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Abbreviation:
CHL = coracohumeral ligament

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Frozen Shoulder: MR Arthrographic Findings[1]

PURPOSE: To evaluate the magnetic resonance (MR) arthrographic findings in patients with frozen shoulder.

MATERIALS AND METHODS: Preoperative MR arthrograms of 22 patients (six women, 16 men; mean age, 54.7 years) with frozen shoulder treated with arthroscopic capsulotomy were compared with arthrograms of 22 age- and sex-matched control subjects without frozen shoulder. The thickness of the coracohumeral ligament (CHL) and the joint capsule, as well as the volume of the axillary recess, were measured (Mann-Whitney test). Abnormalities in the CHL, subcoracoid fat, superior glenohumeral ligament, superior border of the subscapularis tendon, long biceps tendon, and subscapularis recess were analyzed in consensus by two blinded radiologists (χ^2 test).

RESULTS: Patients with frozen shoulder had a significantly thickened CHL (4.1 mm vs 2.7 mm in controls) and a thickened joint capsule in the rotator cuff interval (7.1 mm vs 4.5 mm; $P < .001$ for both comparisons, Mann-Whitney test) but not in the axillary recess. The volume of the axillary recess was significantly smaller in patients with frozen shoulder than in control subjects ($P = .03$, Mann-Whitney test). Thickening of the CHL to 4 mm or more had a specificity of 95% and a sensitivity of 59% for diagnosis of frozen shoulder. Thickening of the capsule in the rotator cuff interval to 7 mm or more had a specificity of 86% and a sensitivity of 64%. Synovitis-like abnormalities at the superior border of the subscapularis tendon were significantly more common in patients with frozen shoulder than in control subjects ($P = .014$, χ^2 test). Complete obliteration of the fat triangle between the CHL and the coracoid process (subcoracoid triangle sign) was specific (100%) but not sensitive (32%).

CONCLUSION: Thickening of the CHL and the joint capsule in the rotator cuff interval, as well as the subcoracoid triangle sign, are characteristic MR arthrographic findings in frozen shoulder.

The term *frozen shoulder* was used in 1934 by Codman (1). Clinical symptoms were slow onset of pain, inability to sleep on the affected arm, and restriction of both active and passive elevation and external rotation. In 1945, Neviaser (2) described characteristic synovial changes in the glenohumeral joint in patients with frozen shoulder and suggested the term *adhesive capsulitis*. He reported that the contracted capsule peeled from the humeral head like "adhesive plaster from skin." The estimated prevalence of frozen shoulder is 2%–3% (3–5) in the general population and 5%–6% in patients evaluated by shoulder surgeons (6,7). Patients are commonly 40–70 years old and predominantly female (8). Frozen shoulder may be idiopathic, preceded by trauma, or associated with diabetes mellitus or conditions such as Dupuytren disease (9) or with cardiac surgery (10). Treatment options include physical therapy, intraarticular corticosteroid injection, closed mobilization with anesthesia, and capsulotomy.

Magnetic resonance (MR) imaging is widely used to assess shoulder pain. A large number of publications have described the MR imaging assessment of the rotator cuff, labrum, capsule, and biceps tendon (11–20), and abnormalities of these structures are frequently described in radiology reports. The diagnosis of frozen shoulder is probably less frequent, but recognition of this abnormality has an important effect on therapeutic decisions and may prompt invasive therapy, such as manipulation during anesthesia, or arthroscopic capsular release.

The MR literature is relatively sparse with regard to frozen shoulder (21–25). Thickening of the joint capsule in the axillary recess has been described as a characteristic sign of frozen shoulder (23), but this characterization has not been confirmed by other investigators (24) and, moreover, is not in agreement with the orthopedics literature. Studies based on findings at arthroscopy (9,26–28) and at open surgery (29–31) have shown that the main abnormalities in patients with frozen shoulder were inflammation of extraarticular tissue in the region of the rotator cuff interval (bordered superiorly by the anterior margin of the supraspinatus tendon and inferiorly by the superior border of the subscapularis tendon) (32), synovitis at the anterosuperior glenohumeral joint, and thickening of the coracohumeral ligament (CHL).

