Rheumatology International (2019) 39:453–460
https://doi.org/10.1007/s00296-018-04238-9

Rheumatology INTERNATIONAL

IMAGING

Determination of magnetic resonance imaging criteria for diagnosis of adhesive capsulitis

Jae Hoon Jung[1] · Du Hwan Kim[2] · Jaehyuck Yi[3] · Du-Han Kim[4] · Chul-Hyun Cho[4]

Received: 21 November 2018 / Accepted: 29 December 2018 / Published online: 7 January 2019

Abstract

The objective of this study was to identify optimal magnetic resonance imaging (MRI) parameters and their cutoff values for diagnosing adhesive capsulitis (AC). One hundred shoulder MRI images with stage 2 AC (AC group) and 100 MRI images without AC (control group) were randomly reviewed by two experienced shoulder specialists. They were asked whether MRI findings were compatible with AC and measurement of MRI parameters. Sensitivity, specificity, and accuracy were calculated. Correlation between MRI parameters and the range of motions was also analyzed. The mean capsular thickness in the axillary recess (AR) (5.9 mm in the AC group vs. 3.6 mm in the control group) on coronal oblique T2-weighted images and the rotator interval (RI) (7.2 mm vs. 4.8 mm, respectively) on oblique sagittal proton-density images were significantly greater in the AC group than in the control group, whereas the width of RI showed no significant difference between two groups. The highest diagnostic cutoff values were 4.5 mm for the AR and 6 mm for the RI, with sensitivity (91% and 88%, respectively), specificity (90% and 90%), and accuracy (90% and 89%). Capsular thickness in the AR and RI was significantly correlated with external rotation ($P = 0.047$) and internal rotation ($P = 0.023$). On conventional MRI, capsular thickness greater than 4.5 mm in the AR or 6 mm in the RI can be an optimal criterion for diagnosing AC. Capsular thickness in the AR and RI was correlated with the range of rotational motion.

Keywords Adhesive capsulitis · Axillary recess · Rotator interval · Magnetic resonance image

✉ Chul-Hyun Cho
oscho5362@dsmc.or.kr

Jae Hoon Jung
imapak@hanmail.net

Du Hwan Kim
ri-pheonix@hanmail.net

Jaehyuck Yi
yijh7@dsmc.or.kr

Du-Han Kim
osmdkdh@gmail.com

1 Department of Orthopedic Surgery, City Hospital, Daegu, South Korea

2 Department of Rehabilitation Medicine, Dongsan Medical Center, School of Medicine, Keimyung University, Daegu, South Korea

3 Department of Radiology, Dongsan Medical Center, School of Medicine, Keimyung University, Daegu, South Korea

4 Pain Research Center, Department of Orthopedic Surgery, Dongsan Medical Center, School of Medicine, Keimyung University, 56 Dalseong-ro, Jung-gu, Daegu 41931, South Korea

Introduction

Adhesive capsulitis (AC) is a painful shoulder condition characterized by a significant restriction of both active and passive shoulder motion [1]. Although the etiology is controversial, histologic and arthroscopic studies have demonstrated that the abnormalities of the synovium and capsule are involved in the pathogenesis of AC [2–5]. The pathophysiology of AC is associated with inflammatory changes of the joint capsule and synovium, which result in subsequent capsular fibrosis and stiff shoulder [6].

The diagnosis of AC can usually be made on the basis of clinical findings [7, 8]. However, if symptoms are atypical, AC may mimic other causes of shoulder pain such as rotator cuff tear, impingement syndrome, calcific tendinitis, or osteoarthritis. Imaging studies including arthrography, ultrasonography, and magnetic resonance imaging (MRI) may play an important role in the identification of AC [8]. To date, arthrography has been advocated as an imaging test of choice to assess AC with decreased joint capacity, obliteration of the axillary recess (AR), and irregularity of the anterior capsular insertion at the anatomic neck of the humerus [2, 9]. However, arthrography cannot be used as a routine diagnostic tool for AC because of its invasiveness. Moreover, it cannot explore changes of the glenohumeral joint capsule and synovium such as inflammation, thickening, or fibrosis. Ultrasonography provides some specific findings that may help to orient the diagnosis of AC [8]. However, the role of ultrasonography is still controversial.

MRI has been commonly used to investigate shoulder problems; it can help differentiate any underlying disease that can mask the symptoms of AC [7]. MRI is obviously a non-invasive diagnosing modality and has an advantage in evaluating soft tissue lesions such as those of the capsule and synovium, which is the main pathologic focus of AC. When clinical diagnosis is challenging, MRI is capable of diagnosing early AC and ruling out concurrent pathology [10]. Several studies have shown that MRI can provide reliable imaging indicators for AC including thickening of the coracohumeral ligament (CHL), the joint capsule in the rotator interval (RI) and AR, as well as obliteration of the fat triangle under the coracoid process and enhancing tissue in the RI [8, 11–16]. These MRI findings correlate well with surgical findings [7, 17].

