^\circ$; $P = .005$), and acromial slope angle ($24.5 \pm 8.1^\circ$ vs. $33.5 \pm 7.9^\circ$, $P = .003$).

Conclusion: Scapular morphologic characteristics, rather than RCT patterns, were associated with the development of acetabularization of the coracoacromial arch when the remaining rotator cuff could not stabilize the humeral head. Patients with captured GHFK exhibited larger anterior acromial coverage, smaller acromial tilt, and a more curved acromion than those with unstable GHFK.

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Rotator cuff tendons, enveloping the glenohumeral joint on its anterior, posterior, and cranial aspects, assist in stabilizing the humeral head socketed into the glenoid and preventing it from proximal migration during deltoid activation.^{9,21} In patients with massive rotator cuff tears (MRCTs), if the remaining rotator cuff cannot control the humeral head centered on the glenoid, anterosuperior escape of the humeral head or impingement on the acromion or coracoacromial arch occurs, which is classified as abnormal glenohumeral fulcrum kinematics (GHFK).^{4,24,28}

The study was approved by the Ethics Committee of Shanghai Sixth People's Hospital Approval number:2020-KY-121(K)-(1).

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There are 2 subtypes of abnormal GHFK: unstable and captured GHFK.⁴ Patients with an unstable GHFK have anterosuperior escape of the humeral head during attempted active elevation.^{4-6,28,33} After impinging the acromion or coracoacromial arch, the humeral head cannot rotate on the newly formed contact point, resulting in a loss of range of motion. However, active shoulder motion is preserved in patients with a captured GHFK, although the remaining rotator cuff cannot stabilize the humeral head centered on the glenoid. This outcome is due to a new fulcrum developing at the undersurface of the acromion or coracoacromial arch, allowing the humeral head to rotate, which is known as acetabularization of the coracoacromial arch.^{15,19} The term 'acetabularization', described by Hamada,⁹ refers to an excavating deformity of the acromion undersurface or an excessive spur deformity along the coracoacromial ligament. According to Burkhart's findings, the unstable GHFK was associated with tears that involved virtually all of the superior and posterior rotator cuff. And the captured GHFK

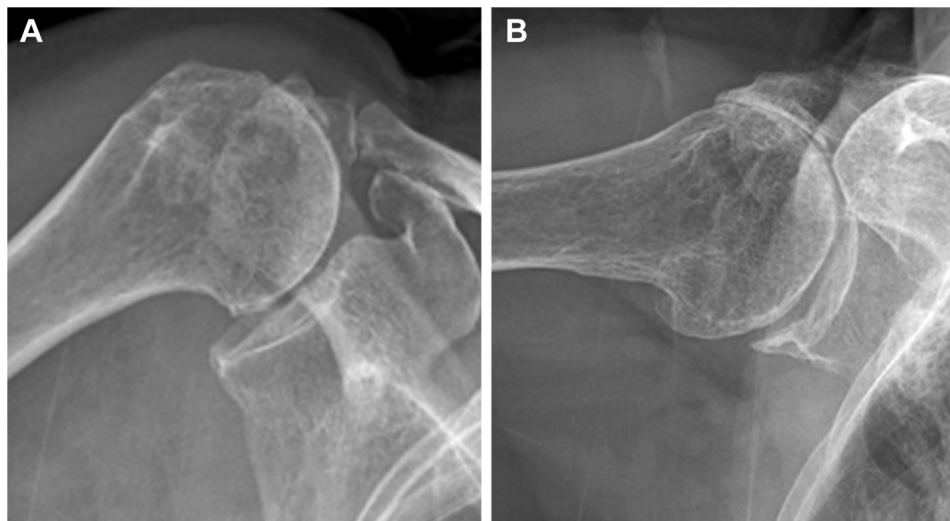


Figure 1 Radiographic features of different abnormal glenohumeral kinematics during active glenohumeral abduction. (A) An unstable GHFK, which was defined as the humeral head showing anterosuperior escape without acetabularization of the coracoacromial arch during attempted active glenohumeral abduction; (B) a captured GHFK, which was defined as the humeral head migrating proximally to impinge at the acromion (or excessive spur formation along coracoacromial ligament) with acetabularization of the coracoacromial arch. GHFK, glenohumeral fulcrum kinematics.

were associated with tears that involved the supraspinatus, a major portion of the posterior rotator cuff, and a major portion of the subscapularis.⁴ It appears that the abnormal GHFK subtype depends on rotator cuff tear (RCT) patterns. However, the sample size in Burkhart's study was relatively small and included only 2 patients in the unstable GHFK group and 4 in the captured GHFK group. Furthermore, no studies have verified the association between RCT patterns and unstable vs. captured GHFK.

