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SHOULDER

Correlations of magnetic resonance imaging findings with clinical symptom severity and prognosis of frozen shoulder

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Abstract

Purpose To evaluate the correlation between indirect magnetic resonance (MR) arthrographic imaging findings and the clinical symptoms and prognosis of patients with frozen shoulder.

Methods Indirect MR arthrography was performed for 52 patients with primary frozen shoulder (mean age 55.1 ± 9.0 years) and 52 individuals without frozen shoulder (mean age 53.1 ± 10.7 years); capsular thickening and enhancement of the axillary recess as well as soft tissue thickening of the rotator interval were evaluated. Clinical symptom severity was assessed using the Visual Analogue Scale for Pain (VAS Pain), simple shoulder test (SST), Constant score, American Shoulder and Elbow Surgeons (ASES) score, and range of motion (ROM). At 6-month follow-up, we evaluated whether MR arthrography findings correlated with the clinical symptoms and prognosis.

Results Capsular thickening and enhancement of the axillary recess as well as soft tissue thickening of the rotator interval were significantly greater in the patient group than in the controls ($p < 0.001$). Capsular thickening of the axillary recess did not correlate with clinical symptoms or ROM (n.s.); however, capsular enhancement correlated with clinical symptom severity according to VAS Pain ($p = 0.005$), SST ($p = 0.046$), and ASES scores ($p = 0.009$). Soft tissue thickening of the rotator interval did not correlate with clinical symptom severity, but was associated with external rotation limitation ($p = 0.002$). However, none of the parameters correlated with clinical symptoms at 6-month follow-up.

Conclusions Indirect MR arthrography provided ancillary findings, especially with capsular enhancement, for evaluating clinical symptom severity of frozen shoulder, but did not reflect the prognosis. MR findings in frozen shoulder should not replace clinical judgments regarding further prognosis and treatment decisions.

Level of evidence IV.

Keywords Frozen shoulder · MR finding · Indirect MR arthrogram · Clinical symptom · Correlation

Introduction

Frozen shoulder is a condition characterized by limitations in both active and passive motion of the shoulder and the occurrence of more severe pain at night than during the day, with normal radiographs of the shoulder [25]. This is a disabling and sometimes severely painful condition that is commonly managed in the primary care setting [6]. Inflammation combined with a fibrotic reaction is the major underlying pathological change, leading to thickening, contraction, and subsequent adherence of the capsule and synovium, as well as the surrounding ligamentous structures [27]. Traditionally, the diagnosis and treatment decisions for frozen shoulder essentially depend on the clinical diagnosis, and only a few laboratory tests and radiological

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findings are used for its diagnosis. A few studies have reported characteristic magnetic resonance imaging (MRI) findings in patients with frozen shoulder and assessed the usefulness of these findings in diagnosing frozen shoulder with non-enhanced MRI, contrast-enhanced MRI, or direct MR arthrographic imaging [11, 18]. Thickened capsule and enhanced tissue on contrast-enhanced MRI have been described as typical findings of frozen shoulder. Other studies have determined the dimensions of the rotator interval based on direct measurements from dissected cadavers [12, 19].

Currently, MRI is frequently performed for patients with shoulder pain; in recent times, our understanding of radiological findings regarding shoulder pathologies has improved. In particular, indirect MR arthrography has become an effective evaluation tool for frozen shoulder since it closely reflects the hyperaemic pathological condition by gadolinium enhancement and demonstrates the thickened joint capsule [29]. However, a correlation between radiological findings and clinical factors in frozen shoulder has not been reported, and clinicians seldom use these radiological findings to assess frozen shoulder. Since frozen shoulder has a long clinical course with a poor prognosis in certain patients, we believe that it is crucial to identify the radiological findings related to the clinical symptoms and prognosis of frozen shoulder. That is, clarity regarding MRI findings in frozen shoulder and their correlations with the clinical symptoms would be useful for understanding the natural disease course as well as for individualizing and quantifying each patient's condition. However, to the best of our knowledge, no study has investigated the correlations between MRI findings and the clinical symptom severity and prognosis of frozen shoulder.