Although MRI can be helpful for diagnosing AC, optimal parameters and reliable criteria of MRI findings have not been fully established. To our knowledge, several studies have investigated reliable criteria for diagnosis of AC and correlation between MRI parameters and the range of shoulder motion [12–16, 18–21]. However, there are few data on the sensitivity, specificity, accuracy, and reliability of conventional MRI parameters for the diagnosis of AC.

Therefore, the primary objective of this study was to identify optimal MRI parameters and their cutoff values for diagnosing AC. The secondary objective was to determine the correlation between MRI parameters and the range of motions (ROMs). Our study was conducted to test the hypothesis that capsular thickness in AR and RI can be optimal MRI parameters for diagnosing AC.

Patients and methods

Patients and control subjects

An approval from our institutional review board was obtained for this study (IRB No. 201607032). One hundred patients who were clinically diagnosed with stage 2 AC according to the Hannafin and Chiaia criteria [22] by a single experienced shoulder specialist and underwent conventional MRI in 2014 and 2015 were included. Patients were diagnosed with AC if they had restricted passive motion of greater than 30° in two or more planes of movement and normal radiographic findings. Patients with secondary AC with associated conditions including rotator cuff tear, calcific tendinitis, fracture, osteoarthritis, autoimmune disease, infection, neoplastic condition, neurologic deficit, or previous shoulder surgery were excluded. From the pool of patients who did not have limited ROM in any direction and underwent shoulder MRI in a single institution between 2007 and 2015, 100 subjects who were matched for age and sex with the MUA group using propensity score matching were included as a control group.

MRI protocol

MRI was performed on a 1.5-T scanner (Avanto; Siemens, Erlangen, Germany) with a dedicated shoulder coil. Patients were placed in a supine position with their arm in a neutral position.

Pulse sequences were as follows:

1. Oblique coronal T2-weighted turbo spin-echo fat saturated (TR/TE, 4030/93 ms); the parameters were: 3 mm section thickness with a 0.6 mm intersection gap, a matrix size of 320 × 256, and a 17 cm field of view centered around glenohumeral joint.
2. Sagittal oblique proton-density fat saturated (TR/TE, 3000/35 ms); the parameters were: 5 mm section thickness with a 1.5 mm intersection gap, a matrix size of 320 × 256, and a 17 cm field of view centered around glenohumeral joint.

Evaluation of MRI findings

Two hundred MRI images (100 from the AC group and 100 from the control group) were randomly evaluated on high-resolution monitors of a picture archiving and communication system by two experienced shoulder specialists (9 years and 13 years of experience) twice with a 3-week interval to assess intraobserver reliability. The two specialists were asked whether MRI findings were compatible with AC and measurement of MRI parameters. They were blinded to patients' information and clinical diagnosis during assessment.

MRI parameters included capsular thickness in the AR, capsular thickness in the RI, and the width of the RI. Capsular thickness in the AR was measured in the thickest portion of the capsule and synovium at its insertion at the humeral head perpendicular to the adjacent cortical bone on coronal oblique T2-weighted images. Capsular thickness in the RI was measured in the thickest portion of the capsule and synovium between the superior aspect of the subscapularis and the anterior aspect of the supraspinatus perpendicular to the adjacent humeral head cortex on sagittal oblique proton-density images. The width of the RI was measured as the shortest length between the superior border of the subscapularis and the anterior border of the supraspinatus at the level of the tip of the coracoid process on sagittal oblique proton-density images (Fig. 1).

Statistical analysis

The SPSS statistical package (version 20.0; IBM, Armonk, NY, USA) software was used to perform the statistical analysis. An independent *t* test was used to compare MRI parameters (capsular thickness in the AR and RI, and width of RI) between the two groups. The intraclass correlation coefficient (ICC) under the random-effect model was used to evaluate intraobserver and interobserver reliability for the measurements of MRI parameters. The interpretation of ICC was as follows: <0.50, poor reliability; 0.50–0.75, moderate reliability; 0.75–0.90, good reliability; and >0.90, excellent reliability.

To establish optimal cutoff values for the diagnosis of AC, the sensitivity, specificity, and accuracy were calculated using cutoff values of 4, 4.5, 5, 5.5, and 6 mm for the capsular thickness in the AR, and 5, 5.5, 6, 6.5, and 7 mm for the capsular thickness of the RI. A receiver operating characteristic (ROC) curve and the area under the curve (AUC) were also calculated.

Pearson correlation coefficient was used to evaluate the correlation between MRI parameters and ROMs in the AC group. Internal rotation was assessed from the level at the back the patient was able to reach with the thumb. For statistical analysis of internal rotation, we converted values into contiguous numbers: T1 through T12–1 through 12, respectively; L1 through L5–13 through 17; sacrum–18; coccyx–19; and buttock–20. In all analyses, $p<0.05$ was taken to indicate statistical significance.

Results

In the AC group, there were 61 women and 39 men with a mean age of 54.3 years (range 37–72 years). The mean duration of symptoms was 7.1 months (range 1–48 months). Fifteen patients had diabetes mellitus. At the first visit, the mean visual analog scale (VAS) pain score was 7.1 and American Shoulder and Elbow Surgeons (ASES) score was 31.4. The mean angles were: forward flexion, 106.1°; abduction, 91.6°; and external rotation with the arm at the side, 31.5°; internal rotation, 17.4. In the control group, there were 60 women and 40 men with a mean age of 54.6 years (range 38–80 years).