In addition to RCT patterns, another structural parameter potentially associated with acetabularization of the coracoacromial arch comprises scapular morphologic characteristics. Previous studies have shown an association between acromion morphology and MRCTs.³ For example, a high critical shoulder angle has been clinically and biomechanically identified as a risk factor for RCTs.^{23,26} Besides, in patients with captured GHFK, conventional acromioplasty might result in anterosuperior migration of the humeral head and active shoulder motion loss because the acromion and the coracoacromial ligament have been found to be anterosuperior restraints of the humeral head.³⁵ However, the relationship between scapular morphology and the development of acetabularization of the coracoacromial arch in patients incapable of stabilizing the humeral head has not been investigated to date.

Therefore, this study aimed to identify whether RCT patterns and scapular morphologic characteristics are associated with acetabularization of the coracoacromial arch when the remaining rotator cuff cannot stabilize the humeral head centered on the glenoid. We hypothesized that patients with captured GHFK would have significant differences in RCT patterns and scapular morphologic characteristics compared with those with unstable GHFK.

Methods

Patient selection

All patients enrolled in this study signed a written consent form, and our Institutional Review Board approved the study. From May 2016 to April 2020, 186 consecutive patients with chronic MRCTs (≥ 2 fully torn tendons¹³) were invited to participate in our study. We defined an unstable GHFK (Fig. 1A) as the humeral head

showing anterosuperior escape without acetabularization of the coracoacromial arch during attempted active glenohumeral abduction.⁴ A captured GHFK (Fig. 1B) was defined as the humeral head migrating proximally to impinge at the acromion (or at the excessive spur formation along the coracoacromial ligament) with acetabularization of the coracoacromial arch during active glenohumeral abduction.

Inclusion criteria comprised patients who had unstable or captured GHFK with complete reports of active and passive range of motion and with magnetic resonance imaging (MRI), computed tomography (CT), and standardized true anteroposterior radiographic images. Because pain significantly influenced the humeral migration and glenohumeral kinematics as reported previously,¹⁷ we excluded patients with a reported visual analog pain score of > 3 . Besides, we also excluded patients with: (i) stiffness on attempted abduction, (ii) traumatic MRCTs, (iii) neurological impairment, and (iv) prior shoulder surgery. In total, 32 patients were included in the study. The patient cohort was then divided into 2 groups: those with unstable GHFK ($n = 16$) and those with captured GHFK ($n = 16$).

Imaging analysis

Because we have no idea which tear pattern or scapular morphologic characteristics were associated with the development of acetabularization of the coracoacromial arch, we detected as many imaging parameters as possible based on our best knowledge.

Magnetic resonance imaging (MRI) measurements

Measurements on MRI (6-point Dixon, 3.0-T, Prisma; Siemens Healthcare, Germany) included rotator cuff fatty infiltration according to an MRI adaptation of the Goutallier classification^{12,14} and RCT extensions (anterior, posterior, and global). The exact degree of anterior (subscapularis) and posterior (infraspinatus and teres minor) tear extension was analyzed on preoperative parasagittal MRI, according to the methods described by Wieser et al.³⁴ Zero degrees was defined as the tear extension exactly to be confined by the equatorial line of the humeral head. A positive or negative value