Therefore, the purpose of this study was to evaluate the correlation between indirect MR arthrographic imaging findings and the clinical symptoms and prognosis of frozen shoulder. The hypothesis was that MR findings reflected patients' clinical symptoms and could predict the prognosis of primary frozen shoulder.

Materials and methods

Patient selection

Seventy-six patients with frozen shoulder (adhesive capsulitis) who underwent indirect MR arthrography between 2011 and 2014 were initially evaluated. We included patients who first experienced shoulder symptoms (pain or discomfort) between 6 months and 1 year before MR evaluation as well as those who complained of progressive loss of shoulder motion (frozen phase of the condition). All patients had limited active and passive ranges of motion (ROM) in at least two directions (abduction and forward flexion <100°, external rotation <20°, or internal rotation <L3) [24]. Patients with secondary causes of frozen shoulder, such as rotator cuff tear or calcific tendinitis, and those with glenohumeral arthritis were excluded. We excluded 8 patients with a full-thickness rotator cuff tear, 10 with a partial-thickness rotator cuff tear, 2 with calcific tendinitis, and 2 with glenohumeral arthritis. No patient had a history of previous shoulder trauma or operation on the same shoulder, and none was in a worker's compensation status. Ultimately, 52 patients (mean [SD] age, 55.1 [9.0] years), 15 men and 37 women, were diagnosed with primary frozen shoulder (idiopathic adhesive capsulitis, group I) in the frozen phase and enrolled in this study. To compare the patients' radiological differences, a group of 52 patients who underwent indirect MR arthrography in our institution in the same study period but did not show limited ROM were included (non-frozen shoulder group) using random selection. These patients had minor shoulder pathology, such as rotator cuff tendinopathy, impingement, or bursitis; however, none of them had rotator cuff tear, calcific tendinitis, or glenohumeral arthritis, which were the exclusion criteria of this study. No significant differences in the demographic and baseline data were observed between groups I and II (Table 1). During the study period, all patients underwent conventional nonsurgical treatment, including medication and a home-based physical therapy exercise programme. However, none of the patients received local steroid injection or hydrodistention therapy. Medication comprised a non-steroidal anti-inflammatory drug (NSAID) and muscle relaxant agents for approximately 4 weeks. For physical therapy exercises, active-assisted ROM exercises, including stick exercise, were performed for approximately 10 weeks depending on the recovery of ROM; subsequently, muscle-strengthening exercises, including periscapular exercise, were performed.

Clinical variables

All data were prospectively collected by a clinical researcher (A.S.J.) who was blinded to the study design; this researcher had 3 years of experience in clinical scoring, including shoulder ROM measurement and data collection. The patients' demographic and other characteristics, including age, sex, dominant shoulder, symptom duration, smoking habit, and underlying disease (diabetes mellitus, hypertension, and thyroid disease), were recorded. The level of sports activity was defined as high (dynamic or contact sports such as boxing, basketball, rugby, or tennis), medium (static sports such as yoga or jogging), or low (mild or no sports activities) [3]. The work level was defined as high, medium, or low if the work involved heavy manual labour, manual labour with less physical activity, or sedentary physical activity, respectively [4].

Table 1 Demographic factors and clinical variables

Variable	Frozen shoulder group	Non-frozen shoulder group	*p* value
No. of patients	52	52	
Age	55.1 (9.0)	53.1 (10.7)	n.s.
Sex (male/female)	15:37	23:29	n.s.
Dominant side (dominant/non-dominant)	29:23	32:20	n.s.
Symptom duration (months)	8.4 (3.4)	9.2 (3.5)	n.s.
Diabetes (*n*)	8:44	6:46	n.s.
Hypertension (*n*)	11:41	12:40	n.s.
Thyroid disease (*n*)	4:48	3:49	n.s.
Smoking (*n*)	6:46	8:44	n.s.
Work level (low/medium/high)	13:16:23	11:24:17	n.s.
Level of sports activity (high/moderate/low)	20:15:17	19:22:11	n.s.
Overhead sports (yes/no)	5:47	8:44	n.s.