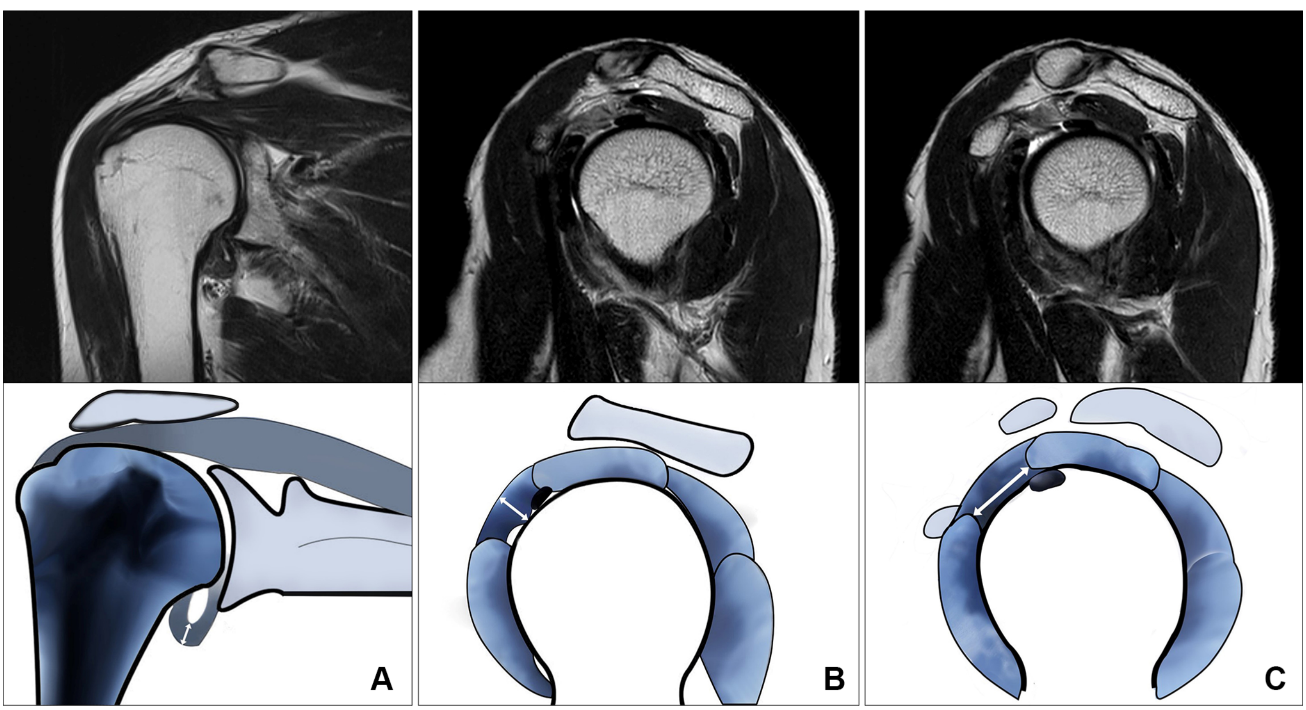

Fig. 1 **a** Capsular thickness in the axillary recess is measured at the thickest portion of the capsule and synovium at its insertion at the humeral head perpendicular to the adjacent cortical bone on coronal oblique T2-weighted images. **b** Capsular thickness in the rotator interval is measured at the thickest portion of the capsule and synovium between the superior aspect of subscapularis and the anterior aspect of the supraspinatus perpendicular to the adjacent humeral head cortex on sagittal oblique proton-density images. **c** The width of the rotator interval is measured by shortest length between the superior border of the subscapularis and the anterior border of the supraspinatus at the level of the tip of the coracoid process on sagittal oblique proton-density images

The mean capsular thickness in the AR and RI, and the mean width of the RI are shown in Table 1. There were significant differences between the AC and control groups in the capsular thickness in the AR (5.9 mm vs. 3.6 mm, respectively) and RI (7.2 mm vs. 4.8 mm), but not in the width of the RI. Intraobserver and interobserver reliabilities are shown in Table 2. Intraobserver reliability was excellent for capsular thickness in the AR and RI, and the width of the RI (ICC = 0.92, 0.93, and 0.92, respectively), whereas interobserver reliability was good (ICC = 0.83, 0.77, and 0.78, respectively).

For the capsular thickness in the AR, a 4.5 mm cutoff value gave the highest diagnostic accuracy for AC, with a sensitivity, specificity, and accuracy of 91%, 90%, and 90%, respectively (Youden index = 0.81). For the capsular thickness in the RI, a 6 mm cutoff value gave the highest diagnostic accuracy, with a sensitivity, specificity, and accuracy of 88%, 90%, and 89%, respectively (Youden index = 0.78) (Table 3). The AUCs for capsular thickness in the AR and RI were 0.98 and 0.96 (Fig. 2).