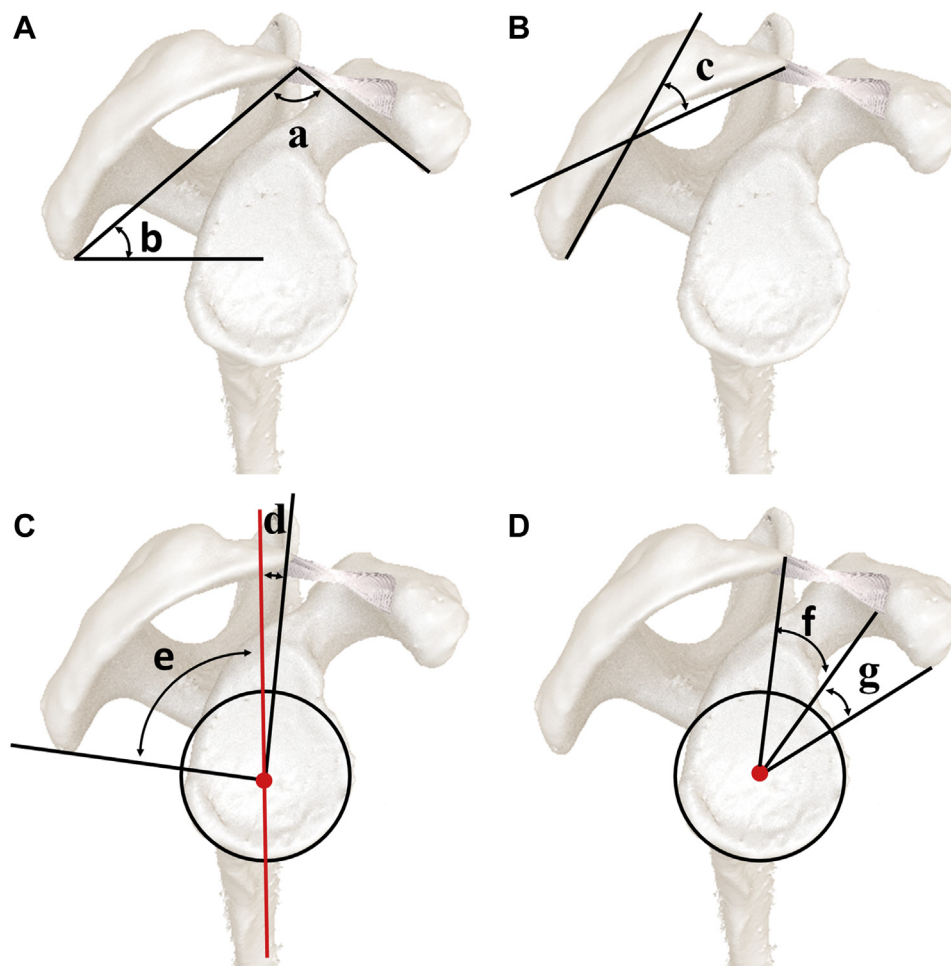


Figure 2 Measurements of scapular bony parameters based on 3-dimensional reconstruction of a CT scan. (A) Coracoacromial angle ($\angle a$) and acromial tilt ($\angle b$), according to Zuckerman³⁶; (B) acromial slope angle ($\angle c$), according to Alraddadi¹; (C) anterior ($\angle d$) and posterior ($\angle e$) acromial coverage, according to Beeler³; and (D) coracoacromial ligament coverage ($\angle f$) and coracoid process coverage ($\angle g$), according to Sakama.²⁹ CT, computed tomography.

indicated a tear extension superior or inferior to this line, respectively. The global tear extension (in degrees) was calculated with the following formula: $180^\circ - (\text{anterior tear extension angle} + \text{posterior tear extension angle})$. Additionally, the anterior and posterior tear extension was divided into 25% increments, ranging from grade 0 (no tear) to grade 4 (complete tear).¹¹ The ratio of the anterior and posterior tear extension was calculated and defined as a force couple, with a ratio of 1 indicating a balanced situation, a ratio > 1 indicating a shift toward a stronger posterior rotator cuff, and a ratio < 1 indicating a shift toward stronger anterior rotator cuff.¹¹ The glenoid version angle was measured on axial MRI scan as described previously.⁷

Plain radiographic measurements

Each patient underwent true anteroposterior radiographs in scaption (the scapular plane) without weightlifting, according to methods described in a previous study.²² To acquire true anteroposterior radiographs, the patients were positioned with scapular malrotation inferior to 20° of internal rotation or extension and inferior to 20° of external rotation or flexion.²² The radiographs were first taken with the arm in neutral rotation at 0° scaption (static state). Patients were then required to abduct their arm to 90° to elicit adequate muscular activity (active state). Radiographs were taken again in this active state. Measurements using static, plain

radiographs included the acromiohumeral distance (AHD),^{25,30} glenoid inclination (GI),²⁰ the lateral acromial angle (LAA),² the acromial index (AI),²⁶ and the critical shoulder angle (CSA).²²

Computerized tomography (CT) measurements

A CT (Discovery CT750HD, GE Healthcare, Wisconsin, USA) scan was performed within 3 days prior to surgery. Three-dimensional reconstruction of CT scans was performed using the Mimics program (21.0, Materialise Corp., Belgium). The lateral acromial roof was defined as the acromion, which extended beyond the glenoid plane, according to previously described methods.³ The length of the lateral acromial roof was defined as the anteroposterior extension parallel to the glenoid plane, whereas the width was defined as the distance between the most lateral edge and the glenoid plane. The coracoacromial angle and the acromial tilt were defined in accordance with that of Zuckerman³⁶ (Fig. 2A). Acromial slope angle was determined as the angle between 2 lines connecting the midpoint on the inferior acromion with the anterior and posterior ends of the acromion, respectively¹ (Fig. 2B). Coverage of the acromion was defined as the anteroposterior covering angle of the acromion relative to the glenoid center.³ Anterior acromial coverage was defined as the angle between the scapular plane and a line connecting the anterior acromion tip with the glenoid center. A positive value indicated that the anterior tip of the acromion was anterior to the scapular plane

Table 1
A comparison of MRI measurements between unstable GHFK and captured GHFK shoulders.*

	Unstable GHFK	Captured GHFK	P Values
Shoulders, n	16	16	
SSP FI	3.6 ± 0.6	3.8 ± 0.6	.559
SSC FI qw65re	2.3 ± 1.0	2.0 ± 0.7	.426
ISP FI	2.8 ± 0.9	2.6 ± 0.9	.700
TM FI	1.0 ± 0.7	0.9 ± 0.8	.649
SSP rupture	4 ± 0	4 ± 0	—
SSC rupture	2.1 ± 1.4	1.8 ± 1.2	.593
ISP/TM rupture	2.8 ± 0.9	2.5 ± 0.8	.426
Anterior tear extension, deg [†]	-14 ± 15	-5 ± 16	.123
Posterior tear extension, deg [†]	-19 ± 10	-19 ± 15	.957
Global tear extension, deg	213 ± 19	204 ± 26	.255
Force couple ratio	0.8 ± 0.5	0.8 ± 0.6	.917
Glenoid version angle	-1.63 ± 4.16	-1.46 ± 4.40	.918

FI, fatty infiltration; GHFK, glenohumeral fulcrum kinematics; ISP, infraspinatus; MRI, magnetic resonance imaging; SSC, subscapularis; SSP, supraspinatus; TM, teres minor.

