

Correlation of Ultrasound Findings With Clinical Stages and Impairment in Adhesive Capsulitis of the Shoulder

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Background: Ultrasound is an essential tool for diagnosing shoulder disorders. However, the role of ultrasound in assessing and diagnosing adhesive capsulitis has not been fully studied.

Purpose: To evaluate the ultrasound features of adhesive capsulitis and estimate the correlations between clinical impairment and ultrasound parameters.

Study Design: Case series; Level of evidence, 4.

Methods: A total of 61 patients with clinically diagnosed unilateral adhesive capsulitis were retrospectively reviewed using high-resolution ultrasound. To compare ultrasound parameters, we performed ultrasound examinations on both affected and unaffected shoulders. Ultrasound parameters, including thickness of the coracohumeral ligament (CHL), rotator interval (RI), axillary recess (AR), hypervascularity of the RI, and effusion of the long head of the biceps tendon sheath, were measured. Passive range of motion (PROM), visual analog scale for pain, and the Shoulder Pain and Disability Index were used for clinical assessment.

Results: The CHL, the RI, and the AR in affected shoulders were significantly thicker than in unaffected shoulders ($P < .05$). CHL thickness in affected shoulders was significantly correlated with PROM limitation, which included forward elevation, abduction, external rotation (ER), and internal rotation (IR) ($P < .05$). AR thickness correlated with passive forward elevation limitation and passive IR limitation ($P < .05$). The CHL was significantly thicker in stage 2 compared with stage 1, and the RI was thicker in stage 2 compared with stage 3. The diagnostic cutoff values for adhesive capsulitis were 2.2 mm for CHL thickness (77% sensitivity, 91.8% specificity) and 4 mm for AR thickness (68.9% sensitivity, 90.2% specificity).

Conclusion: The ultrasound parameters associated with structural changes were correlated with clinical characteristics of adhesive capsulitis. Thickened CHL, RI, and AR were observed in affected shoulders. The cutoff values of 2.2 mm for CHL thickness and 4 mm for AR thickness can be used as cutoff diagnostic values for adhesive capsulitis.

Keywords: adhesive capsulitis; frozen shoulder; ultrasonography; shoulder joint; coracohumeral ligament

Adhesive capsulitis is a common condition characterized by progressive pain and limited range of motion in the glenohumeral joint. The pathogenesis of adhesive capsulitis remains poorly understood but is thought to be the result of synovial inflammation and subsequent capsular fibrosis.^{3,22} Adhesive capsulitis has been diagnosed as a clinical entity that has progressive shoulder pain with accompanying decreases in both active and passive range of motion in the glenohumeral joint. Arthroscopy, magnetic resonance imaging (MRI), and ultrasound allow for visualization of confirmed findings to aid in proper diagnosis and rule out concurrent pathology.^{8,23,32} MRI is a standard imaging approach for shoulder disorders, and reliable signs of adhesive capsulitis on MRI correlate with clinical impairment.^{1,31} However, MRI requires MR-

compatible hardware, needs relatively long examination time, and has other limitations, including high cost. Arthroscopy provides an accurate assessment of the joint capsule, but because of its invasive nature, its use is limited for diagnostic purposes. High-resolution ultrasound has been widely used as a suitable imaging option for musculoskeletal problems, as it is noninvasive, inexpensive, and easy to perform bilaterally in specific positions.

Previous shoulder MRI studies of adhesive capsulitis have reported several important radiologic features, such as enhancement and fat obliteration of the rotator interval (RI), hyperintensity of the inferior glenohumeral ligament, and thickening of the coracohumeral ligament (CHL) and the axillary recess (AR).^{3,8,16,32} However, the role of ultrasound in assessing and diagnosing adhesive capsulitis has not been fully studied. A few studies have evaluated specific ultrasound parameters, including CHL, RI, and AR thickening. Effusion in the long head of the biceps tendon

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(LHBT) sheath and hypervascularity in the RI have been reported as useful diagnostic features of adhesive capsulitis.^{6,14,17,20,36-38} However, previous studies included relatively few participants and their results were inconsistent.

Many conditions can cause symptoms similar to those of adhesive capsulitis, including full- and partial-thickness rotator cuff tears, calcific tendinitis, glenohumeral or acromioclavicular arthritis, and cervical radiculopathy.¹⁶ An accurate diagnosis of adhesive capsulitis can reduce patient morbidity by shortening pain duration through physical therapy and intra-articular steroid injections. Radiologic findings could play an important role in adhesive capsulitis diagnosis during the early stages or when clinical features are atypical.^{8,33} In this regard, characteristic ultrasound findings and cutoff values for adhesive capsulitis parameters could be useful for creating a differential diagnosis between adhesive capsulitis and other diseases that mimic adhesive capsulitis. The natural course of adhesive capsulitis can be divided into 4 stages based on clinical presentation and arthroscopic appearance: prefrozen, freezing, frozen, and thawing.^{3,23,24} Identifying the clinical stages is of high importance, as treatment varies according to disease stage.^{7,11,16} No studies have comprehensively assessed the correlations between ultrasound findings and clinical features of adhesive capsulitis. Estimating the correlations between ultrasound characteristics and clinical features would be useful for individualizing and appropriately treating patients with adhesive capsulitis.