The correlations between MRI parameters and ROMs are shown in Table 4. Statistically significant correlation was found between capsular thickness in the AR and external rotation ($r = -0.199$, $p = 0.047$). Statistically significant correlation was found between capsular thickness in the RI and internal rotation ($r = 0.227$, $p = 0.023$). No statistically significant correlation was found between the width of the RI and any ROM ($p > 0.05$).

Discussion

The current study revealed that capsular thickness in the AR and RI are optimal MRI parameters for diagnosing AC. The cutoff values of capsular thickness in the AR and RI were 4.5 mm on coronal oblique T2-weighted images and 6 mm on oblique sagittal proton-density images of conventional MRI, respectively. In the AC group, capsular thickness in the AR and RI on conventional MRI correlated with the range of rotational motion.

Although the etiology of AC is poorly understood, capsular changes are thought to be the main pathology of AC and can occur at any stage of AC [22]. Synovial proliferation and hypervascular changes are typical in the early stage, whereas fibrosis is typical in the late stage [6]. Hence, it is perfectly reasonable that the evaluation of capsular changes on MRI can be helpful for diagnosing AC. Because the main pathologic sites of AC are known to be the RI and AR, most reports related to AC and MRI have focused on these sites for evaluation [10]. Previously described MRI parameters included capsular thickness and the width of the AR and RI, and the thickness of the CHL.

Table 1 Comparison of MRI parameters between AC group and control group

MRI measurement (mm)	Reader I						Reader II					
	First measuring			Second measuring			First measuring			Second measuring		
	AC group	Control group	*p* value	AC group	Control group	*p* value	AC group	Control group	*p* value	AC group	Control group	*p* value
AR thickness	6.3 ± 1.0	4.0 ± 1.0	< 0.0001	6.3 ± 1.0	4.0 ± 1.0	< 0.0001	5.9 ± 1.3	3.3 ± 0.9	< 0.0001	5.2 ± 1.2	3.0 ± 0.8	< 0.0001
RI thickness	7.0 ± 1.6	4.7 ± 1.3	< 0.0001	6.9 ± 1.6	4.7 ± 1.4	< 0.0001	7.6 ± 1.4	5.1 ± 1.2	< 0.0001	7.2 ± 1.3	4.7 ± 1.0	< 0.0001
RI width	16.0 ± 2.3	15.7 ± 2.1	0.488	16.1 ± 2.3	15.9 ± 2.1	0.467	17.1 ± 2.1	17.1 ± 1.9	0.916	16.8 ± 2.0	16.6 ± 1.8	0.392

Values are presented as number or mean ± standard deviation

MRI magnetic resonance imaging, *AC* adhesive capsulitis, *AR* axillary recess, *RI* rotator interval

Table 2 Intraobserver and interobserver reliability for measurements of MRI parameters

	Intraobserver reliability (ICC)		Interobserver reliability (ICC)	
	Reader I	Reader II	First measuring	Second measuring
AR thickness	0.97	0.86	0.83	0.82
RI thickness	0.96	0.89	0.78	0.75
RI width	0.97	0.87	0.76	0.79

MRI magnetic resonance imaging, *ICC* intraclass correlation coefficient, *AR* axillary recess, *RI* rotator interval

Recent studies have recommended the use of intravenous (IV) gadolinium injection and arthrography for the diagnosis of AC using MRI [11, 13–15, 18, 19, 23, 24]. On MRI obtained after a IV gadolinium injection, enhancement of the joint capsule and synovial membrane, and enhanced fibrovascular tissue in the RI and AR may be helpful in the identification of AC [11, 13, 16, 23]. Several authors have suggested that MR arthrography is useful for accurate measurements of capsular thickness [14, 15, 19, 20]. Yet, these MR modalities need IV or intra-articular contrast injection, which is an invasive procedure, may potentially lead to complications, and are costly. Furthermore, researchers have reported no significant differences in diagnostic performance between conventional MRI and MR arthrography or enhanced MRI in identifying abnormalities of the joint capsule [11, 24–26]. Gondim Teixeira et al. [25] reported that a change in capsular intensity on T2-weighted images offers a high performance for the diagnosis of AC without the need for intravenous or intra-articular contrast injection. A systematic review and meta-analysis by Suh et al. [27] identified that six informative MRI features for diagnosing AC included CHL thickening, fat obliteration of the RI, RI enhancement, axillary joint capsule enhancement, inferior glenohumeral ligament hyperintensity and thickening. They concluded that the use of non-arthrogram MRI is recommended for diagnosing AC. We agree with their opinion and consider conventional MRI to be good enough for diagnosing AC. Our study demonstrated that diagnostic parameters including capsular thickness in the AR and RI showed high specificity, sensitivity and accuracy with excellent intraobserver and interobserver reliability in conventional MRI findings.