Thickening of the joint capsule in the axillary recess as seen on standard MR images (ie, MR images obtained without the injection of intraarticular contrast material) may not relate to hypertrophy or scarring but rather to a normal appearance of the capsule when not under tension. If this hypothesis is correct, MR arthrography may be more reliable for measurement of capsular thickness. A previously published study in which patients with frozen shoulder were assessed by using MR arthrography did not identify any specific findings; the number of patients was relatively small, however, and no surgical correlation was available (24). The purpose of our study, therefore, was to evaluate the MR arthrographic findings in patients with frozen shoulder.

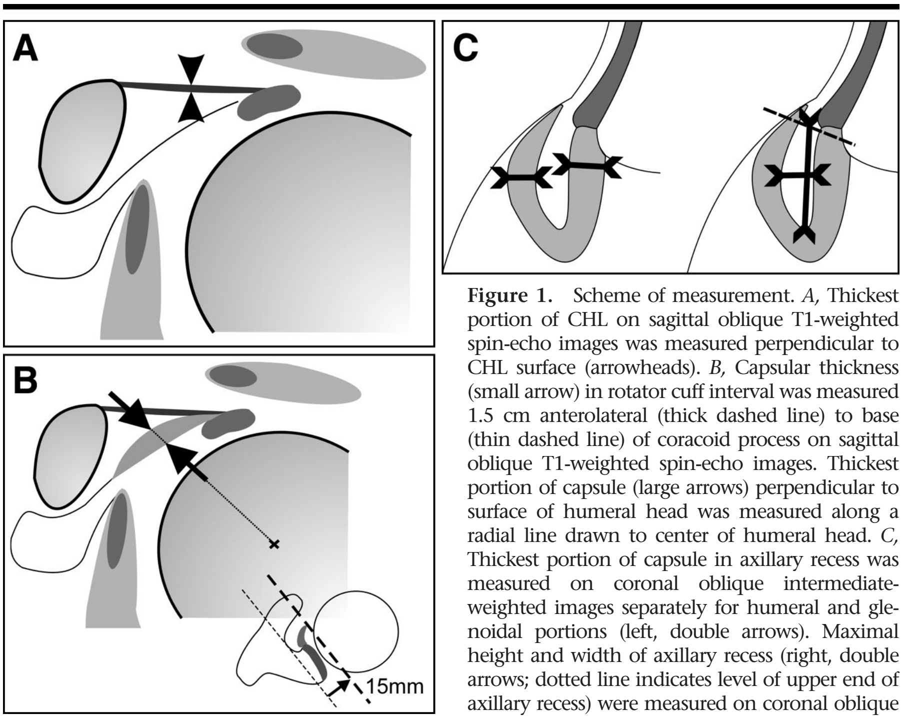


Figure 1. Scheme of measurement. *A,* Thickest portion of CHL on sagittal oblique T1-weighted spin-echo images was measured perpendicular to CHL surface (arrowheads). *B,* Capsular thickness (small arrow) in rotator cuff interval was measured 1.5 cm anterolateral (thick dashed line) to base (thin dashed line) of coracoid process on sagittal oblique T1-weighted spin-echo images. Thickest portion of capsule (large arrows) perpendicular to surface of humeral head was measured along a radial line drawn to center of humeral head. *C,* Thickest portion of capsule in axillary recess was measured on coronal oblique intermediate-weighted images separately for humeral and glenoidal portions (left, double arrows). Maximal height and width of axillary recess (right, double arrows; dotted line indicates level of upper end of axillary recess) were measured on coronal oblique images, and depth was measured on corresponding transverse images (not shown).