The purpose of this study was to evaluate the ultrasound features of patients with shoulder adhesive capsulitis and to determine whether there are any correlations between clinical impairment and ultrasound parameters. We hypothesized that the ultrasound features would be related with adhesive capsulitis and that there is a close relationship between ultrasound features and clinical impairment.

METHODS

This was a retrospective cohort study of 61 patients with unilateral adhesive capsulitis performed at a musculoskeletal clinic in a tertiary hospital from November 2017 to November 2019. This study protocol was approved by our institutional review board, and informed consent was waived by the board because of the retrospective study design. Adhesive capsulitis diagnosis was based on the following criteria: unilateral shoulder pain for at least 1 month; shoulder stiffness; and limitation of passive and

TABLE 1
Clinical Stages of Adhesive Capsulitis

Stage	Symptom Duration	Symptoms
1. Prefreezing	0-3 months	Pain and limited range of motion
2. Freezing	3-9 months	Severely restricted range of motion and pain
3. Frozen	9-15 months	Severe stiffness and minimal pain
4. Thawing	15-24 months	Improvement in range of motion and minimal pain

active range of motion in a capsular pattern. The exclusion criteria were as follows: rotator cuff tear or bursitis confirmed by ultrasound; calcification in the rotator cuff or arthritis in the shoulder region confirmed by routine radiographic examination; presence of cervical radiculopathy or peripheral nerve disorder of the upper limb; and history of trauma or surgery. Patients who were clinically diagnosed with adhesive capsulitis underwent bilateral shoulder ultrasound examination.

Hannafin and Chiaia¹² described the clinical stages of adhesive capsulitis. In stage 1 (prefreezing), there is usually pain with limited range of motion. In stage 2 (freezing), there is chronic pain with severely restricted active and passive range of motion. In stage 3 (frozen), there is minimal pain with significant limitation of range of motion with a rigid “end feel.” In stage 4 (thawing), there is minimal pain with progressive improvement in range of motion. In our study, clinical staging was determined according to symptom duration (stage 1: 0-3 months; stage 2: 3-9 months; stage 3: 9-15 months; and stage 4: 15-24 months) (Table 1).

Clinical Assessment

Passive range of motion (PROM), visual analog scale (VAS) for pain, and the Shoulder Pain and Disability Index (SPADI) were used for clinical assessment of adhesive capsulitis. With the patient sitting on a stool and measurements performed, shoulder PROM was assessed using a universal goniometer to record forward elevation (FE), abduction, external rotation (ER), and internal rotation (IR) at the back. FE was measured as the maximal arm-trunk degree when the examiner elevated the upper arm in the sagittal plane of the trunk. Abduction was measured in degrees between the arm and the thorax when the examiner elevated the upper arm in the coronal plane. The ER was measured in degrees in the sagittal plane, with the arm

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Ethical approval for this study was obtained from the Ethics Committee of Kangbuk Samsung Hospital (approval No. 2020-01-005).