Thickening of the CHL, thickening of the joint capsule in the RI, the subcoracoid triangle sign, and the presence of abnormal tissue in the RI have been reported as reliable MRI indicators for AC [1, 11, 15, 17, 18, 20]. Because the RI is a complex structure composed of several structures including the CHL, superior glenohumeral ligament, and surrounding capsular tissue, delineation of the exact margins of these structures on MRI is not easy. Mengiardi et al. [15] suggested that thickening of the CHL more than 4 mm showed a specificity of 95% and sensitivity of 59% for diagnosing AC with MR arthrography. On the other hand, Emig et al. [12] found no significant difference in CHL thickness between patients with AC and controls. They concluded that the RI was not useful for assessing changes of AC. Li et al. [17] found that the CHL was not visualized by MRI in 20% of AC patients. We sometimes find it hard to measure CHL thickness because of technical errors in sagittal scans. So, in the present study, we simplified MRI parameters in the RI and used its capsular thickness and width on oblique sagittal proton-density images. The mean capsular thickness in the RI was significantly greater in the AC group (7.2 mm) than in the control group (4.8 mm), whereas the width of the RI showed no significant difference between two groups. Our results are consistent with those of previous studies by Mengiardi et al. [15] and Zhao et al. [1], capsular thickness in the RI significantly differs between patients with and without AC (7.1 mm vs. 4.5 mm [15]; 7.2 mm vs. 4.4 mm [1]). However, the width of the RI, which may be shortened by

Table 3 Diagnostic accuracy according to cutoff values of capsular thickness in axillary recess and rotator interval

	Cutoff level (mm)	Sensitivity	Specificity	Accuracy	Youden index
AR thickness	4	92% (92/100)	85% (85/100)	88% (177/200)	0.77
	4.5	91% (91/100)	90% (90/100)	90% (181/200)	0.81
	5	50% (50/100)	97% (97/100)	73% (147/200)	0.47
	5.5	32% (32/100)	98% (98/100)	65% (130/200)	0.30
	6	23% (23/100)	100% (100/100)	61% (123/200)	0.23
RI thickness	5	95% (95/100)	67% (67/100)	81% (162/200)	0.62
	5.5	90% (90/100)	83% (83/100)	86% (173/200)	0.73
	6	88% (88/100)	90% (90/100)	89% (178/200)	0.78
	6.5	80% (80/100)	94% (94/100)	87% (174/200)	0.74
	7	58% (58/100)	97% (97/100)	77% (155/200)	0.55

AR axillary recess, *RI* rotator interval

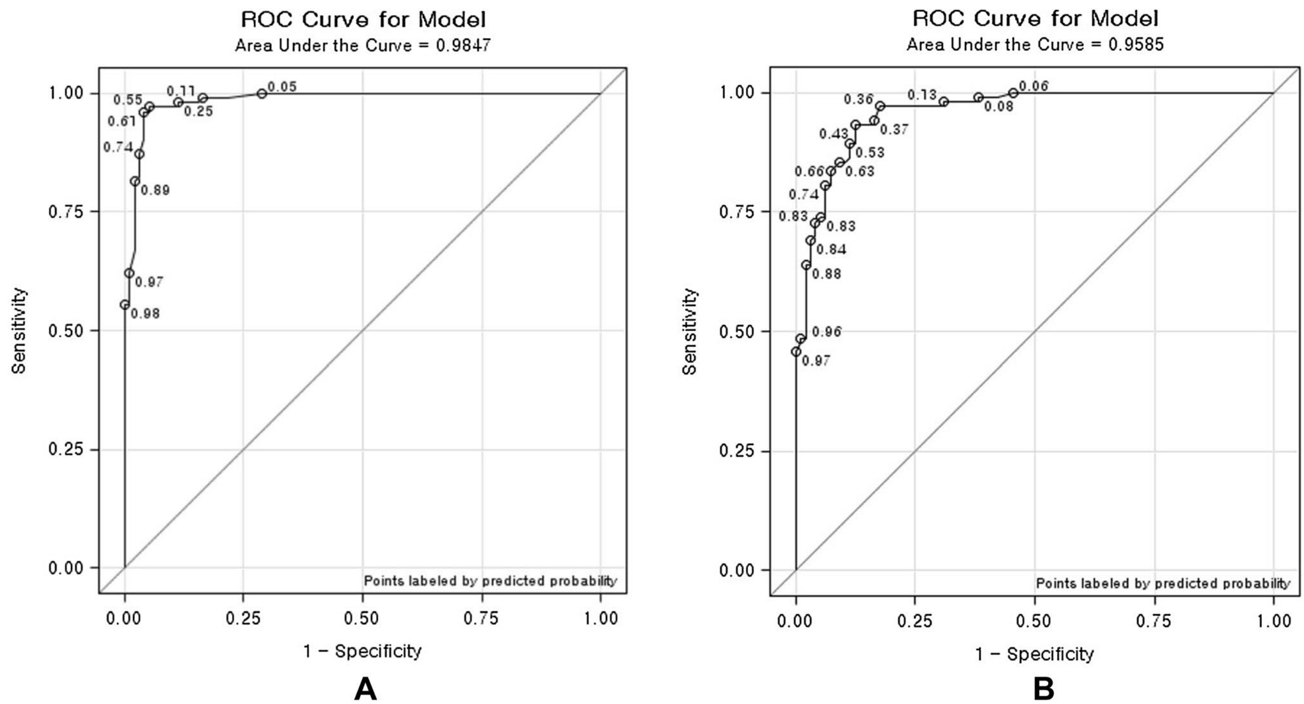

Fig. 2 **a** Receiver operating characteristic curve and area under curve (AUC) for diagnosis of adhesive capsulitis using capsular thickness in the axillary recess evaluated on coronal T2-weighted images (AUC = 0.98). **b** Receiver operating characteristic curve and area under curve (AUC) for diagnosis of adhesive capsulitis using capsular thickness in rotator interval evaluated on sagittal oblique proton-density images (AUC = 0.96)