MATERIALS AND METHODS

Patients and Control Subjects

Between January 1998 and April 2003, a total of 142 patients with frozen shoulder were treated with arthroscopic capsulotomy at our institution. Twenty-two patients (six women, 16 men) were included in our retrospective analysis on the basis of the following criteria: *(a)* clinical diagnosis of frozen shoulder, surgical confirmation of the diagnosis (thickened capsule and synovitis in the area of the rotator cuff interval), and treatment with arthroscopic capsulotomy; *(b)* arthroscopic capsulotomy performed less than 3 months after MR arthrography; and *(c)* MR arthrography of the shoulder performed at our institution according to a standardized protocol. Of the 120 excluded patients, 84 did not undergo capsulotomy within 3 months after MR arthrography and 36 did not undergo MR arthrography at our institution.

Our institutional review board does not require its approval or informed consent for the review of patient records or images. Patient rights are protected by a law that requires patients to be informed at the time of examination about the possibility that their medical records and radiographs will be reviewed for scientific purposes.

The patients' ages ranged from 31 to 77 years (mean, 54.7 years). The age range among women was 45–77 years (mean, 61.8 years) and among men was 31–63 years (mean, 52.1 years). Five patients had no history of trauma or prior surgery, 12 patients had prior shoulder trauma, and five patients developed frozen shoulder after shoulder surgery. None of the patients had diabetes mellitus or systemic inflammatory disease. All patients underwent conservative therapy before capsulotomy. The mean duration of symptoms was 11 months (range, 3–24 months). Prior to capsulotomy, MR arthrography was performed in all patients to demonstrate additional pathologic conditions that might influence the surgical procedure. The referring clinician initiated MR arthrography to rule out an additional rotator cuff tear in 20 patients with frozen shoulder and to rule out an additional lesion of the long biceps tendon in two patients. At arthroscopy, all patients showed signs of synovitis in the area of the rotator cuff interval. Eight patients had an intact rotator cuff. Three patients had a full-thickness tear of both the supraspinatus and the infraspinatus tendons, seven patients had a full-thickness supraspinatus tendon tear, and four patients had a partial-thickness tear of the supraspinatus tendon. In five patients an additional partial or complete tear of the subscapularis tendon was present. In one patient the tendon of the long head of the biceps was torn.

The control group consisted of 22 subjects (matched to the 22 patients) who underwent arthroscopy and MR arthrography no more than 3 months prior to surgery but who did not show any clinical or arthroscopic signs of frozen shoulder. Matching criteria for control subjects were age (range, 28–77 years; mean, 54.9 years; range in women, 47–77 years; mean in women, 61.0 years; range in men, 28–74 years; mean in men, 52.6 years), sex (six women, 16 men), and medical history (five without prior trauma or surgery, 12 with prior trauma, and five with prior surgery). The indications for arthroscopy were rotator cuff tear (n = 7), shoulder impingement syndrome (n = 13), instability (n = 1), and suspected lesion of the reflection pulley

TABLE 1
Quantitative Criteria

Criterion	Patients with Frozen Shoulder		Control Group		
	Mean	Range	Mean	Range	*P* Value*
Thickness of CHL (mm)†	4.1	3.0–6.0	2.7	0–4.0	<.001
Thickness of capsule in rotator cuff interval (mm)†	7.1	4.0–11.0	4.5	2.0–7.0	<.001
Thickness of capsule in axillary recess (mm)†					
Humeral side	3.9	2.0–6.0	3.6	2.0–6.0	.40
Glenoidal side	4.1	3.0–6.0	3.8	2.0–7.0	.18
Axillary recess					
Volume (mL)‡	0.53	0.07–1.36	0.88	0.18–2.11	.026
Height (mm)	8.7	6.0–13.0	10.6	6.0–16.0	.017
Width (mm)	4.3	2.0–9.0	6.0	2.0–12.0	.033
Depth (mm)	26.6	16.0–33.0	25.6	18.0–35.0	.34

* Result of the Mann-Whitney test.
† See Figure 1 for method of measurement.
‡ Calculated by using the formula for elliptical volume $v = 0.52(hwd)$.