Values are presented as mean (standard deviation)

Clinical symptoms were evaluated at the time of inclusion in the study and at 6 months after the initial evaluation. The time gap between the initial evaluation of clinical symptoms and MR evaluation was <2 weeks in all patients. Clinical symptom severity was evaluated using the Visual Analogue Scale for Pain (VAS Pain; range 0–10, with 10 being the worst), shoulder ROM, and various scoring systems, namely the simple shoulder test (SST) [16], Constant score [5], and American Shoulder and Elbow Surgeons (ASES) score [21]. At 6-month follow-up, we evaluated whether MRI findings correlated with the clinical symptoms and prognosis of frozen shoulder.

Passive shoulder ROM, which consisted of forward flexion, abduction, external rotation at the side, and internal rotation at the back, was measured using a goniometer by the same clinical researcher (A.S.J.), with the patients in the supine position (except for internal rotation at the back) to stabilize the scapula by letting the patient's body weight minimize compensatory scapular motion. Internal rotation at the back was examined with the patients in a seated position. Passive abduction was measured in degrees between the arm and thorax in the scapular plane. External rotation at the side was measured in degrees between the thorax and forearm, with the arm held in an adducted position at 90° of flexion at the elbow. Internal rotation at the back was measured at the vertebral level as reached with the tip of the thumb. For the analysis, the vertebral level was numbered serially as follows: 12 for the 12th thoracic vertebra, 13 for the 1st lumbar vertebra, 17 for the 5th lumbar vertebra, and 18 for any level below the sacral region [23].

MRI protocol

All MR images were acquired digitally using a picture archiving and communication system (PACS) in the digital imaging and communications in medicine (DICOM) format. Image assessments were subsequently performed using the PACS software (Impax; Agfa, Antwerp, Belgium) with a 3-T Signa HDxt MRI scanner/Discovery MR750w system (General Electric, Milwaukee, WI, USA). Indirect MR arthrography, which is more sensitive than conventional MRI and less invasive and cumbersome than direct MR arthrography [10, 30], is known to be a reliable diagnostic tool for the investigation of suspected rotator cuff tear [13] and labral pathology [9] as well as for accurate visualization of frozen shoulder [29], although its use is limited. Therefore, indirect MR arthrography is used as the imaging modality for shoulder pathology in our institution. Indirect MR arthrography was initiated after intravenous injection of gadobutrol (0.1 mmol/kg body weight; Gadovist; Schering) into an antecubital vein.

Immediately after the injection of the contrast medium, the patient was instructed to move the shoulder for 15 min. The patient was positioned for imaging with the humerus in a neutral position and the thumb pointing upward. Indirect MR arthrography was performed using the following imaging sequences: Fat-suppressed T1-weighted turbo spin-echo sequences were performed in the axial and coronal oblique planes [repetition time (TR) range/echo time (TE) range 434–565/18–24; section thickness 3 mm; field of view (FOV) 15 cm; matrix size 224 × 224], parallel to the long axis of the supraspinatus tendon and in the sagittal oblique plane. In addition, T1-weighted (TR/TE range 471–477/8), T1 contrast-enhanced (TR/TE range 715–724/15), T2-weighted coronal (TR/TE range 4137–4337/83–84), and T1-weighted sagittal images (TR/TE range 625–629/8) were obtained. The slice thickness was 3 mm in all of the images. We obtained 20 × 20 cm FOV images for the coronal view cases and 18 × 18 cm FOV images for the other cases.

Image interpretation

Three MR findings, i.e. the capsular thickness of the axillary recess, capsular enhancement of the axillary recess, and soft tissue thickening of the rotator interval, were assessed. The objective measurement methods used for these three MR findings have been reported in previous studies [14, 20, 28, 29].