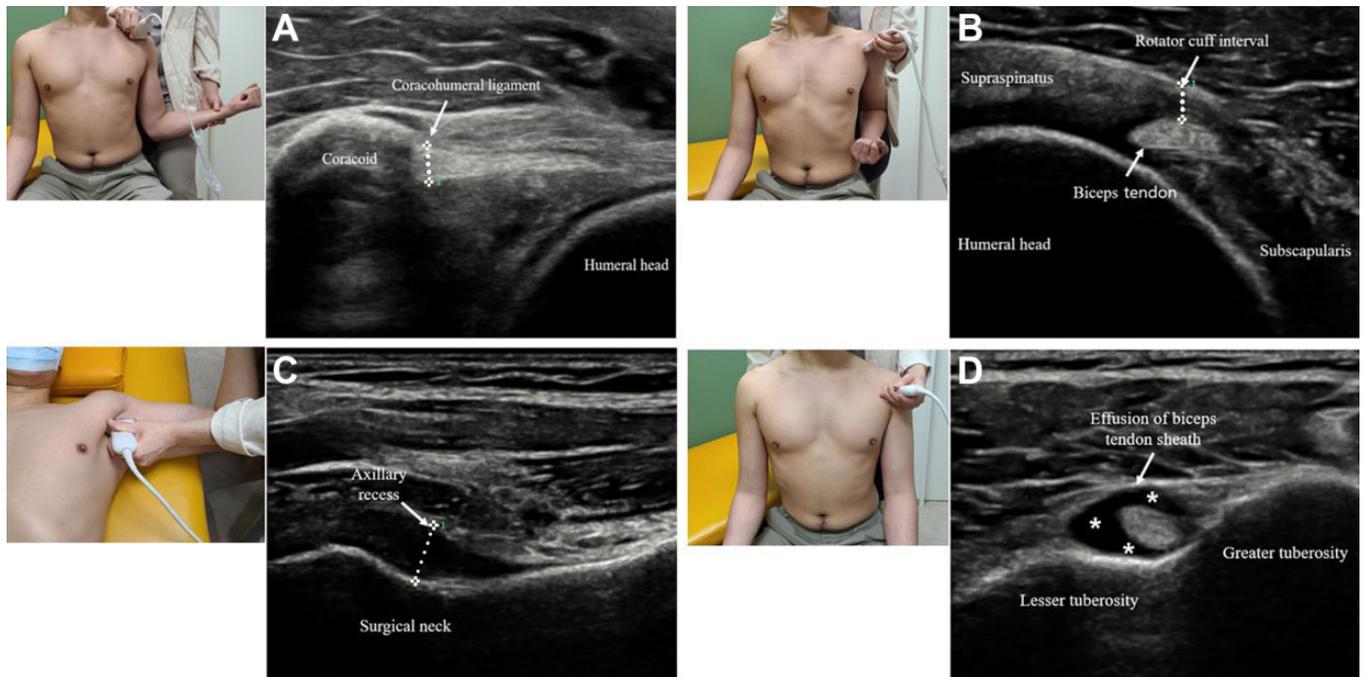


Figure 1. Ultrasound measurement. The B-mode ultrasound scan shows measurement of (A) CHL thickness (dotted line), (B) oblique axial view of the RI (dotted line), (C) AR at the humeral surgical neck (dotted line), and (D) effusion of the LHBT (asterisks). AR, axillary recess; CHL, coracohumeral ligament; LHBT, long head of biceps tendon; RI, rotator interval.

in adduction and with 90° elbow flexion.¹⁸ The IR was measured by noting the highest vertebral level reached with the thumb at the back. For statistical analysis, we converted values into consecutively numbered groups: the 1st thoracic vertebra to the 12th thoracic vertebra = 1-12; the 1st lumbar vertebra to the 5th lumbar vertebra = 13-17; and below the sacrum = 18. When PROM was evaluated, we attempted to diminish the compensatory movement of the spine and stabilize the scapula by pressing firmly on the scapula.^{18,25} The PROM of both shoulders was measured in a sitting position, which is sufficient to minimize the motion of the scapula and easy to perform in the clinic.

Ultrasound Parameters

We performed ultrasound examinations on both affected and unaffected shoulders to compare ultrasound parameters. High-resolution ultrasound examinations of the shoulder were performed using Ultrasound System RS80A with Prestige (Samsung Medison), equipped with a 3-12 MHz linear transducer. The standard protocol for scanning shoulder structures to exclude the rotator cuff and bursa lesions was performed. Then, CHL, RI, and AR thickness, RI hypervascularity, and LHBT sheath effusion were measured in bilateral shoulders. The ratios among the CHL, the RI, and the AR were calculated by dividing the thickness of the affected shoulder by that of the unaffected shoulder. Examinations were performed by a single experienced musculoskeletal physiatrist (J.G.D.).

CHL Thickness. Patients were scanned in a sitting position, with ER of the shoulder to stretch and visualize the

CHL. The axial oblique plane was obtained over the CHL by positioning the transducer on the lateral border of the coracoid process. The CHL was observed as a linear hyperechoic band arising from the coracoid process and reaching up to the RI.² Identification of the CHL from the surrounding structures was achieved by tilting the probe to reduce anisotropy and by dynamic examination under internal and external rotation.³⁷ Longitudinal images of the CHL were captured, and the CHL thickness just lateral to the coracoid process was measured and recorded (Figure 1A).

RI Thickness and Hypervascularity. The RI is a free space bounded above by the anterior aspect of the supraspinatus tendon and below by the superior aspect of the subscapularis tendon, and the medial border is formed by the lateral margin of the coracoid process.³⁴ The RI is the anterior aspect of the glenohumeral joint capsule that contains the CHL, the superior glenohumeral ligament, and the intra-articular portion of the biceps tendon. The RI was evaluated in the oblique axial plane with the patient's fist held at the side in a sitting position, as in a previously published study.^{13,17} For RI assessment, a B-mode ultrasound and power Doppler were performed. RI thickness was measured as the shortest distance between the biceps long head tendon and peribursal fat, including the CHL, the superior glenohumeral ligament, and other RI tissues (Figure 1B). The presence of a power Doppler signal within the RI was scored dichotomously as either absent or present.

AR Thickness. For AR thickness, the patient lay supine, with the elbow flexed at 90° and the forearm neutral. The ultrasound probe was placed longitudinally on the midaxillary line along the long axis of the humeral shaft.^{15,28} AR

TABLE 2
Epidemiologic and Clinical Characteristics of the Patients^a

Characteristic	Total (N = 61)	Stage 1 (n = 20)	Stage 2 (n = 31)	Stage 3 (n = 10)	p Value
Age, y	56.2 ± 8.9	56.8 ± 11.0	56.3 ± 8.0	54.8 ± 7.5	.849
Male, n (%)	31 (50.8)	12 (60.0)	16 (51.6)	3 (30.0)	.334
Right shoulder affected	28 (45.9)	10 (50.0)	12 (38.7)	6 (60.0)	.451
Symptom duration, wk	19.6 ± 14.5	7.2 ± 3.2	18.4 ± 5.1 ^{b,c}	47.9 ± 8.3	<.001
Hypertension	17 (27.9)	6 (30.0)	8 (25.8)	3 (30.0)	.930
Diabetes	15 (24.6)	4 (20.0)	9 (29.0)	2 (20.0)	.723
Thyroid disease	4 (6.6)	1 (5.0)	3 (9.6)	0 (0.0)	.540
Heart disease	4 (6.6)	0 (0.0)	4 (12.9)	0 (0.0)	.160
ROM					
FE, deg	129.7 ± 30.0	145.7 ± 27.7	117.5 ± 27.7 ^b	135.5 ± 26.9	.003
Abduction, deg	100.5 ± 44.1	124.7 ± 39.6	82.2 ± 41.0 ^b	109.0 ± 39.0	.002
ER, deg	39.7 ± 23.6	56.2 ± 21.9	30.4 ± 21.3 ^b	35.5 ± 16.9	< .001
IR level	13.3 ± 3.7	11.2 ± 4.0	14.8 ± 3.0 ^b	12.8 ± 3.2	.003
Clinical scores					
VAS, pain	5.6 ± 2.1	5.6 ± 2.0	5.6 ± 2.3	5.8 ± 1.7	.958
SPADI, pain (%)	49.4 ± 22.7	52.4 ± 21.0	48.1 ± 23.5	47.2 ± 25.0	.772
SPADI, disability (%)	43.3 ± 22.9	46.7 ± 18.0	42.0 ± 25.6	40.6 ± 24.4	.715
SPADI, total (%)	45.3 ± 21.9	48.4 ± 18.6	44.1 ± 23.6	43.1 ± 24.1	.754