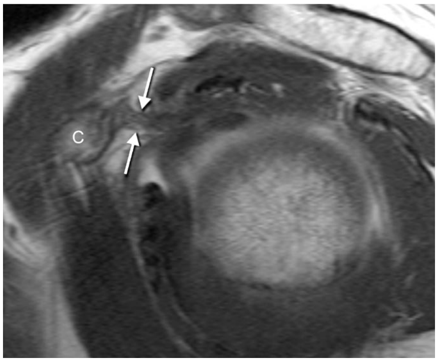


Figure 2. Sagittal oblique T1-weighted (700/12) image shows thickened CHL (arrows) in a 57-year-old patient with frozen shoulder. *C* = coracoid process.

of the biceps tendon ($n = 1$). At arthroscopy, eight control subjects had an intact rotator cuff. Three of these eight subjects had a superior labrum anterior-posterior lesion (12,14), and one had a pulley lesion (lesion of the common insertion of the CHL and superior glenohumeral ligament and the superior border of the subscapularis tendon) (33). Five control subjects had a full-thickness tear, and nine had a partial-thickness tear of the supraspinatus tendon. Three subjects had a partial- or full-thickness tear of the subscapularis tendon.

MR Imaging Protocol

MR imaging was performed with a 1.0- or 1.5-T system (Expert or Symphony; Siemens Medical Solutions, Erlangen, Germany). Informed consent was obtained from the patients before MR arthrography. This method was approved by the ethics committee of the hospital and by the responsible state agency. According to a standard protocol, fluoroscopically guided injection of a maximum of 12 mL of diluted gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany) with a concentration of 2 mmol/L was performed by a musculoskeletal radiologist (J.H., M.Z.) with at least 5 years of experience in arthrography. Injection volume was lower when patients indicated increased pressure or pain. The shoulder was placed in a dedicated receive-only shoulder coil. The arm position was standardized, with the thumb pointing upward. T1-weighted spin-echo images were obtained in the transverse plane (580–600/12–20 [repetition time msec/echo time msec], 3–4-mm section thickness, 160 × 160-mm field of view) and in the sagittal oblique plane, parallel to the glenohumeral joint (600–700/12, 4–5-mm section thickness, 160 × 160-mm field of view). Fat-suppressed T1-weighted spin-echo images were obtained in the coronal oblique plane, perpendicular to the glenohumeral joint space (777–800/12–20, 3–4-mm section thickness, 160 × 160-mm field of view). T2-weighted fast spin-echo images (3300–3500/95–98, 4-mm section thickness, 160 × 160-mm field of view) and intermediate-weighted fast spin-echo images (3300–3500/14–16, 4-mm section thickness, 160 × 160-mm field of view) were both obtained in the coronal oblique plane.

Analysis of MR Images

Quantitative and qualitative criteria for the diagnosis of frozen shoulder were defined on the basis of our analysis of the orthopedics literature related to frozen shoulder (8,9,26–32,34–37).

Quantitative criteria.—Measurements were obtained by a fellow in musculoskeletal radiology (B.M., with 2 years of experience in musculoskeletal radiology), who was blinded to the diagnosis. A picture archiving and communication system workstation (Image Devices, Idstein, Germany) was used. Measurements were obtained to the nearest one-tenth millimeter and then rounded to the nearest whole millimeter.