First, the degree of capsular thickening of the axillary recess was measured on a coronal T2-weighted MR image, which showed the widest portion of the humerus and glenoid, for the widest joint capsule thickness (Fig. 1) [17]. Next, the degree of capsular enhancement of the axillary recess was measured on a coronal T1 contrast-enhanced MR image. Compared with the surrounding muscles, low or maintained capsular enhancement was classified as grade 0; subtle contrast enhancement, as grade 1; and definite and strong enhancement, as grade 2 (Fig. 2) [14, 29]. Finally, the soft tissue thickness of the rotator interval was measured on sagittal T1-weighted MR images. This enhancement was classified as grade 0 if the triangular shape outlined by the coracoid process, coracohumeral ligament, and capsular membrane was intact; as grade 1 if the coracohumeral ligament had hypertrophy without fat tissue obliteration on the triangular structure; and as grade 2 if complete fat tissue obliteration was noted (Fig. 3) [14, 20, 28]. To assess interobserver reliability, one orthopaedic surgeon with over 8-year experience and one musculoskeletal radiologist with over 9-year experience separately and randomly measured the capsular thickness measurement, axillary recess enhancement, and soft tissue rotator interval thickness for all patients. Each rater was unaware of the other rater's ratings. For intraobserver reliability, one rater (an orthopaedic surgeon with more than 8-year experience) performed a second measurement with the same images 2 weeks after the first measurement without knowledge of the first rating. The inter- and intraobserver reliabilities were evaluated using the interclass correlation coefficient (ICC) with a two-way random model with absolute agreement.

The approval of the Kyungpook National University Hospital's institutional review board was obtained for this study protocol (KNUH 2014-12-015).

Statistical analysis

Mean values were compared using Student's *t* test for continuous variables and the Chi-square test or Fisher's exact test for categorical variables to determine the differences between groups. Correlation analysis was performed between capsular thickness of the axillary recess and various clinical variables using Pearson's correlation coefficient. In addition, the relationship of the capsular enhancement of the axillary recess and the soft tissue thickness of rotator interval with various clinical variables was determined using one-way analysis of variance and Scheffe's multiple comparison test for post hoc analysis. SPSS version 12.0 software (SPSS, Chicago, IL, USA) was used, and values of $p < 0.05$ were considered statistically significant. The required sample size to detect a significant difference in the capsular thickness of the axillary recess (mean difference of 3.3 mm, standard deviation of 2.8 mm) for a power of 90 % at a type I error level of 0.05 was 17 patients in each group; this was calculated according to previous studies [7, 14].

Fig. 1 We measured the degree of capsular thickening of the axillary recess on a coronal T2-weighted MR image, which showed the widest portion of the humerus and glenoid, for measuring the widest joint capsule thickness. In this case, the capsular thickness at the axillary recess is 8.39 mm

Results

The interobserver reliability was good, with an interclass correlation coefficient (ICC) of 0.733 for the capsular thickening of the axillary recess ($p < 0.001$), 0.770 for the grade of capsular enhancement of the axillary recess ($p < 0.001$), and 0.746 for the grade of soft tissue thickening in the rotator interval ($p < 0.001$). In addition, the ICC for intraobserver reliability was 0.766 for the capsular thickening of the axillary recess ($p < 0.001$), 0.773 for the grade of capsular enhancement of the axillary recess ($p < 0.001$), and 0.801 for the grade of soft tissue thickening in the rotator interval ($p < 0.001$), all of which were acceptable [8].