*Data are presented as mean ± SD.

[†]Negative value (-) indicates a tear extension inferior to the equatorial line of the humeral head on measurements of the anterior (SSC) and posterior (ISP, and TM) rotator cuff on parasagittal MRI.

(negative if posterior). Posterior acromial coverage was defined as the angle between the scapular plane and a line connecting the posterior acromion tip with the glenoid center (Fig. 2C). In addition,

coracoacromial ligament coverage and coracoid process coverage were evaluated according to methods described in previous studies²⁹ (Fig. 2D).

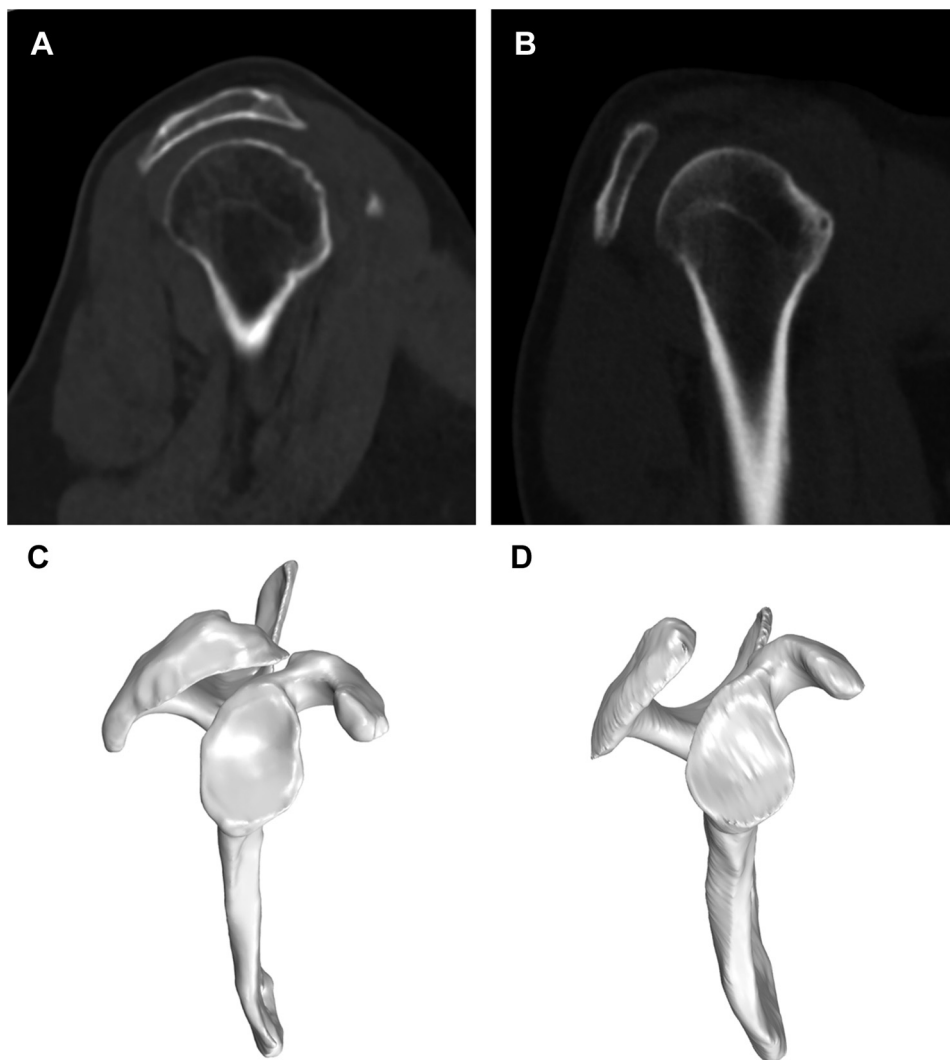


Figure 3 Scapular morphology based on CT scan images and corresponding 3-dimensional reconstruction of CT scan in patients with captured or unstable GHFK. Patients with captured GHFK (A and C) showed larger anterior acromial coverage, a larger acromial slope angle, and a smaller acromial tilt compared with patients with unstable GHFK (B and D). CT, computed tomography; GHFK, glenohumeral fulcrum kinematics.