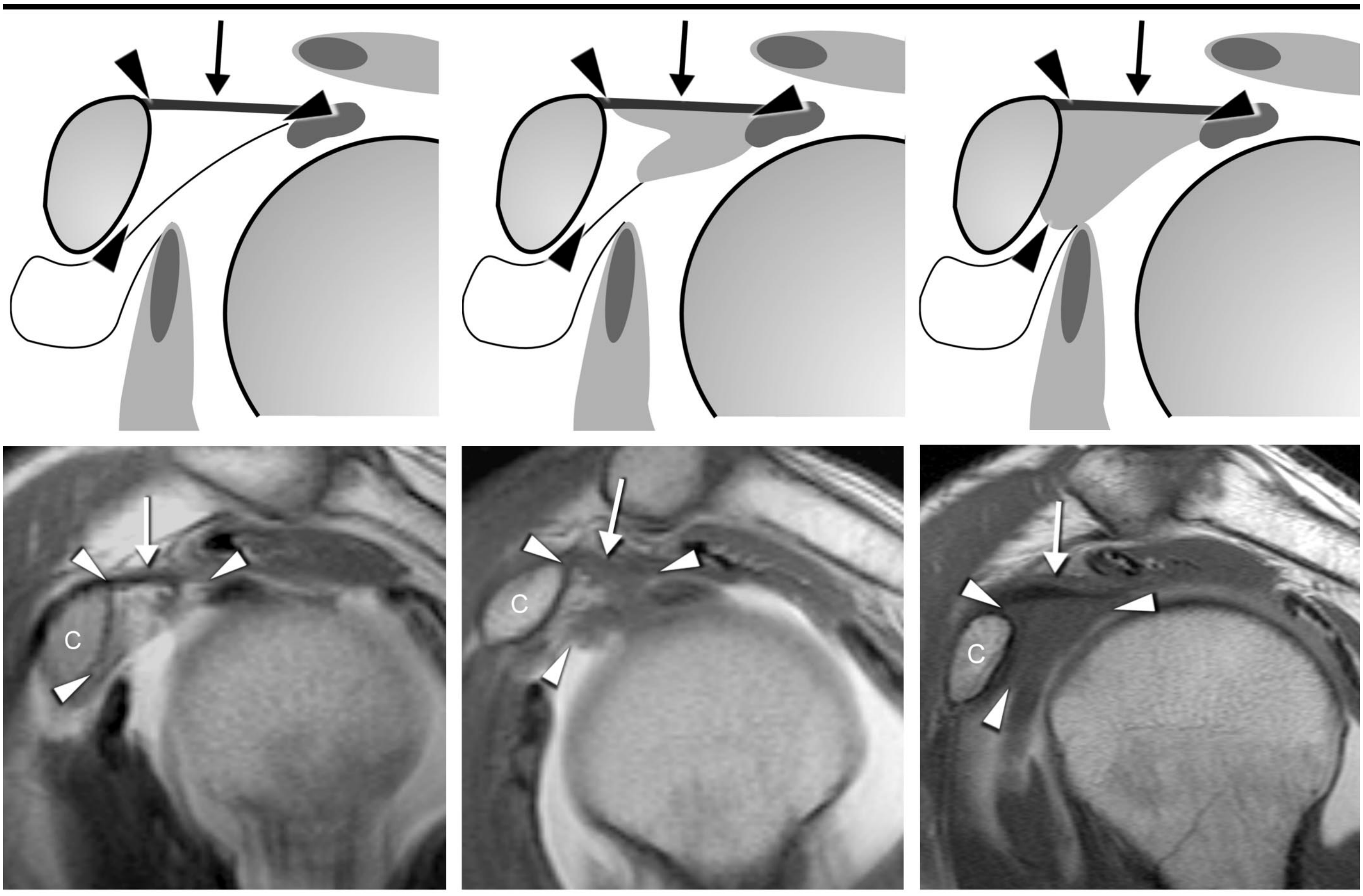
The thickest portion of the CHL was measured on sagittal oblique images (Fig 1). The thickest portion of the capsule was determined both in the rotator cuff interval and in the axillary recess (Fig 1). For measurement in the rotator cuff interval, the sagittal oblique image 1.5 cm lateral to the base of the coracoid process was used (Fig 1). Because the capsule commonly had an irregular form in this region, this measurement was not obtained perpendicular to the capsular surfaces but rather perpendicular to the surface of the humeral head, parallel to a radial line to the center of the humeral head (Fig 1b). In the axillary recess, measurements were obtained on coronal oblique images, on both the humeral and the glenoidal sides. The maximal height and width of the axillary recess were determined on coronal oblique images, and the depth of this structure was determined on transverse images. The volume of the axillary recess was calculated in milliliters by using the equation for elliptical volume, $v = 0.52(hwd)$, where h is height, w is width, and d is depth.