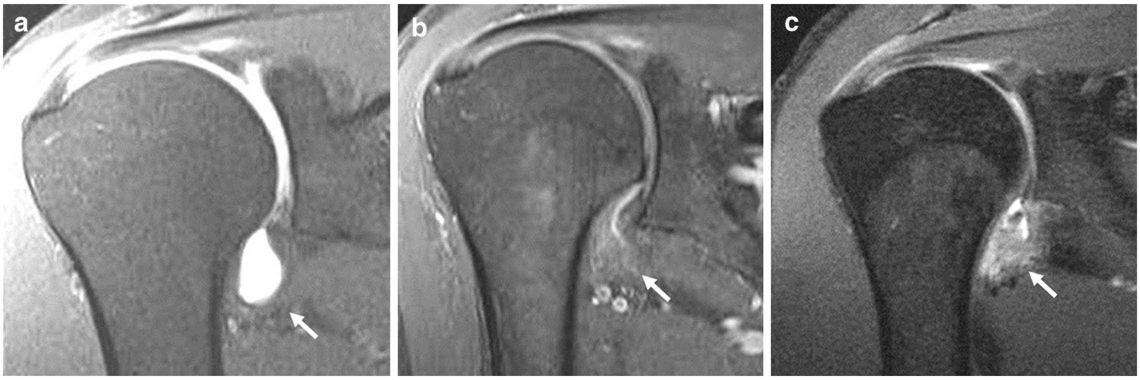

Fig. 2 We measured the degree of capsular enhancement of the axillary recess on a coronal T1 contrast-enhanced MR image. Compared with the surrounding muscles, capsular enhancement was classified as grade 0 when low or unchanged enhancement was observed (**a**), grade 1 when subtle contrast enhancement was observed (**b**), and grade 2 when definite and strong enhancements were observed (**c**)

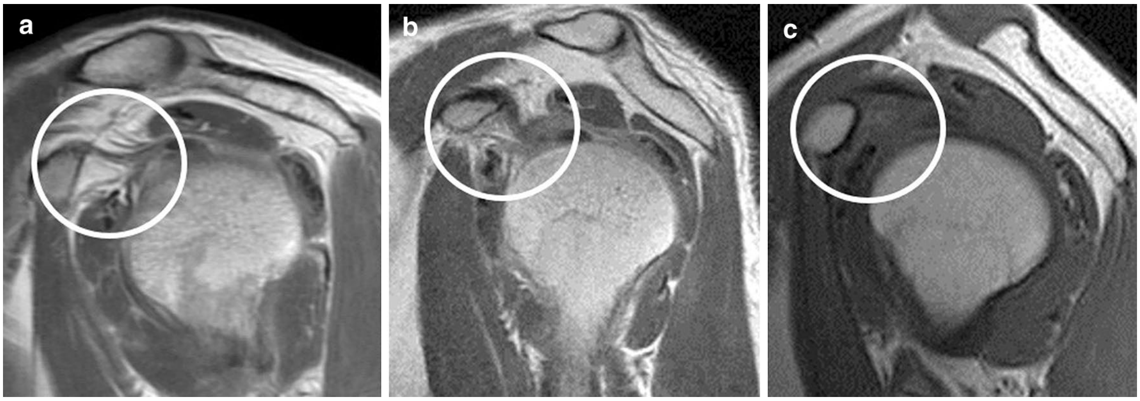

Fig. 3 Finally, the soft tissue thickness of the rotator interval was measured on sagittal T1-weighted MR images. We classified the enhancement as grade 0 if the triangular shape *outlined* by the coracoid process, coracohumeral ligament, and capsular membrane was intact (**a**), as grade 1 if the coracohumeral ligament had hypertrophy without fat tissue obliteration on the triangular structure (**b**), and as grade 2 if complete fat tissue obliteration was present (**c**)

Table 2 Differences in magnetic resonance imaging findings according to the study group

	Frozen	Non-frozen	*p* value
Capsular thickness of the axillary recess (mm)	7.1 (1.8)	3.1 (0.8)	<0.001
No. of capsule thickness >3 mm	52 (100 %)	32 (61.5 %)	<0.001
Capsular enhancement of the axillary recess (grade 0/1/2)	4:15:33	42:10:0	<0.001
Soft tissue thickening of the rotator interval (grade 0/1/2)	4:19:29	29:18:5	<0.001

Values are presented as mean (standard deviation)

Group I (frozen shoulder group) and group II (non-frozen shoulder group) did not differ significantly in terms of demographic factors (Table 1). Capsular thickening, enhancement of the axillary recess, and the soft tissue thickening of the rotator interval were significantly greater in group I than in group II (all $p < 0.001$; Table 2). All patients of group I (52/52) had capsule thickness greater than 3 mm, but 61.5 % of group II (32/52) showed capsule thickness >3 mm.