^aValues are expressed as mean ± SD or n (%). Bolded *P* values indicate statistically significant differences between groups (*P* < .05). ER, external elevation; FE, forward elevation; IR, internal rotation; ROM, range of motion; SPADI, Shoulder Pain and Disability Index; VAS, visual analog scale.

^bSignificantly different from stage 1.

^cSignificantly different from stage 3.

thickness was determined as the distance from the bony cortex to the outer margin of the glenohumeral joint capsule at the humeral surgical neck. The thickest portion of the AR was measured (Figure 1C).

Effusion of the LHBT Sheath. Effusion of the LHBT sheath was evaluated at the proximal humeral metaphysis level, which is the most dependent portion of the tendon sheath. The biceps tendon sheath derives from the extension of the glenohumeral joint capsule; biceps tendon effusion is attributed to intra-articular pathology.⁴ Prominent effusion of the glenohumeral joint increases the biceps tendon sheath effusion.²⁹ In a short-axis scan, effusion surrounding the biceps tendon was considered abnormal (Figure 1D).

Statistical Analysis

Descriptive statistics were used to characterize demographic and clinical variables. Continuous variables are presented as means and standard deviations for normally distributed data and median and interquartile range for non-normally distributed data. Distributions were evaluated by visual inspection of the variable distribution and with the Shapiro-Wilk test. Frequency count and percentage are presented for categorical variables. The paired *t* test or the McNemar test were used to compare ultrasound parameters between affected and unaffected shoulders. One-way analysis of variance and the Fisher exact test with post hoc adjustment (Bonferroni correction) were used to compare ultrasound parameters and clinical characteristics according to clinical stage. Pearson and Spearman rank correlations were used to investigate the relationships between ultrasound parameters and clinical variables. To determine the best cutoff points for ultrasound

parameters to differentiate an adhesive capsulitis shoulder from an unaffected shoulder, we estimated sensitivity and specificity and calculated the area under the curve (AUC) using the receiver operating characteristic (ROC) curve of the Youden index.⁹ Data were analyzed using SPSS Statistics Version 24.0 (IBM). All statistical tests were 2-sided, and significance was set at 5%.

RESULTS

Patient Characteristics

We enrolled 61 patients who met the clinical diagnosis of adhesive capsulitis. The mean age was 56.2 ± 8.9 years, and 31 (50.8%) patients were men. Twenty (32.8%) patients had stage 1, 31 (50.8%) stage 2, and 10 (16.4%) stage 3 adhesive capsulitis; however, none of the patients had stage 4 of the disease. Patient and clinical characteristics are presented in Table 2. There was a statistically significant difference in symptom duration between stage 2 versus stage 1 and stage 3 (*P* < .001 for both). In addition, significant limitations in FE, abduction, ER, and IR were seen in the group with stage 2 versus the group with stage 1 adhesive capsulitis (*P* ≤ .003 for all). However, there were no significant differences among the groups for VAS or SPADI.

Comparison of Ultrasound Parameters Between Affected and Unaffected Shoulders

CHL, RI, and AR thickness in the affected shoulder were significantly greater than in the unaffected shoulder. Effusion of the LHBT sheath and RI hypervascularity were also

significantly greater in the affected shoulders ($P < .001$ for both) (Table 3).

Diagnostic Cutoff Values for Ultrasound Parameters for Adhesive Capsulitis

The ROC analysis was performed to estimate diagnostic cutoff values for ultrasound parameters of adhesive capsulitis. Using 2.2 mm as an optimal cutoff value for CHL thickness, we achieved 77% sensitivity, 91.8% specificity, and 0.91 AUC. For AR thickness, a cutoff value of 4 mm yielded 68.9% sensitivity, 90.2% specificity, and 0.85 AUC.

Correlations Between Ultrasound Parameters and Clinical Variables

CHL thickness in the affected shoulders was significantly correlated with PROM limitation, including FE ($r = -0.340$; $P < .05$), abduction ($r = -0.439$; $P < .001$), ER ($r = -0.600$; $P < .001$), and IR ($r = 0.314$; $P < .05$). AR thickness was correlated with passive limitation in FE ($r = -0.280$; $P < .05$) and IR ($r = 0.456$; $P < .001$). LHBT sheath effusion was significantly correlated with limitations in FE, IR, and total

SPADI. However, hypervascularity at the RI was not significantly correlated with any clinical variables (Appendix Table A1).