Qualitative criteria.—MR images were analyzed in consensus by two staff radiologists with 10 years (M.Z.) and 5 years (C.W.A.P.) of experience in musculoskeletal radiology, who were blinded to the diagnosis and who did not participate in the quantitative assessment. The following qualitative criteria were evaluated and characterized as present or absent: *(a)* abnormalities of the CHL, characterized by signal intensity changes and/or contour irregularity, *(b)* lesion of the superior glenohumeral ligament, characterized by signal intensity changes and/or contour irregularity, *(c)* partial or complete obliteration of the subcoracoid fat triangle, *(d)* synovitis-like abnormality at the superior border of the subscapularis tendon, *(e)* synovitis-like abnormality at the articular surface of the subscapu-

TABLE 2
Qualitative Criteria

Criterion	Patients with Frozen Shoulder (n = 22)	Control Group (n = 22)	P Value*
Abnormality of CHL†	18 (82)	12 (55)	.052
Abnormality of superior glenohumeral ligament†	20 (91)	17 (77)	.21
Obliteration of subcoracoid fat triangle			.005
Partial	10 (45)	9 (41)	
Complete	7 (32)	0	
Synovitis-like abnormality at superior border of subscapularis tendon	13 (59)	5 (23)	.014
Synovitis-like abnormality in articular surface at subscapularis muscle	6 (27)	3 (14)	.26
Synovitis-like abnormality around long biceps tendon	15 (68)	10 (45)	.13
Synovitis-like abnormality in subscapularis recess	14 (64)	8 (36)	.07
Contrast material leakage along subscapularis muscle	4 (18)	4 (18)	1.00

Note.—Data are numbers of study subjects. Numbers in parentheses are percentages of the study group.
* Result of the χ^2 test.
† Abnormality was characterized by signal intensity change and/or contour irregularity.



a. b. c.

Figure 3. Line drawings (top row) and corresponding sagittal oblique T1-weighted (600/12) images (bottom row) of subcoracoid fat triangle. Borders of the triangle (arrowheads) are defined anterosuperiorly by the coracoid process (*C*), superiorly by the CHL (arrow), and posteroinferiorly by the joint capsule. **(a)** Normal anatomy in a subject without frozen shoulder. **(b)** Partial obliteration of subcoracoid fat triangle in a 57-year-old patient with frozen shoulder. **(c)** Complete obliteration of subcoracoid fat triangle (ie, subcoracoid triangle sign) in a 55-year-old patient with frozen shoulder.

laris tendon, *(f)* synovitis-like abnormality around the long biceps tendon, *(g)* synovitis-like abnormality in the subscapularis recess, and *(h)* leakage of contrast material along the subscapularis muscle. The subcoracoid fat triangle was analyzed in the sagittal oblique plane. The borders of the triangle were defined by the coracoid process anterosuperiorly, by the CHL superiorly, and by the joint capsule posteroinferiorly. Synovitis-like abnormalities were diag-

TABLE 3
Diagnostic Value of Significant Quantitative and Qualitative Criteria for Diagnosis of Frozen Shoulder

Criterion	Sensitivity		Specificity	
	Percentage*	95% CI (%)	Percentage*	95% CI (%)
Quantitative†				
≥4-mm thickness of CHL	59 (13/22)	36, 79	95 (21/22)	77, 100
≥7-mm thickness of capsule in rotator cuff interval	64 (14/22)	41, 83	86 (19/22)	65, 97
Qualitative				
Abnormality of CHL‡	82 (18/22)	60, 95	45 (10/22)	24, 68
Obliteration of subcoracoid fat triangle				
Present (partial or complete)	77 (17/22)	55, 92	59 (13/22)	36, 79
Complete	32 (7/22)	14, 55	100 (22/22)	85, 100
Synovitis-like abnormality at superior border of subscapularis tendon	59 (13/22)	36, 79	77 (17/22)	55, 92

Note.—CI = confidence interval.
* Numbers from which percentages were derived are given in parentheses.
† See Figure 1 for method of measurement.
‡ Abnormality was characterized by signal intensity change and/or contour irregularity.

