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FULL PAPER

3D volumetric MR arthrographic assessment of shoulder joint capacity in patients with primary adhesive capsulitis

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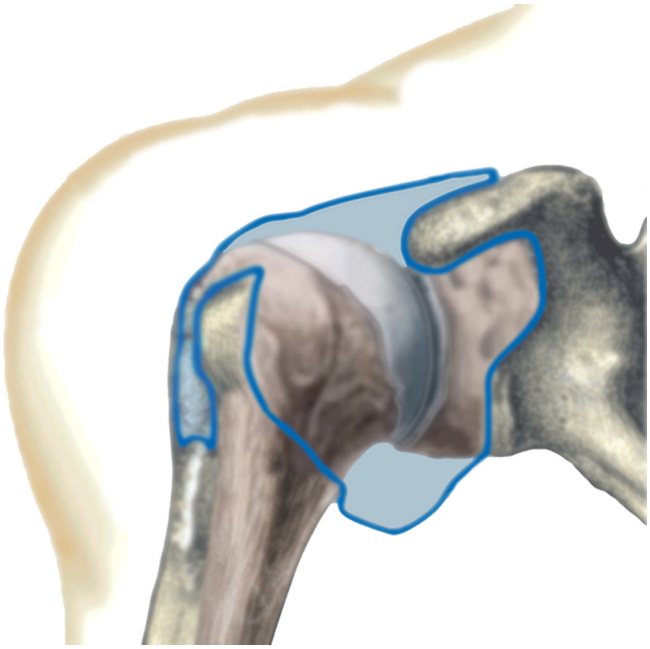
Objective To evaluate the three-dimensional (3D) volumetric MR arthrographic findings of shoulder joint capacity in patients with primary adhesive capsulitis.
Methods Thin-section 3D volumetric MR arthrography sequences of the shoulder joint were obtained in 28 patients with clinically and radiologically proven primary adhesive capsulitis and in 25 controls. Volumetric measurements of the total glenohumeral joint capacity, extra-articular contrast material leakage, and the rotator interval, axillary recess, and biceps tendon sheath capacities were performed for the study and control groups.
Results Mean volume of the rotator interval was 7.67 ± 2.6 cm^3 in the study group, which was significantly lower than in the control group (12.31 ± 2.5 cm^3) ($p < 0.0001$). Mean volume of the bicipital groove was significantly decreased in the patient group compared to the control group (1.67 ± 0.9 cm^3 *vs* 2.88 ± 0.9 cm^3) ($p \leq 0.0001$). Mean volume of extra articular contrast material extravasation was 9.93 ± 1.7 cm^3 in the patient group, which was significantly higher than in the control group (5.1 ± 1.4 cm^3) ($p = 0.002$). Mean total glenohumeral joint volume was 22.52 ± 1.1 cm^3 in the patient group and 26.01 ± 1.2 cm^3 in the control group ($p = 0.003$).
Conclusion On 3D volumetric MR arthrographic examination, obliterations in the biceps tendon sheath and rotator interval as well as decreased joint capacity may be useful imaging criteria for diagnosing primary adhesive capsulitis.
Advances in knowledge In the present study, MR arthrography showed contrast material extravasation in 71% of the patients and showed extra articular contrast material extravasation in 48% of the control subjects. On 3D volumetric MR arthrographic examination, obliterations in the biceps tendon sheath and rotator interval as well as decreased joint capacity may be useful imaging criteria for diagnosing primary adhesive capsulitis.In patients with primary adhesive capsulitis, thin-section 3D volumetric MR arthrography is a useful imaging modality to evaluate both joint capacity and capsular structure.

INTRODUCTION

The glenohumeral joint capsule is attached medially to the neck of the glenoid bone, laterally to the humeral neck, and superiorly to the coracoid process (Figure 1). The three anatomicalallocations affected by adhesive capsulitis in the shoulder joint are the synovium of the long head of the biceps tendon, rotator interval structures, and axillary recess capsule. The long head of the biceps tendon is covered by tendon synovium in the bicipital groove. The rotator interval is a three-angular anatomical structure localized between the anterosuperior border of the supraspinatus tendon and the superior border of the subscapularis tendon. Anterior and posterior bands of the inferior glenohumeral ligament reinforce the axillary recess capsule.

Adhesive capsulitis is commonly diagnosed on the basis of characteristic clinical features. However, in some cases, it may clinically mimic other causes of shoulder pain and restricted joint movement such as rotator cuff tear, subacromial impingement, calcific tendinitis, labral injury, and/or degenerative arthropathy.[1] Imaging methods including ultrasonography, MR imaging, CT, MR arthrography, CT arthrography, and conventional arthrography are frequently used to exclude these causes. Imaging modalities may also be particularly useful when surgical treatment is planned.

Figure 1. Illustration showing normal capsular anatomy of the glenohumeral joint.



Precise diagnosis of primary adhesive capsulitis is highly important for treatment planning. Several studies have shown that direct MR arthrography of the shoulder joint with intra-articular injection of diluted gadolinium contrast agent demonstrates specific imaging findings for adhesive capsulitis, including thickened and contracted axillary pouch, joint capsule biceps synovium, and rotator cuff interval.[2–4] Moreover, MR arthrographic images can clearly reveal thickened coracohumeral ligament and subcoracoid fat inflammation.[5,6] These capsular changes can theoretically result in total joint volume decrease. In this case, it is also expected that shoulder joint space obliteration will occur in specialized compartments such as the rotator interval, axillary pouch, and bicipital groove. To our knowledge, three-dimensional (3D) volumetric MR arthrographic assessment of true joint capacity in patients with adhesive capsulitis has not been previously reported in the literature. Accordingly, by using thin-section 3D volumetric MR arthrography sequencing, we compared joint volumes of patients with and without primary adhesive capsulitis.