Table 4 Correlation between MR parameters and range of motions

	AR thickness		RI thickness		RI width	
	r	*p*	*r*	*p*	*r*	*p*
Forward flexion	− 0.116	0.251	− 0.079	0.433	0.023	0.824
Abduction	0.019	0.848	0.033	0.746	0.073	0.472
External rotation	− 0.199	0.047*	− 0.117	0.245	− 0.056	0.581
Internal rotation	0.176	0.080	0.227	0.023*	0.043	0.673

MRI magnetic resonance imaging, *AR* axillary recess, *RI* rotator interval

*Statistically significant

contraction in AC showed no significant difference. Mengiardi et al. [15] reported that capsular thickness in the RI of 7 mm or more had a specificity of 86% and a sensitivity of 64%. In our study, a 6 mm cutoff value gave the highest diagnostic accuracy with a sensitivity, specificity, and accuracy of 88%, 90%, and 89%, respectively.

Although capsular thickness in the AR has been described as a reliable MRI parameter for diagnosis of AC [12, 14, 19], there have been some debates about its usefulness [15, 26]. Emig et al. [12] reported that thickening of the capsule in the AR on conventional MRI was characteristic of AC, with a significant difference between the mean thickness in patients with AC (5.2 mm) and in controls (2.9 mm). They suggested that capsular thickness in the AR of more than 4 mm on a T2 oblique coronal image is an optimal MR criterion for diagnosing AC with 70% sensitivity and 95% specificity [11]. Ahn et al. [28] reported that a 5.0 mm cutoff value of capsular thickness in the AR (mean values: 6.8 mm in the AC group; 4.3 mm in the control group) on oblique coronal T2-weighted fat-suppression images provided the highest sensitivity (90%) and specificity (81%) with excellent interobserver reliability. Jung et al. [14] demonstrated that capsular thickness in the AR greater than 3 mm on coronal oblique T2-weighted MR arthrography images was a specific sign of AC [14]. On the other hand, Mengiardi et al. [15] found no difference in capsular thickness of the AR between patients with AC (4.1 mm) and controls (5.1 mm). Despite the differences in the measurement methods, the results from our study were similar to those of Emig et al. [12] and Ahn et al. [28]: the mean capsular thickness in the

AR was significantly greater in the AC group (5.9 mm) than in the control group (3.6 mm). A 4.5 mm cutoff value gave the highest diagnostic accuracy for AC, with a sensitivity, specificity, and accuracy of 91%, 90%, and 90%, respectively. If consensus for measuring these parameters exists, we think similar intraobserver reliability between experienced observer and less experienced observer.

In the pathophysiologic process of AC, various structural changes may be associated with clinical findings. RI has received great attention because this site is thought to account for the external rotation deficit found in patients with AC. According to Neer et al. [29], tightened CHL restricts external rotation in AC. This suggestion was supported by several reports of contraction of the CHL and thickening of the capsule in the RI detected during arthroscopy and open surgery [3, 4, 30]. Only two studies have examined the association between MRI findings and the ROMs [20, 31]. To date, the relationship between MRI findings and ROMs in AC has not been firmly established and diverse patterns have been shown. Ahn et al. [31] found that thickening of the joint capsule in the AR correlated with limited external rotation, whereas there was no significant correlation between capsular thickness and limitation in forward flexion or internal rotation [31]. Subcoracoid fat obliteration in the RI was not correlated with limited ROM [31]. Lee et al. [20] reported that CHL thickness on MR arthrography correlates with the limited external and internal rotation in patients with AC, but capsular thickness in the AR was not significantly associated with ROMs [20]. Interestingly, the present study showed that capsular thickness in the AR was significantly correlated with external rotation and that capsular thickness in the RI was significantly correlated with internal rotation. We think that capsular thickness in AR and RI may relate to prominent inflammation of the joint capsule or capsular contracture, which can affect shoulder ROMs in patients with AC. Therefore, measuring capsular thickness in the AR and RI with conventional MRI may be predictive of ROMs in patients with AC. We think that the reasons for the discrepancies among previous studies were different selection criteria for patient groups, the use of different MR modalities and MR parameters, and the use of different measurement methods. We believe that knowledge about the relationship between MRI findings and shoulder ROMs can help to choose treatment strategy, for example suggest the proper site for corticosteroid injection or extent of capsular release during operation. Eventually, we expect that the standardized relationship between MRI findings and shoulder ROMs can help to develop new classification of AC. Further well-designed large-scale studies are necessary to clarify the correlation between MRI parameters and shoulder ROMs.