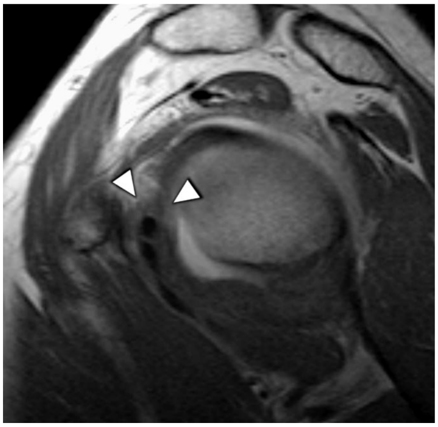


Figure 4. Sagittal oblique T1-weighted (700/12) image shows synovitis-like abnormality (arrowheads) with blurred borders and intermediate signal intensity at superior border of subscapularis tendon in a 55-year-old patient with frozen shoulder.

nosed on the basis of evidence of synovial irregularity and/or thickening.

Statistical Analysis

Surgical findings were used as the standard of reference. Qualitative criteria were compared by using the χ^2 test. Continuous data were analyzed with the Mann-Whitney test or the Kruskal-Wallis test (two-tailed). Sensitivity and specificity, with 95% confidence intervals, were calculated for the qualitative criteria and for different cutoff values of measurement of the thickness of the CHL and the capsule in the rotator cuff interval.

A P value of less than .05 was considered to indicate a statistically significant difference.

RESULTS

Quantitative Criteria

Patients with frozen shoulder had a significantly thicker CHL than did control subjects (mean, 4.1 vs 2.7 mm; range, 2.5–6.0 vs 0.0–4.0 mm; $P < .001$) (Table 1, Fig 2). In one subject in the control group, the CHL was absent and was classified as abnormal. A CHL diameter of 4 mm or greater indicated the diagnosis of frozen shoulder with a specificity of 95% and a sensitivity of 59%. In patients with frozen shoulder, the capsule in the rotator cuff interval was significantly thickened (7.1 vs 4.5 mm; range, 4.0–11.0 vs 2.0–7.0 mm; $P < .001$). A threshold value of 7 mm or more had a specificity of 86% and a sensitivity of 64% for the diagnosis of frozen shoulder. There was no significant difference in capsular thickness in the axillary recess either on the humeral side (mean, 3.9 mm in patients vs 3.6 mm in control subjects) or on the glenoidal side (mean, 4.1 mm in patients vs 3.8 mm in control subjects). The volume of the axillary recess, however, was significantly smaller in patients with frozen shoulder than in control subjects (mean, 0.53 vs 0.88 mL, $P = .03$) because of the significantly smaller height and width of the axillary recess in patients.

Qualitative Criteria

Partial or complete obliteration of the subcoracoid fat triangle was significantly more frequent in patients with frozen shoulder compared with control subjects (77% vs 41%, $P = .005$) (Table 2, Fig 3). Complete obliteration of the fat triangle under the CHL and the coracoid process was highly specific (100%) but not sensitive (32%) for the diagnosis of frozen shoulder (Table 3, Fig 3c). Synovitis-like abnormality on the superior border of the subscapularis tendon was significantly more frequent in patients than in control subjects (59% vs 23%, $P = .014$) (Fig 4). Lesions of the CHL and synovitis-like abnormalities in the subscapularis recess were seen more frequently in patients than in control subjects (82% vs 55% and 64% vs 36%, respectively); these differences, however, were not significant ($P = .052$ and $P = .07$, respectively). Patients were not significantly different from control subjects with regard to synovitis-like abnormalities at the articular surface of the subscapularis tendon or around the long biceps tendon, with regard to superior glenohumeral ligament abnormalities, or with regard to the prevalence of contrast material leakage along the subscapularis muscle ($n = 4$).

No significant differences were found between the three subgroups of patients with frozen shoulder (idiopathic, posttraumatic, or postoperative cause) in any of the quantitative or qualitative criteria ($P > .2$).

DISCUSSION

The precise pathogenesis of frozen shoulder is not known. Histologic and immunocytochemical investigations have demonstrated active fibroblastic proliferation accompanied by transformation of fibroblasts to myofibroblasts (9).