Capsular thickening of the axillary recess did not correlate with any of the initial clinical symptoms with respect to VAS Pain, SST, Constant, and ASES scores (n.s.) and ROM in each direction (n.s.; Table 3). However, the capsular enhancement of the axillary recess correlated with clinical symptom severity according to the VAS Pain, SST, and ASES scores ($p = 0.005$, 0.046, and 0.009, respectively), although it did not correlate with Constant score and ROM (Table 3). The soft tissue thickening of the rotator interval

Table 3 Correlations between the three magnetic resonance imaging findings and clinical variables

	Capsular thickness (PCC)	*p*	Capsular enhancement (grade 0:1:2)	*p*	Soft tissue thickening (grade 0:1:2)	*p*
VAS Pain	0.161	0.254	5.0 (0.8):5.7 (2.1):7.1 (1.5)	0.005*	6.0 (3.0):6.6 (1.7):6.5 (1.7)	n.s.
Simple shoulder test	0.020	0.888	5.8 (1.7):3.0 (3.0):2.5 (2.1)	0.046*	2.8 (3.6):3.2 (2.6):2.8 (2.3)	n.s.
Constant score	0.231	0.099	70.3 (11.5):51.8 (16.6):50.6 (16.6)	n.s.	51.5 (20.0):50.3 (14.7):54. 8 (15.0)	n.s.
ASES score	0.038	0.792	67.5 (9.3):53.9 (12.4):50.6 (8.8)	0.009*	52.3 (15.2):54.9 (11.4):51.6 (10.0)	n.s.
Forward flexion	0.075	0.595	115.0 (23.8):108.7 (20.7):99.9 (20.9)	n.s.	102.5 (12.6):98.8 (26.0):106.9 (18.6)	n.s.
Abduction	0.069	0.628	112.5 (35.0):101.3 (20.3):89.9 (21.8)	n.s.	82.5 (5.0):90.5 (27.6):99.5 (20.7)	n.s.
External rotation	0.051	0.718	17.5 (9.6):24.0 (11.1):18.8 (9.4)	n.s.	35.0 (13.0):21.6 (11.2):17.2 (6.5)	0.002*
Internal rotation	0.178	0.205	16.7 (1.0):15.0 (3.2):16.0 (3.0)	n.s.	15.3 (4.3):16.4 (2.4):15.5 (3.2)	n.s.

Values are presented as mean (standard deviation)

VAS Visual Analogue Scale, *PCC* Pearson's correlation coefficient, *ASES score* American Shoulder and Elbow Surgeons score

* $p < 0.05$

Table 4 Correlations between the three MR findings and clinical variables at 6-month follow-up

	Capsular thickness (PCC)	*p*	Capsular enhancement (grade 0:1:2)	*p*	Soft tissue thickening (grade 0:1:2)	*p*
VAS Pain at 6 months	0.014	0.922	2.8 (0.5):2.7 (1.7):2.1 (1.3)	n.s.	3.7 (1.6):2.5 (1.3)::2.0 (1.3)	n.s.
Simple shoulder test at 6 months	0.049	0.0732	8.0 (2.2):8.1 (2.2):7.6 (2.1)	n.s.	6.7 (2.6)::7.7 (2.4):8.0 (1.9)	n.s.
Constant score at 6 months	0.127	0.369	77.5 (15.0):73.6 (16.8):78.0 (13.3)	n.s.	65.7 (10.2):77.3 (14.9):77.8 (14.3)	n.s.
ASES score at 6 months	0.095	0.501	75.6 (12.0):69.6 (15.1):67.9 (12.1)	n.s.	70.5 (16.0):68.7 (13.1):68.9 (12.8)	n.s.