Comparison of Ultrasound Parameters According to Clinical Stage

Ultrasound parameters according to clinical stage are shown in Table 4. The CHL thickness and ratio were significantly thicker in stage 2 than in stage 1 ($P = .013$ and $.034$, respectively), and RI thickness was significantly thicker in stage 2 than in stage 3 ($P = .036$). In addition, LHBT effusion was significantly different in stage 2 compared with stage 3 (71% vs 20%, respectively; $P = .016$). There were no significant differences between clinical stages regarding the remaining ultrasound parameters (Table 4).

DISCUSSION

This study evaluated ultrasound findings in 61 patients with unilateral adhesive capsulitis by measuring correlations between ultrasound parameters and clinical features of adhesive capsulitis. CHL, RI, and AR in affected shoulders were significantly thicker than in unaffected shoulders. CHL thickness correlated with a decreased range of motion of the glenohumeral joint. Cutoff values of 2.2 mm for CHL thickness and 4 mm for AR thickness yielded optimal diagnostic values for adhesive capsulitis. Furthermore, we found significant differences in ultrasound findings according to the clinical stage of adhesive capsulitis.

Adhesive capsulitis can be divided into different stages depending on pain, duration of symptoms, and arthroscopic findings. Neviaser and Neviaser²⁴ described the arthroscopic stages of adhesive capsulitis, and Hannafin and Chiaia¹² reported 4 stages of adhesive capsulitis based on clinical presentation and arthroscopic appearance. The stages of adhesive capsulitis are sometimes difficult to define in clinical conditions because they do not fit well with

TABLE 3
Ultrasound Parameters Between Affected and Unaffected Shoulders (N = 61)^a

Ultrasound Parameter	Affected Shoulder	Unaffected Shoulder	P Value
CHL thickness, mm	2.7 ± 0.6	1.5 ± 0.4	<.001
RI thickness, mm	2.2 ± 0.8	1.9 ± 0.7	.004
AR thickness, mm	4.5 ± 1.4	2.6 ± 1.1	<.001
Effusion of the LHBT sheath	34 (55.7)	3 (4.9)	<.001
Hypervascularity of the RI	11 (18)	1 (1.6)	<.001

^aValues are expressed as mean ± SD or n (%). Bolded P values indicate statistically significant differences between groups ($P < .05$). AR, axillary recess; CHL, coracohumeral ligament; LHBT, long head of biceps tendon; RI, rotator interval.

TABLE 4
Ultrasound Parameters of Affected Shoulders According to Clinical Stage^a

Ultrasound Parameter ^b	Stage 1 (n = 20)	Stage 2 (n = 31)	Stage 3 (n = 10)	P Value
CHL thickness, mm	2.3 ± 0.6	2.9 ± 0.6 ^c	2.7 ± 0.6	.013
CHL ratio, %	151.3 ± 38.3	206.5 ± 91.5 ^c	196.4 ± 56.9	.034
RI thickness, mm	2.1 ± 0.8	2.4 ± 0.8 ^d	1.7 ± 0.6	.036
RI ratio, %	116.7 ± 44.2	119.8 ± 32.8	108.1 ± 36.8	.690
AR thickness, mm	4.5 ± 1.6	4.8 ± 1.4	4.1 ± 0.9	.426
AR ratio, %	172.4 ± 51.7	212.4 ± 125.9	222.0 ± 92.3	.310
Effusion of the LHBT sheath	10 (50)	22 (71) ^d	2 (20)	.016
Hypervascularity of the RI	3 (15)	6 (19.4)	2 (20)	>.999

^aValues are expressed as mean ± SD or n (%). Bolded P values indicate statistically significant differences between groups ($P < .05$). AR, axillary recess; CHL, coracohumeral ligament; LHBT, long head of biceps tendon; RI, rotator interval.

^bRatio = percentage of affected/unaffected shoulders.

^cSignificantly different from stage 1.

^dSignificantly different from stage 3.

clinical findings, and arthroscopic examination is not performed solely for the diagnosis of adhesive capsulitis because of its invasive nature. In our study, the 4 clinical stages were based on the duration of symptoms. This might be the reason for the lack of significant differences among the stage groups in VAS or SPADI scores. Prospective cohort studies are needed for changes of pathology according to clinical stage to better understand the pathogenesis of adhesive capsulitis. In the early adhesive capsulitis stages, especially in the prefrozen stage, many symptoms of early-stage adhesive capsulitis are similar to those in other conditions. In this regard, we routinely performed shoulder ultrasound and radiography to exclude rotator cuff tears, calcific tendinitis, and glenohumeral arthritis.