Table II
A comparison of plain radiographic and CT measurements between unstable and captured GHFK shoulders.*

	Unstable GHFK	Captured GHFK	P Values
Shoulders, n	16	16	
AHD, mm	6.7 ± 2.3	5.9 ± 2.3	.318
GI, deg	20.5 ± 14.3	17.5 ± 16.4	.586
LAA, deg	73.6 ± 8.0	78.8 ± 4.9	.037
AI, deg	0.71 ± 0.08	0.72 ± 0.08	.449
CSA, deg	36.2 ± 4.5	37.8 ± 3.8	.262
Acromial tilt, deg	34.9 ± 8.9	26.7 ± 6.2	.005
acromial slope angle, deg	24.5 ± 8.1	33.5 ± 7.9	.003
Length of lateral acromial roof, mm	38.3 ± 9.9	42.5 ± 4.9	.146
Width of lateral acromial roof, mm	28.7 ± 6.1	29.4 ± 4.7	.738
Anterior acromial coverage, deg [†]	-5.8 ± 13.8	13.8 ± 11.3	< .001
Posterior acromial coverage, deg	77.2 ± 8.9	72.3 ± 11.0	.181
Coracoacromial angle, deg	108.1 ± 25.5	119.5 ± 9.4	.106
Coracoacromial ligament coverage, deg	57.2 ± 9.1	50.1 ± 7.4	.021
Coracoid process coverage, deg	21.2 ± 4.9	19.5 ± 7.3	.444

AHD, acromiohumeral distance; AI, acromial index; CSA, critical shoulder angle; CT, computed tomography; GHFK, glenohumeral fulcrum kinematics; GI, glenoid inclination; LAA, lateral acromial angle.

*Data are presented as mean ± SD.

[†]A positive anterior acromial coverage value indicates the anterior tip of the acromion is anterior to the scapular plane, whereas a negative value indicates the anterior tip of the acromion is posterior to the scapular plane.

Statistical analysis

Statistical analysis was performed using SPSS software (version 20.0; IBM Corp., Armonk, NY, USA). Student *t*-test statistical analysis was used for comparisons of normally distributed data, and a Mann–Whitney *U* test was conducted for non-normally distributed data. Between-group categorical variables were compared using a chi-square test, except for small sample sizes, in which case a Fisher’s exact test was performed. Furthermore, the partial correlation coefficient was calculated after adjusting for baseline characteristics, which was classified as strong (> 0.6), moderate (0.4–0.6), and weak (< 0.4), according to the Pearson coefficient. All measurements were performed by 2 independent observers. Intraclass correlation coefficients were calculated to evaluate interrater reliability. The interpretation of intraclass correlation coefficients was as follows: poor, < 0.4; marginal, 0.4 to 0.75; good, > 0.75.¹⁸ All data are reported as the mean ± standard deviation (SD). Statistical significance was defined as a 2-tailed *P* value < .05.

Results

Demographic analysis

Each group comprised 4 men and 12 women (unstable GHFK group, mean age: 62 years [range, 49–72 years]; captured GHFK group, mean age: 65 years [range, 55–72 years], *P* = .116). The active shoulder abduction angle in the unstable GHFK group was significantly smaller compared with that in the captured GHFK group (32° ± 12° vs. 101° ± 44°, respectively; *P* < .001).

MRI measurements

No relevant differences were found in terms of MRI measurements between the unstable GHFK group and the captured GHFK group, including fatty infiltration, tear location, tear extension, force couple ratio, and the glenoid version. All patients in each group showed a complete tear (grade 4) of the supraspinatus (SSP) and a major portion (range, grade 2–4) of the posterior cuff (infraspinatus and teres minor). In total, 13 of 16 (81.25%) patients in each group had a global tear extension involving at least 3 tendons (SSP, ISP, and SSC) with no remaining rotator cuff tendon connections above the equatorial line of the humeral head. (Table I)

Plain radiographic and CT measurements

Plain radiographic and CT scan measurements showed differences between patients with unstable GHFK and those with captured GHFK in terms of the lateral acromial angle (73.6° ± 8.0° vs. 78.8 ± 4.9°; *P* = .037), acromial tilt (34.9° ± 8.9° vs. 26.7° ± 6.2°; *P* = .005), the acromial slope angle (24.5° ± 8.1° vs. 33.5 ± 7.9°; *P* = .003), anterior acromial coverage (-5.8° ± 13.8° vs. 13.8° ± 11.3°; *P* < .001), and coracoacromial ligament coverage (57.2° ± 9.1° vs. 50.1° ± 7.4°; *P* = .021). In particular, all patients in the captured GHFK group showed a positive anterior acromial coverage value (range, 3.18°–32.94°). Further details are shown in Figure 3 and Table II.