This study has several limitations. First, a different MRI protocol may have been applied to each patient may because the study was retrospective. Second, MRI parameters were not optimized or consistent among the patients. Standardized methods for measuring MRI parameters are needed for the diagnosis of AC. Third, we did not perform multivariate analysis for the correlation between MRI findings and ROMs. Fourth, we did not evaluate the correlation between MRI findings and clinical staging because only stage 2 AC patients were included in this study. Further studies are needed to evaluate sequential capsular changes according to staging.

Nevertheless, our study has some strong points. Patient characteristics were homogeneous in that most patients were stage 2 (freezing phase). This is a meaningful study that provides optimal MRI parameters with cutoff values for diagnosing AC.

Conclusion

On conventional MRI, capsular thickness in the AR greater than 4.5 mm on an oblique coronal T2-weighted image or capsular thickness in the RI greater than 6 mm on an oblique sagittal proton-density image can be an optimal criterion for diagnosing AC. Capsular thickness in AR and RI was correlated with the range of rotational motion. These findings will aid the diagnosis and treatment of AC in clinical practice.

Acknowledgements Jae Hoon Jung and Du Hwan Kim are co-first authors. We thank Eun-Ji Jeon and Yeji Kim for their support with data collection. We thank Scott Timpano for editing a draft of this manuscript.

Author contributions JHJ, DHK, and C-HC were responsible for the conceptualization and design of the study, and wrote the manuscript. D-HK collected the data and statistical analysis. JHY contributed interpretation of data and critical review.

Funding This work was supported by the Bisa Research Grant of Keimyung University in 2016.

Compliance with ethical standards

Conflict of interest Jae Hoon Jung declares that he has no conflict of interest. Du Hwan Kim declares that he has no conflict of interest. Jaehyuck Yi declares that he has no conflict of interest. Du-Han Kim declares that he has no conflict of interest. Chul-Hyun Cho declares that he has no conflict of interest.

Ethical standards This study was performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The authors obtained the approval of Keimyung University Dongsan Medical Center institutional review board (IRB number 2016-07-032) with exemption of Informed consent for this study.