The primary pathophysiology underlying painful restriction of the glenohumeral joint in adhesive capsulitis is inflammatory contracture of the shoulder joint capsule. CHL thickening and inferior glenohumeral ligament abnormalities have previously been reported as important findings of adhesive capsulitis in imaging studies.^{20,30,31} Several studies have shown that the CHL is thickened and stiffened in adhesive capsulitis on ultrasound.^{6,13,37} Homs et al¹³ found that the mean thickness of the CHL was significantly greater in adhesive capsulitis (3 mm) than in asymptomatic (1.34 mm) and painful (1.39 mm) shoulders. Cheng et al⁶ reported that patients with adhesive capsulitis had significantly thickened CHL (mean, 3.1 mm) on ultrasound. A shear-wave elastography study also showed that the CHL elastic modulus was greater in symptomatic adhesive capsulitis shoulders than in unaffected shoulders.³⁷ A histological study observed fibroblastic proliferation in the CHL in adhesive capsulitis cases.²⁶ In clinical practice, surgical release of the CHL can improve shoulder function and range of motion. Contracture of the CHL and RI during surgery was observed in a study of 17 patients with adhesive capsulitis.²⁷ Based on these results, the CHL is a major morphologic abnormality in adhesive capsulitis, and the CHL measurement is important in adhesive capsulitis. We estimated the cutoff values for the CHL to diagnose adhesive capsulitis. The sensitivity, specificity, and AUC values of 77%, 91.8%, and 0.91, respectively, were observed when using CHL thickness of 2.2 mm as the best cutoff value for adhesive capsulitis diagnosis. As CHL thickening could be indicative of adhesive capsulitis, the optimal CHL cutoff value that we estimated here might be useful for adhesive capsulitis diagnosis.

In our study, thickened CHL was associated with limited ROM in all orientations, especially ER, and AR thickness was inversely correlated with IR. These results are consistent with previous findings. The CHL stabilizes the humeral head in ER: It is stretched in maximal ER and is lax in the IR.² Previous researchers suggested that the CHL plays a role in limiting the range of ER of the glenohumeral joint and that a tightened CHL restricts ER in patients with adhesive capsulitis.²¹ Gagey and Boisrenoult¹⁰ reported that IR, ER, and abduction diminished after shrinkage of the inferior glenohumeral ligament, which is a component of the AR. It is thought that AR and CHL thickening are important anatomic abnormalities

related to adhesive capsulitis pathophysiology because they are highly correlated with functional restriction of the glenohumeral joint.

Previous studies have shown that AR thickening is a key diagnostic finding of adhesive capsulitis.^{20,30} In an ultrasound study of 20 patients with adhesive capsulitis, the mean thickness was 4 mm in affected shoulders and 1.3 mm in asymptomatic shoulders ($P < .001$).²⁰ A retrospective study of 29 patients with adhesive capsulitis reported that the mean AR thickness in the adhesive capsulitis group was higher than that in the control group on MRI (4.61 ± 1.53 mm vs 2.55 ± 1.03 mm; $P < .001$). Additionally, a cutoff value of 4 mm for AR thickness yielded an excellent diagnostic accuracy, with 58.62% sensitivity and 100% specificity.³⁰ These studies showed that AR thickening represents an important structural change associated with adhesive capsulitis.¹⁹ In our study, AR thickness was significantly different between affected and unaffected shoulders, corresponding to the results of previous studies. The mean AR thickness was 4.5 ± 1.4 mm in affected shoulders and 2.6 ± 1.1 mm in unaffected shoulders. Also, the optimal AR cutoff value for adhesive capsulitis diagnosis was 4 mm, with 68.9% sensitivity and 90.2% specificity. Assessment of AR using ultrasound has several advantages. It can be used to measure bilateral and comparative images. AR measurement using ultrasound is regarded as a practical and reliable tool for adhesive capsulitis diagnosis.

Fibrovascular scar tissue within the RI is a reliable sign of adhesive capsulitis, and the RI can be thickened in adhesive capsulitis.^{17,34} Previously, a study reported that increased vascularity of the RI might be related to adhesive capsulitis.¹⁷ However, controversy remains about hypervascularity of the RI in adhesive capsulitis. Cheng et al⁶ reported hypervascularity in the RI in 71.1% of adhesive capsulitis shoulders, while Tandon et al³⁵ and Walmsley et al³⁶ found that only 10% and 29% of patients with adhesive capsulitis showed increased RI vascularity. In our study, increased RI vascularity was observed in 18% of patients with adhesive capsulitis. It is difficult to find a usefulness for RI hypervascularity in assessing adhesive capsulitis.

Few studies have evaluated the association between clinical stages and ultrasound findings. An MRI study⁵ reported that effusion of the LHBT was more frequently observed in early stages (1 or 2) than in later stages (3 or 4), and CHL thickness was not associated with clinical stages. In our study, the RI was thicker in stage 2 than in stage 3, and the CHL was significantly thicker in stage 2 than in stage 1. Thickened synovium and synovial proliferation with adhesion in the RI were revealed in stage 2 in arthrography.^{8,23} The synovial inflammation with proliferation could affect thickened RI and CHL in stage 2.

This study had several limitations. First, this was a study with a retrospective design, and although we reviewed the data thoroughly, we had insufficient information about some adhesive capsulitis risk factors, such as cardiovascular disease and obesity. Despite our retrospective study design, we were able to collect precise clinical features and ultrasound measurements using the

standardized shoulder registry program of our institute. Second, none of our patients underwent arthroscopic shoulder examination. Third, it is difficult to measure the CHL because of its anatomic variability and restricted scanning position. Also, ultrasound is an experience-dependent method; thus, it is performed at our institute only by an experienced musculoskeletal physiatrist.