Values are presented as mean (standard deviation)

VAS Visual Analogue Scale, *PCC* Pearson's correlation coefficient, *ASES score* American Shoulder and Elbow Surgeons score

did not correlate with any of the clinical symptoms with respect to VAS Pain, SST, Constant, and ASES scores (n.s.). However, severe soft tissue thickening of the rotator interval was associated with greater limitations in external rotation ($p = 0.002$; Table 3).

In the analysis of the correlations between the three MR findings and various clinical variables evaluated during the 6-month follow-up period, the MR findings did not correlate with any of the clinical symptoms as quantified by VAS Pain, SST, Constant, and ASES scores or ROM in any direction (Table 4).

Discussion

The most important finding of the present study was that patients with frozen shoulder showed characteristic MR findings that correlated with initial clinical symptoms; however, these findings did not reflect the prognosis. The frozen shoulder showed greater thickening and enhancement of the capsule of the axillary recess and greater thickening of the soft tissue of the rotator interval as compared with the non-frozen shoulder. Although this remains somewhat controversial [20], there appears to be a relationship between a thickened capsule in the axillary recess and frozen shoulder [29]. Emig et al. [7] reported that capsular thickening >4 mm in the axillary recess might be a criterion for the diagnosis of frozen shoulder. Similarly, Jung et al. [14] revealed that capsular and synovial thickness of the axillary recess >3 mm is a practical MR criterion for diagnosing frozen shoulder. Although there may be differences in the methods used to measure capsular thickness in the axillary recess, the reported mean capsular thickness of the axillary recess in the frozen shoulder was 5.2–9.0 mm [7, 17]. Similar results were observed in this study, with the mean capsular thickness of the axillary recess being 7.1 mm in patients with frozen shoulder.

In addition, capsular enhancement in the axillary recess was also significantly higher in the frozen shoulder group than in the non-frozen shoulder group. In our study, most patients in the frozen shoulder group (48/52; 92 %) showed an enhanced joint capsule, while 63 % of the patients (33/52) showed strongly enhanced lesions (grade 2). In contrast, only 19.2 % of the patients (10/52) in the non-frozen shoulder group showed joint capsule enhancement, while none of the patients from group II showed grade 2 enhancement. In frozen shoulder, inflammation of the joint capsule may cause hyperemia in the surrounding tissue, which is enhanced on MRI. Unlike capsular thickness, the characteristics of post-contrast enhancement of the joint capsule seem to be clear in the frozen shoulder, which was also proven in the present study [2, 17]. Thus, we consider that capsular enhancement may be the most distinct MR characteristic of frozen shoulder.

Furthermore, not only the thickened and enhanced capsule in the axillary recess but also thickening of the capsule and soft tissue in the rotator interval were also significant findings of frozen shoulder. This result is supported by those previously reported. For example, Jung et al. [14] showed that patients with frozen shoulder showed an increased rotator interval width and the presence of abnormal tissue in the rotator interval. Similarly, Mengiardi et al. [20] reported that the thickening of the coracohumeral ligament and the joint capsule in the rotator interval as well as the subcoracoid fat triangle are characteristic MR arthrographic findings of frozen shoulder. Therefore, we believe that each of these three MR findings could be used as a confirmative imaging diagnostic tool when used in addition to clinical diagnosis.

Among the three MR findings of frozen shoulder, capsular thickness in the axillary recess or soft tissue thickening of the rotator interval did not show any correlation with the initial clinical symptoms. However, capsular enhancement in the axillary recess was well correlated with the initial clinical symptoms of frozen shoulder, although the assessment of symptom severity primarily remains clinical. Many authors have previously reported abnormalities of the joint capsule and synovium in frozen shoulder [22, 32]. This hyperaemic change in the synovium and vascularized structures may enhance the joint capsule and the surrounding soft tissues [29, 31]. Many reports have shown the relationship between synovial inflammation and clinical symptoms. Barakat et al. [1] revealed that the characteristic pain index score was well correlated with the arthroscopic grading of synovitis in patients with temporomandibular disorder. In addition, Scanzello et al. [26] demonstrated that synovial inflammation was present in 43 % of patients, being associated with worse preoperative pain and functional scores independent of age, gender, or cartilage pathology in patients with meniscal injury without clinical or radiographic evidence of osteoarthritis. Similarly, inflammatory synovitis or vasculitis detected as an enhancing capsular lesion in patients with frozen shoulder could indicate worsening of pain and functional scores.