During surgery, inflammatory and fibrotic changes have been found in patients with frozen shoulder. Neer et al (29) suggested that a tightened CHL restricts external rotation in patients with frozen shoulder. Several investigators confirmed this hypothesis on the basis of data obtained during arthroscopy (27,31) and open surgery (30). Contraction of the CHL and thickening of the joint capsule in the rotator cuff interval were found. Other investigators observed synovitis around the tendon origin of the long head of the biceps and the opening of the subscapularis recess in patients with frozen shoulder (26,28).

The radiology literature thus far has only partly addressed these surgical findings. Decreased joint capacity, obliteration of the axillary recess, and variable filling of the biceps tendon sheath have been described on the basis of arthrographic data (38). Emig et al (23) reported, on the basis of a retrospective MR analysis that included 10 patients with frozen shoulder, that capsular thickening of more than 4 mm in the axillary recess was a useful criterion for the diagnosis of frozen shoulder. This result was not confirmed by the results of an MR arthrography study performed by Manton et al (24) in nine patients with frozen shoulder. In neither of these two studies was any abnormality found in the rotator cuff interval. Conventional arthrography, however, was used as the standard of reference in both studies (except in one patient in whom findings were surgically confirmed), and this may have resulted in the underestimation of abnormalities in the rotator cuff interval. On MR images obtained after the intravenous injection of gadopentetate dimeglumine, Carrillon et al (21) reported enhancement of the joint capsule and synovial membrane in the rotator cuff interval and in the axillary recess. Tamai and Yamato (25) demonstrated similar enhancement in the axillary recess. Connell et al (22) found enhanced fibrovascular tissue in the rotator cuff interval, that encased the CHL and superior glenohumeral ligament in 22 patients and the biceps anchor in 17 of 24 patients with surgical correlation.

In our patient population, the CHL and the capsule in the rotator cuff interval were both significantly thickened in patients with frozen shoulder. Moreover, in most (17 of 22) patients the subcoracoid fat triangle was obliterated by the inflammatory process. The complete obliteration of this fat triangle was specific for the diagnosis of frozen shoulder. This subcoracoid triangle sign is easy to assess on sagittal oblique images and thus is helpful for daily routine work. The sensitivity of the subcoracoid triangle sign, however, is low (32%). The synovitis-like abnormalities at the superior border of the subscapularis tendon or the opening of the subscapularis recess that were found in our study were similar to previously described orthopedic findings (26,28). Many patients with frozen shoulder also had synovitis-like abnormalities around the long biceps tendon. This finding, however, was not significantly different from findings in the control group ($P = .13$).

Like the data obtained from a study of conventional arthrography (38), our study results confirmed a significantly smaller volume of the axillary recess in patients with frozen shoulder than in control subjects. This finding was previously attributed to adhesions (2). A number of arthroscopic investigations, however, have failed to demonstrate adhesions in the axillary recess (26,28,30,31,34). Thus, the finding of smaller recess volume in patients with frozen shoulder may not represent a true abnormality but rather a reduced volume of intraarticular contrast material or early leakage of contrast material caused by weakening in the joint capsule. The latter of these two possible explanations, however, is not supported by our data: In both study groups, images of only four patients (18%) demonstrated contrast material leakage. The exact amount of contrast material injected into each patient was not documented, but the 12 mL required by our standard protocol was reduced only in patients who reported increased pressure and/or pain.

In our MR arthrographic study, no significant thickening of the joint capsule in the axillary recess was found in patients with frozen shoulder, contrary to the findings reported by Emig et al (23), who used standard MR imaging. On the basis of this difference and on the basis of surgical data, we believe that capsular thickening in the axillary recess should not be diagnosed on MR images obtained without the injection of intraarticular contrast material.

To ensure the availability of surgical correlation in all patients, we included in our study only patients who underwent arthroscopic capsulotomy. We acknowledge that patients with severe frozen shoulder therefore may be overrepresented in our series and that our MR findings may be less typical in a more diverse patient population.

In conclusion, MR arthrography reveals characteristic findings in patients with frozen shoulder. Thickening of the CHL and the capsule at the rotator cuff interval and complete obliteration of the fat triangle under the coracoid process (subcoracoid triangle sign) are the most characteristic MR findings in frozen shoulder.

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