CONCLUSION

The ultrasound parameters associated with structural changes were correlated with clinical characteristics and clinical stages of adhesive capsulitis. Thickened CHL, RI, and AR were observed in affected shoulders, and CHL and AR thickening on the ultrasound images were associated with both FE and IR restriction with PROM. CHL >2.2 mm and AR >4 mm can be used as cutoff diagnostic values for adhesive capsulitis. Ultrasound can be a useful technique to assess adhesive capsulitis patients.

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REFERENCES

- Ahn KS, Kang CH, Oh YW, Jeong WK. Correlation between magnetic resonance imaging and clinical impairment in patients with adhesive capsulitis. *Skeletal Radiol.* 2012;41(10):1301-1308.
- Bianchi S, Jacob D, Lambert A, Draghi F. Sonography of the coracoid process region. *J Ultrasound Med.* 2017;36(2):375-388.
- Brue S, Valentin A, Forssblad M, Werner S, Mikkelsen C, Cerulli G. Idiopathic adhesive capsulitis of the shoulder: a review. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(8):1048-1054.
- Chang KV, Wu WT, Ozcakar L. Association of bicipital peritendinous effusion with subacromial impingement: a dynamic ultrasonographic study of 337 shoulders. *Sci Rep.* 2016;6:38943.
- Chellathurai A, Subbiah K, Elangovan A, Kannappan S. Adhesive capsulitis: Magnetic resonance imaging (MRI) correlation with clinical stages and proposal of MRI staging. *Indian J Radiol Imaging.* 2019;29(1):19-24.
- Cheng X, Zhang Z, Xuanyan G, et al. Adhesive capsulitis of the shoulder: evaluation with ultrasound-arthrography using a sonographic contrast agent. *Sci Rep.* 2017;7(1):5551.
- D'Orsi GM, Via AG, Frizziero A, Oliva F. Treatment of adhesive capsulitis: a review. *Muscles Ligaments Tendons J.* 2012;2(2):70-78.
- Fields BKK, Skalski MR, Patel DB, et al. Adhesive capsulitis: review of imaging findings, pathophysiology, clinical presentation, and treatment options. *Skeletal Radiol.* 2019;48(8):1171-1184.
- Fluss R, Faraggi D, Reiser B. Estimation of the Youden Index and its associated cutoff point. *Biom J.* 2005;47(4):458-472.
- Gagey OJ, Boisrenoult P. Shoulder capsule shrinkage and consequences on shoulder movements. *Clin Orthop Relat Res.* 2004(419):218-222.
- Griggs SM, Ahn A, Green A. Idiopathic adhesive capsulitis: a prospective functional outcome study of nonoperative treatment. *J Bone Joint Surg Am.* 2000;82(10):1398-1407.
- Hannafin JA, Chiaia TA. Adhesive capsulitis: a treatment approach. *Clin Orthop Relat Res.* 2000;372:95-109.
- Homsy C, Bordalo-Rodrigues M, da Silva JJ, Stump XM. Ultrasound in adhesive capsulitis of the shoulder: is assessment of the coracohumeral ligament a valuable diagnostic tool? *Skeletal Radiol.* 2006;35(9):673-678.
- Kim DH, Cho CH, Sung DH. Ultrasound measurements of axillary recess capsule thickness in unilateral frozen shoulder: study of correlation with magnetic resonance imaging measurements. *Skeletal Radiol.* 2018;47(11):1491-1497.
- Kim KT, Lee DG, Lee S, Kim du H. Ultrasonographic measurement of the thickness of the axillary recess capsule in healthy volunteers. *Ann Rehabil Med.* 2016;40(3):502-508.
- Le HV, Lee SJ, Nazarian A, Rodriguez EK. Adhesive capsulitis of the shoulder: review of pathophysiology and current clinical treatments. *Shoulder Elbow.* 2017;9(2):75-84.
- Lee JC, Sykes C, Saifuddin A, Connell D. Adhesive capsulitis: sonographic changes in the rotator cuff interval with arthroscopic correlation. *Skeletal Radiol.* 2005;34(9):522-527.
- Lee YT, Chun KS, Yoon KJ, et al. Correlation of joint volume and passive range of motion with capsulo-synovial thickness measured by contrast-enhanced magnetic resonance imaging in adhesive capsulitis. *PM R.* 2018;10(2):137-145.
- Lefevre-Colau MM, Drape JL, Fayad F, et al. Magnetic resonance imaging of shoulders with idiopathic adhesive capsulitis: reliability of measures. *Eur Radiol.* 2005;15(12):2415-2422.
- Michelin P, Delarue Y, Duparc F, Dacher JN. Thickening of the inferior glenohumeral capsule: an ultrasound sign for shoulder capsular contracture. *Eur Radiol.* 2013;23(10):2802-2806.
- Neer CS 2nd, Satterlee CC, Dalsey RM, Flatow EL. The anatomy and potential effects of contracture of the coracohumeral ligament. *Clin Orthop Relat Res.* 1992;280:182-185.
- Neviasser AS, Hannafin JA. Adhesive capsulitis: a review of current treatment. *Am J Sports Med.* 2010;38(11):2346-2356.
- Neviasser AS, Neviasser RJ. Adhesive capsulitis of the shoulder. *J Am Acad Orthop Surg.* 2011;19(9):536-542.
- Neviasser RJ, Neviasser TJ. The frozen shoulder: diagnosis and management. *Clin Orthop Relat Res.* 1987;223:59-64.
- Oh JH, Kim SH, Lee HK, Jo KH, Bin SW, Gong HS. Moderate preoperative shoulder stiffness does not alter the clinical outcome of rotator cuff repair with arthroscopic release and manipulation. *Arthroscopy.* 2008;24(9):983-991.
- Omari A, Bunker TD. Open surgical release for frozen shoulder: surgical findings and results of the release. *J Shoulder Elbow Surg.* 2001;10(4):353-357.
- Ozaki J, Nakagawa Y, Sakurai G, Tamai S. Recalcitrant chronic adhesive capsulitis of the shoulder: role of contracture of the coracohumeral ligament and rotator interval in pathogenesis and treatment. *J Bone Joint Surg Am.* 1989;71(10):1511-1515.
- Park GY, Lee JH, Kwon DG. Ultrasonographic measurement of the axillary recess thickness in an asymptomatic shoulder. *Ultrasonography.* 2017;36(2):139-143.
- Park I, Lee HJ, Kim SE, et al. Evaluation of the effusion within biceps long head tendon sheath using ultrasonography. *Clin Orthop Surg.* 2015;7(3):351-358.
- Park J, Choi YH, Chai JW, et al. Anterior capsular abnormality: another important magnetic resonance imaging finding for the diagnosis of adhesive capsulitis of the shoulder. *Skeletal Radiol.* 2019;48(4):543-552.
- Park S, Lee DH, Yoon SH, Lee HY, Kwack KS. Evaluation of adhesive capsulitis of the shoulder with fat-suppressed T2-weighted magnetic resonance imaging (MRI): association between clinical features and MRI Findings. *AJR Am J Roentgenol.* 2016;207(1):135-141.
- Suh CH, Yun SJ, Jin W, et al. Systematic review and meta-analysis of magnetic resonance imaging features for diagnosis of adhesive capsulitis of the shoulder. *Eur Radiol.* 2019;29(2):566-577.
- Sun Y, Liu S, Chen S, Chen J. The effect of corticosteroid injection into rotator interval for early frozen shoulder: a randomized controlled trial. *Am J Sports Med.* 2018;46(3):663-670.