Correlations between scapular morphologic parameters

The strongest correlation was found between anterior acromial coverage and the acromial slope angle (*r* = 0.691, *P* < .001). In addition, anterior acromial coverage moderately correlated with acromial tilt (*r* = -.588, *P* = .001) and coracoacromial ligament coverage (*r* = -.454, *P* = .012). The acromial slope angle also moderately correlated with acromial tilt (*r* = -.401, *P* = .028) and coracoacromial ligament coverage (*r* = -.537, *P* = .002). There was a weak correlation between acromial tilt and coracoacromial ligament coverage (*r* = -.287, *P* = .125, Table III).

Good interrater reliability for the measurements was detected in all parameters, and the details are shown in Table IV.

Discussion

This study is the first to investigate RCT patterns and scapular morphologic characteristics in relation to differing abnormal GHFK when the remaining rotator cuff cannot control the humeral head centered on the glenoid. The key finding was that scapular morphologic characteristics, rather than RCT patterns, were significant in the development of different abnormal GHFKs. Patients with captured GHFK exhibited larger anterior acromial coverage, smaller acromial tilt, and a more curved acromion than those with unstable GHFK.

Regarding scapular morphology, anterior acromial coverage showed the most significant difference between patients with unstable and captured GHFK. In patients with small anterior

Table III
Partial correlation analysis of scapular morphologic parameters.*

	Anterior acromial coverage	Acromial slope angle	Acromial tilt	Coracoacromial ligament coverage
Anterior acromial coverage	1 (—)	.691 (<.001)	– .588 (.001)	– .454 (.012)
Acromial slope angle	.691 (<.001)	1 (—)	– .401 (.028)	– .537 (.002)
Acromial tilt	– .588 (.001)	– .401 (.028)	1 (—)	.287 (.125)
Coracoacromial ligament coverage	– .454 (.012)	– .537 (.002)	.287 (.125)	1 (—)

*Values are presented as Pearson coefficients (*P* value). Strong and moderate correlations are indicated in bold.

acromial coverage, the superior surface of the humeral head would contact the coracoacromial ligament rather than the undersurface of the acromion when the humeral head migrated proximally (Fig. 4A). Therefore, the humeral head may not rotate on the soft coracoacromial ligament during deltoid activation, leading to loss of glenohumeral motion. In contrast, in patients with a large anterior acromial coverage, the humeral head was able to rotate at the rigid contact point, which consisted of the superior surface of the humeral head and the undersurface of the anterior acromion border (or excessive spur formation along the coracoacromial ligament) (Fig. 4B). Furthermore, the average acromial slope angle in the captured GHFK group was also larger than that in the unstable GHFK group. The acromial slope angle indicated curvature of the acromion in a posteroinferior-anterosuperior direction. A small acromial slope angle indicated a steep acromion, which would develop an ineffective contact point between the sidewall of the humeral head and the sidewall of the acromion (Fig. 4C and D). When the acromial slope angle was large with anterior curvature of the acromion, the humeral head first contacted the undersurface of the acromion anterior border (or the excessive spur along the coracoacromial ligament) during proximal migration and developed an effective contact point (Fig. 4E and F). This effective contact point has the potential to establish an excavating deformity at the undersurface of the acromion (or at the undersurface of the excessive spur formation along the coracoacromial ligament), namely, acetabularization of the coracoacromial arch.^{15,19}

Because the acromial tilt and coracoacromial ligament coverage both negatively correlated with anterior acromial coverage and the acromial slope angle, the smaller acromial tilt and coracoacromial ligament coverage values in the captured GHFK group were

Table IV
Interrater reliability for the measurements.

	r*	95% CI†
X-ray parameters		
Acromiohumeral distance	0.93	0.87–0.97
Glenoid inclination	0.96	0.91–0.98
Lateral acromial angle	0.79	0.59–0.89
Acromial index	0.86	0.73–0.93
Critical shoulder angle	0.86	0.72–0.93
CT scan parameters		
Acromial tilt	0.85	0.72–0.93
Acromial slope angle	0.79	0.55–0.90
Length of lateral acromial roof	0.80	0.57–0.91
Width of lateral acromial roof	0.82	0.66–0.91
Anterior acromial coverage	0.95	0.90–0.98
Posterior acromial coverage	0.85	0.72–0.93
Coracoacromial angle	0.88	0.77–0.94
Coracoacromial ligament coverage	0.86	0.73–0.93
Coracoid process coverage	0.88	0.78–0.94
MRI parameters		
Anterior tear extension	0.92	0.82–0.96
Posterior tear extension	0.90	0.71–0.96
Glenoid version angle	0.80	0.62–0.90

CT, computed tomography; MRI, magnetic resonance imaging.

*r, intraclass correlation coefficients.

†95% CI, 95% confidence interval.

presumably due to a larger anterior acromial coverage and a larger acromial slope angle in this group. It was readily observable that an excessive spur along the coracoacromial ligament significantly reduced the coracoacromial ligament coverage, and a more curved acromion reduced the acromial tilt. Additionally, the lateral acromial angle in the captured GHFK group was larger than that in the unstable GHFK group, suggesting that a flatter undersurface of the acromion in the lateral-medial direction was more beneficial for the development of acetabularization of the coracoacromial arch.