Further, although soft tissue thickening of the rotator interval did not correlate with clinical symptom severity on VAS Pain and functional scores, greater thickening of the rotator interval was associated with greater limitation of external rotation. That is, fibrotic tissue thickening merely reflected mechanical stiffness, but did not reflect the pathological activities of intra-articular soft tissues that presented as clinical symptoms. The relationship between rotator interval soft tissue thickening and loss of passive external rotation motion is supported by previous studies [15, 33]. Kerimoglu et al. [15] showed a very strong correlation between the limitation of external rotation and the widespread non-fatty soft tissue infiltration at the rotator interval tissue that was shown as soft tissue obliteration and thickening of the rotator interval. In addition, Wolf et al. [33] reported that fibrosis and thickening of the rotator interval compromised the coracohumeral ligament and limited external rotation.

However, the MR findings of the frozen shoulder after 6–12 months of persisting symptoms, i.e. findings in the frozen stage, were not correlated with the clinical symptoms observed at 6 months of follow-up. Further research may be needed to see whether MR findings in other stages of the disease may be correlated; however, the evidence acquired from the current study suggests that although the MR findings of the frozen stage can reflect the current fibrosis and inflammatory synovitis of the joint capsule or interval tissue and clinical symptom severity or external rotation motion limitations, it does not appear to be able to reflect the clinical symptoms or shoulder motion of the later period. In other words, the present MR characteristics of the frozen stage of frozen shoulder cannot be prognostic factors indicative of the future clinical course or outcomes of frozen shoulder. Other factors, such as the natural course of the disease or treatment compliance, might be related to a greater degree with the prognosis of frozen shoulder, although this could not be proven in the present study. Therefore, these MR findings of the frozen stage of frozen shoulder are useful only for the assessment of patients' current symptoms and understanding the natural disease history.

This study is the first to comprehensively analyse the relationships between MR findings and the current and subsequent clinical symptom severities. Nevertheless, several limitations should be noted when interpreting our findings. First, although we tried to confine the patients of the frozen group to those in the frozen stage among freezing, frozen, and thawing phases [6] based on history taking (symptom onset of between 6 months and 1 year and progressive loss of shoulder motion), the length of the frozen stage may vary greatly. Therefore, it is possible that the frozen shoulder group was not homogenous, i.e. not all patients with frozen shoulder may be perfectly in the frozen phase. Second, the time point for prognosis was only 6 months of follow-up. We set 6 months as the follow-up evaluation period because we consider that 6 months is an appropriate period of time to evaluate the treatment results and to determine the further treatment plan for patients undergoing conservative treatment for primary frozen shoulder. However, the correlations might differ at longer follow-up points, and further studies with longer follow-up may be needed. Third, pain and stiffness in patients with frozen shoulder may affect the precise evaluation of shoulder scoring. Fourth, although the interobserver and intraobserver reliabilities of the measurements were good in this study, they could be poor for general surgeons or non-specialized radiologists without much experience. Thus, care should be taken in interpreting the results of MRI arthrography for frozen shoulder. Finally, since the diagnosis of frozen shoulder is a clinical diagnosis, the use of expensive imaging studies is not suitable in all settings. The routine use of MR arthrogram is thus not recommended for the diagnosis of frozen shoulder and should only be used to correlate clinical symptom severities.

Conclusions

This study demonstrated that MRI can provide ancillary findings, with capsular enhancement being the most distinct one, for evaluating the clinical symptom severity of frozen shoulder; however, these MR findings did not reflect disease prognosis. Thus, caution is indicated for the interpretation of MR findings of frozen shoulder, which should not be allowed to replace clinical judgments regarding further prognosis and treatment decisions for these patients.

Compliance with ethical standards

Conflict of interest This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2015R1C1A1A02036478).

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