34. Tamborini G, Moller I, Bong D, et al. The rotator interval — a link between anatomy and ultrasound. *Ultrasound Int Open*. 2017;3(3): e107-e116.
35. Tandon A, Dewan S, Bhatt S, Jain AK, Kumari R. Sonography in diagnosis of adhesive capsulitis of the shoulder: a case control study. *J Ultrasound*. 2017;20(3):227-236.
36. Walmsley S, Osmotherly PG, Walker CJ, Rivett DA. Power doppler ultrasonography in the early diagnosis of primary/idiopathic adhesive capsulitis: an exploratory study. *J Manipulative Physiol Ther*. 2013; 36(7):428-435.
37. Wu CH, Chen WS, Wang TG. Elasticity of the coracohumeral ligament in patients with adhesive capsulitis of the shoulder. *Radiology*. 2016; 278(2):458-464.
38. Zappia M, Di Pietto F, Aliprandi A, et al. Multimodal imaging of adhesive capsulitis of the shoulder. *Insights Imaging*. 2016;7(3): 365-371.

APPENDIX

TABLE A1
Correlation Between Ultrasound Parameters and Clinical Variables^a

	Forward Elevation	Abduction	External Rotation	Internal Rotation	VAS Score	SPADI Score		
						Pain	Disability	Total
CHL thickness								
<i>r</i>	-0.34	-0.439	-0.6	0.314	0.003	-0.24	-0.16	-0.18
<i>P</i>	.008	<.001	<.001	.014	.203	.097	.17	.132
CHL ratio								
<i>r</i>	-0.31	-0.241	-0.46	0.327	0.072	0.07	0.091	0.021
<i>P</i>	.016	.061	<.001	.010	.581	.594	.487	.874
RI thickness								
<i>r</i>	0.033	-0.021	0.003	0.038	-0.01	-0.27	-0.17	-0.23
<i>P</i>	.803	.873	.984	.77	.93	.038	.199	.081
RI ratio								
<i>r</i>	0.072	0.046	0.126	-0.01	-0.06	-0.01	-0.02	-0.04
<i>P</i>	.579	.722	.332	.971	.651	.955	.907	.759
AR thickness								
<i>r</i>	-0.28	-0.152	-0.22	0.456	-0.05	-0.05	0.004	-0.03
<i>P</i>	.028	.243	.088	<.001	.704	.708	.976	.848
AR ratio								
<i>r</i>	-0.03	-0.016	-0.2	0.057	0.29	0.045	0.122	0.099
<i>P</i>	.809	.904	.13	.66	.024	.728	.348	.446
Effusion of LHBT sheath								
<i>r</i>	-0.341	-0.249	-0.18	0.382	0.031	-0.22	-0.25	-0.25
<i>P</i>	.007	.053	.165	.002	.811	.089	.057	.049
Hypervascularity in the RI								
<i>r</i>	0.039	-0.006	-0.041	0.163	0.004	0.095	0.195	0.161
<i>P</i>	.766	.963	.752	.209	.978	.468	.132	.215

^aBolded *P* values indicate statistically significant differences between groups ($P < .05$). AR, axillary recess; CHL, coracohumeral ligament; LHBT, long head of biceps tendon; RI, rotator interval; SPADI, Shoulder Pain and Disability Index; VAS, visual analog scale.