No relevant differences were found in RCT patterns between patients with unstable and captured GHFK. Therefore, the subtypes of the abnormal GHFK (according to whether there was acetabularization of the coracoacromial arch) depended on scapular morphologic features rather than RCT patterns. Interestingly, most patients (81.25%, 13/16) with unstable and captured GHFK had global RCT extension involving all the rotator cuff connections above the equatorial line of the humerus (supraspinatus, infraspinatus, and superior subscapularis). This finding is partially consistent with Burkhart’s study,⁴ in which the captured GHFK was associated with supraspinatus, a major portion of the posterior rotator cuff, and a major portion of the subscapularis. However, in Burkhart’s study,⁴ no subscapularis tears were found in the unstable GHFK group, which was not in line with our findings. It may be owing to the small number cases (only 2 patients) in Burkhart’s study. Three patients with unstable GHFK in our study also had no subscapularis tears. Nonetheless, the majority of the patients with unstable GHFK (13/16) had superior subscapularis tears. Our result agreed with previous studies in which supraspinatus, infraspinatus, and subscapularis tendons have been reported to be important stabilizing structures of the glenohumeral joint, and massive tears involving the supraspinatus, infraspinatus, and superior subscapularis have been associated with the superior translation of the humeral head during active abduction.^{8,10,16,27,28,31,32} Therefore, it appears that RCT patterns might determine the stabilizing function of the remaining rotator cuff and be associated with the development of abnormal (unstable and captured) GHFK. Further studies are required to compare RCT patterns between patients with normal and abnormal GHFK.

One advantage of this study was that we undertook plain radiographs in active scaption to evaluate unstable or captured GHFK, which enabled us to detect abnormal kinematics such as humeral head anterosuperior translation and impingement between the humeral head and the coracoacromial arch during deltoid and rotator cuff activation.²⁸ Most previous studies have analyzed the stabilizing function of the rotator cuff using static, plain radiographs. However, static, plain radiographs cannot reflect the true rotator cuff stabilizing function because the deltoid muscle and the rotator cuff are not activated in this state and because the acromiohumeral distance is increased due to gravity. While the determining of an abnormal GHFK by using static, plain radiographs was challenging, it was straightforward using plain radiographs in active scaption (Fig. 5). Therefore, we recommend that anteroposterior view radiography in active scaption should be performed preoperatively to determine whether an unstable or captured GHFK is involved. When considering the treatment