References

1. Zhao W, Zheng X, Liu Y, Yang W, Amirbekian V, Diaz LE, Huang X (2012) An MRI study of symptomatic adhesive capsulitis. PLoS One 7(10):e47277. https://doi.org/10.1371/journal.pone.0047277
2. Neviaser TJ (1980) Arthrography of the shoulder. Orthop Clin N Am 11(2):205–217
3. Omari A, Bunker TD (2001) Open surgical release for frozen shoulder: surgical findings and results of the release. J Shoulder Elbow Surg 10(4):353–357. https://doi.org/10.1067/mse.2001.115986
4. Warner JJ, Allen A, Marks PH, Wong P (1996) Arthroscopic release for chronic, refractory adhesive capsulitis of the shoulder. J Bone Jt Surg Am 78(12):1808–1816
5. Wiley AM (1991) Arthroscopic appearance of frozen shoulder. Arthroscopy 7(2):138–143
6. Rodeo SA, Hannafin JA, Tom J, Warren RF, Wickiewicz TL (1997) Immunolocalization of cytokines and their receptors in adhesive capsulitis of the shoulder. J Orthop Res 15(3):427–436. https://doi.org/10.1002/jor.1100150316
7. Hsu JE, Anakwenze OA, Warrender WJ, Abboud JA (2011) Current review of adhesive capsulitis. J Shoulder Elbow Surg 20(3):502–514. https://doi.org/10.1016/j.jse.2010.08.023
8. Zappia M, Di Pietto F, Aliprandi A, Pozza S, De Petro P, Muda A, Sconfienza LM (2016) Multi-modal imaging of adhesive capsulitis of the shoulder. Insights Imaging 7(3):365–371. https://doi.org/10.1007/s13244-016-0491-8
9. Loyd JA, Loyd HM (1983) Adhesive capsulitis of the shoulder: arthrographic diagnosis and treatment. South Med J 76(7):879–883
10. Harris G, Bou-Haidar P, Harris C (2013) Adhesive capsulitis: review of imaging and treatment. J Med Imaging Radiat Oncol 57(6):633–643. https://doi.org/10.1111/1754-9485.12111
11. Connell D, Padmanabhan R, Buchbinder R (2002) Adhesive capsulitis: role of MR imaging in differential diagnosis. Eur Radiol 12(8):2100–2106. https://doi.org/10.1007/s00330-002-1349-7
12. Emig EW, Schweitzer ME, Karasick D, Lubowitz J (1995) Adhesive capsulitis of the shoulder: MR diagnosis. Am J Roentgenol 164(6):1457–1459. https://doi.org/10.2214/ajr.164.6.7754892
13. Gokalp G, Algin O, Yildirim N, Yazici Z (2011) Adhesive capsulitis: contrast-enhanced shoulder MRI findings. J Med Imaging Radiat Oncol 55(2):119–125. https://doi.org/10.1111/j.1754-9485.2010.02215.x
14. Jung JY, Jee WH, Chun HJ, Kim YS, Chung YG, Kim JM (2006) Adhesive capsulitis of the shoulder: evaluation with MR arthrography. Eur Radiol 16(4):791–796. https://doi.org/10.1007/s00330-005-0020-5
15. Mengiardi B, Pfirrmann CW, Gerber C, Hodler J, Zanetti M (2004) Frozen shoulder: MR arthrographic findings. Radiology 233(2):486–492. https://doi.org/10.1148/radiol.2332031219
16. Song KD, Kwon JW, Yoon YC, Choi SH (2011) Indirect MR arthrographic findings of adhesive capsulitis. Am J Roentgenol 197(6):W1105–W1109. https://doi.org/10.2214/ajr.10.6099
17. Li JQ, Tang KL, Wang J, Li QY, Xu HT, Yang HF, Tan LW, Liu KJ, Zhang SX (2011) MRI findings for frozen shoulder evaluation: is the thickness of the coracohumeral ligament a valuable diagnostic tool? PLoS One 6(12):e28704. https://doi.org/10.1371/journal.pone.0028704
18. Kim KC, Rhee KJ, Shin HD (2009) Adhesive capsulitis of the shoulder: dimensions of the rotator interval measured with magnetic resonance arthrography. J Shoulder Elbow Surg 18(3):437–442. https://doi.org/10.1016/j.jse.2008.10.018
19. Lee MH, Ahn JM, Muhle C, Kim SH, Park JS, Kim SH, Kim SM, Kang HS (2003) Adhesive capsulitis of the shoulder: diagnosis using magnetic resonance arthrography, with arthroscopic findings as the standard. J Comput Assist Tomogr 27(6):901–906
20. Lee SY, Park J, Song SW (2012) Correlation of MR arthrographic findings and range of shoulder motions in patients with frozen shoulder. Am J Roentgenol 198(1):173–179. https://doi.org/10.2214/ajr.10.6173
21. Park S, Lee DH, Yoon SH, Lee HY, Kwack KS (2016) Evaluation of adhesive capsulitis of the shoulder with fat-suppressed T2-weighted MRI: association between clinical features and MRI findings. Am J Roentgenol 207(1):135–141. https://doi.org/10.2214/ajr.15.15200
22. Hannafin JA, Chiaia TA (2000) Adhesive capsulitis. A treatment approach. Clin Orthop Relat Res 372:95–109
23. Lefevre-Colau MM, Drape JL, Fayad F, Rannou F, Diche T, Minvielle F, Demaille-Wlodyka S, Mayoux-Benhamou MA, Fermanian J, Poiraudeau S, Revel M (2005) Magnetic resonance imaging of shoulders with idiopathic adhesive capsulitis: reliability of measures. Eur Radiol 15(12):2415–2422. https://doi.org/10.1007/s00330-005-2830-x
24. Sofka CM, Ciavarra GA, Hannafin JA, Cordasco FA, Potter HG (2008) Magnetic resonance imaging of adhesive capsulitis: correlation with clinical staging. HSS J 4(2):164–169. https://doi.org/10.1007/s11420-008-9088-1
25. Gondim Teixeira PA, Balaj C, Chanson A, Lecocq S, Louis M, Blum A (2012) Adhesive capsulitis of the shoulder: value of inferior glenohumeral ligament signal changes on T2-weighted fat-saturated images. Am J Roentgenol 198(6):W589–W596. https://doi.org/10.2214/ajr.11.7453
26. Manton GL, Schweitzer ME, Weishaupt D, Karasick D (2001) Utility of MR arthrography in the diagnosis of adhesive capsulitis. Skelet Radiol 30(6):326–330
27. Suh CH, Yun SJ, Jin W, Lee SH, Park SY, Park JS, Ryu KN (2018) Systematic review and meta-analysis of magnetic resonance imaging features for diagnosis of adhesive capsulitis of the shoulder. Eur Radiol. https://doi.org/10.1007/s00330-018-5604-y
28. Ahn KS, Kang CH, Kim Y, Jeong WK (2015) Diagnosis of adhesive capsulitis: comparison of contrast-enhanced MRI with noncontrast-enhanced MRI. Clin Imaging 39(6):1061–1067. https://doi.org/10.1016/j.clinimag.2015.08.006
29. Neer CS, Satterlee CC, Dalsey RM, Flatow EL (1992) The anatomy and potential effects of contracture of the coracohumeral ligament. Clin Orthop Relat Res 280:182–185
30. Ozaki J, Nakagawa Y, Sakurai G, Tamai S (1989) Recalcitrant chronic adhesive capsulitis of the shoulder. Role of contracture of the coracohumeral ligament and rotator interval in pathogenesis and treatment. J Bone Jt Surg Am 71(10):1511–1515
31. Ahn KS, Kang CH, Oh YW, Jeong WK (2012) Correlation between magnetic resonance imaging and clinical impairment in patients with adhesive capsulitis. Skelet Radiol 41(10):1301–1308. https://doi.org/10.1007/s00256-012-1391-8