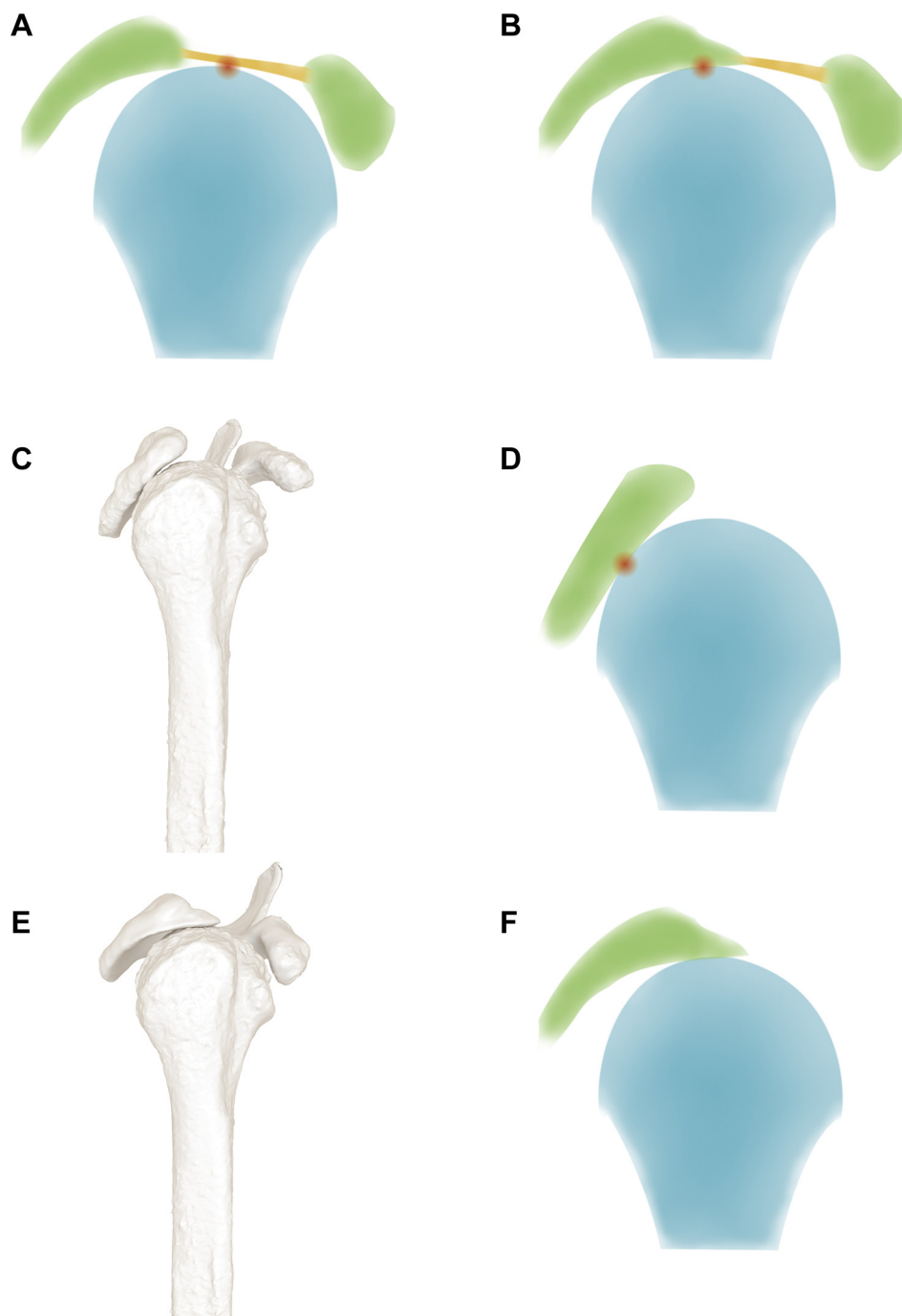


Figure 4 Specific scapular morphologic characteristics in patients with captured GHFK and those with unstable GHFK based on 3-dimensional reconstruction of a CT scan. (A) A small anterior acromial coverage led to a soft contact point between the superior surface of the humeral head and the coracoacromial ligament; (B) a large anterior acromial coverage led to a rigid contact point between the superior surface of the humeral head and the undersurface of the acromion anterior border (or the excessive spur formation along the coracoacromial ligament); (C, D) a small acromial slope angle led to a contact point between the sidewall of the humeral head and the sidewall of the acromion; (E, F) a large acromial slope angle led to a contact point between the superior surface of the humeral head and the undersurface of the acromion anterior border (or the excessive spur formation along the coracoacromial ligament). *CT*, computed tomography; *GHFK*, glenohumeral fulcrum kinematics.

strategies for patients with a captured GHFK, acromioplasty should be cautiously performed or not be performed because both the hyperplastic acromion and excessive spur formation along the coracoacromial ligament were beneficial to the development of acetabularization of the coracoacromial arch. If these patients undergo thorough acromioplasty but have a failure of surgery or rotator cuff re-tear, the shoulder function may not return to its

previous state and become worse because such patients preserved their active motion or partial active motion preoperatively. In patients with unstable GHFK, bony surgeries such as anterior acromial coverage enhancement and adjusting the acromial slope may potentially be applied to transfer the unstable GHFK to captured GHFK if these patients cannot meet the surgical indications for reverse shoulder arthroplasty or if soft tissue



Figure 5 Determination of abnormal GHFK using plain radiographs. In patients with unstable GHFK, plain radiographs in active scaption (A) showed an obvious proximal migration of the humeral head, which could not be observed on static, plain radiographs (B). In patients with captured GHFK, plain radiographs in active scaption (C) showed the humeral head abutted on the undersurface of the acromion, which could not be observed using static, plain radiographs (D). GHFK, glenohumeral fulcrum kinematics.

procedures such as partial repair and superior capsular reconstruction have failed. Further studies are necessary to provide proper treatment strategies for patients with captured and unstable GHFK.

This study had some limitations. First, acetabularization of the coracoacromial arch should be verified intraoperatively, based on abrasion of the coracoacromial ligament at the anterior acromion undersurface and an excavating deformity at this site. However, this study focused on preoperative radiography in active scaption but intraoperative observations. Second, this was a retrospective descriptive study, which could only identify relevant differences between unstable and captured GHFK in terms of scapular morphology and RCT patterns. Prospective studies are required to further investigate these correlations. Third, a larger sample size would be necessary to detect statistically significant differences. However, it took a long time to collect these patients with captured or unstable GHFK. These patients were all in the advanced stage of rotator cuff tears, and recruitment of completely pain-free and stiffness-free patients with no degenerative changes was not possible. Also, it may be difficult to enroll more patients with captured GHFK because these patients may preserve an active arm elevation angle $> 90^\circ$, which make them not present to the hospital or may not agree to participate in the study. Last, there was some inaccuracy when measuring

3-dimensional bony parameters using 2-dimensional images. Therefore, it is important to employ 3-dimensional measurement techniques in future studies.

Conclusion

This study showed that scapular morphologic characteristics rather than RCT patterns were associated with the development of acetabularization of the coracoacromial arch when the remaining rotator cuff could not stabilize the humeral head. Patients with captured GHFK exhibited larger anterior acromial coverage, smaller acromial tilt, and a more curved acromion than those with unstable GHFK.

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