METHODS AND MATERIALS

Patients

This retrospective study included 474 consecutive shoulder MR arthrograms of the patients that were referred to our hospital for MR arthrography of the shoulder joint between December 2010 and December 2017. The institutional review board at our hospital approved the study and all the patients gave consent for both MR arthrography imaging and injection procedures. A list of MR arthrograms of the shoulder joint obtained over a 7-year-period was retrieved from the database of our Radiology Department. We examined all the reports for MR arthrography findings suggestive of primary adhesive capsulitis on shoulder joint.

All shoulder MR arthrograms were retrieved and reviewed retrospectively by a musculoskeletal radiologist with 15 years of experience in musculoskeletal radiological procedures. As a result of review, shoulder MR arthrography images of 53 patients were included in the study. Of these, 28 (52.8%) patients that were diagnosed with primary adhesive capsulitis based on MR arthrography and clinical findings were assigned to the study group and the remaining 25 (47.2%) patients without clinical and radiological evidence of primary adhesive capsulitis were assigned to the control group. The clinical diagnostic criteria used for primary adhesive capsulitis included painful stiff shoulder for at least 5 weeks, severe shoulder pain interfering with performance of daily activities, night pain, painful restriction of both active and passive motion. MR arthrographic criteria for adhesive capsulitis included presence of thickened capsule and inflamed synovium in the areas of the rotator interval, axillary pouch, and bicipital synovium.

Patients with clinical and radiological findings of secondary adhesive capsulitis and those who had full-thickness rotator cuff tear, calcific tendinitis, subacromial impingement, previous cerebrovascular accident, cervical radiculopathy or syringomyelia, prior tumor surgery, or prior bone fracture were excluded from the study. The control patients had partial-thickness tear of rotator cuff, superior labral anterior posterior (SLAP) lesion, glenohumeral ligament rupture, articular cartilage defect, and arthrographically normal patients. Due to increased joint capacity,[7] patients with an unstable shoulder (Bankart and Bankart variant lesions) were not included in the control group. Patients with contrast media extravasation into the subacromial-subdeltoid and subcoracoid bursae were excluded from both groups. Some of the patients in the study group had idiopathic adhesive capsulitis associated with systemic diseases such as diabetes mellitus, thyroid disorders, connective tissue disease, or chronic renal failure. Other patients had no systemic disorders.

Injection technique

All injections were performed by a single radiologist on an outpatient basis, without sedation or pre-medication and using an ultrasonography system (Applio 500 Ultrasound System; Toshiba Medical Systems, Tokyo, Japan) equipped with a broadband 7.5–12 MHz linear array transducer. The posterior approach was preferred for the glenohumeral joint arthrography procedure. A 20-gauge needle was inserted into the glenohumeral joint space between the posterior glenoid labrum and humeral head using real-time ultrasound guidance. A diluted contrast media (0.5 mmol l^{-1} gadoterate meglumine dimeglumine, Dotarem; Guerbet, Aulnay-sous-Bois, France) was injected at a concentration of 1:200 (0.1 ml contrast media diluted by 20 ml normal saline). A volume of 10–20 ml gadolinium-based solution was injected until the joint capsule was appropriately distended. The volume of injection was determined according to the patient's comfort level and resistance to the injection.

MR arthrography technique

MR arthrography examinations were performed using a 3T MR (Magnetom Skyra; Siemens Healthcare, Erlangen, Germany) within 10–15 min after the shoulder joint injection. Our MR

arthrography protocol includes spin-echo T_1 weighted (repetition time/ echo time, 650/15 ms; echo train length, 8; section thickness, 3 mm; spacing, 0.3 mm; field of view, 130–200 mm; matrix, 256 × 256; three signals acquired) and fat-suppressed spin-echo T_1 weighted images. Arthrography images were obtained in the axial, oblique coronal, and oblique sagittal planes with surface coils placed around the shoulder joint. In our clinical practice, a fat-suppressed 3D volumetric interpolated breath-hold examination (VIBE) sequence (repetition time/ echo time, 13.2/4.7 ms; flip angle, 11◦; 130 × 150 mm FOV; matrix, 512 × 512; one slab of 112 slices with a slice thickness of 0.6 mm; one acquisition) was also added to the shoulder MR arthrography protocol.

Image analysis

All the MR arthrography images were reviewed on high-resolution monitors using a picture archiving and communication system (Syngo Via console, software v. 2.0; Siemens Medical Solutions, Erlangen, Germany). The MR arthrography images in random order were retrospectively reviewed by one musculoskeletal radiologist with 15 years of experience.

Volumetric measurements of total glenohumeral joint capacity, extra-articular contrast material leakage, rotator interval capacity, axillar recess capacity, and bicipital groove space were performed on a 3D volume measurement workstation (Myrian Pro, Intrasense, France) for the study and control groups (Figures 2 and 3). The aforementioned volumetric examinations were compared between the two groups.

Statistical analysis

Statistical analyses were performed using SPSS for Windows v. 20.0 (Armonk, NY: IBM Corp.). Normality of the data was analyzed using the Kolmogorov-Smirnov test. The Mann-Whitney U test was performed for comparison of extravasation, rotator interval, axillary recess, and bicipital groove volumes between the study and control groups. Total and residual glenohumeral joint capacities for study and control groups were also compared using the Mann-Whitney U test. The Kruskal-Wallis test was used to compare the relationship between age and all the volumetric measurements. Relationship between sex and all the volumetric measurements were assessed using the Chi-square test. A p value of ≤ 0.05 was considered significant.

Figure 2. The axillary pouch and rotator interval volume measurement methods in an MR arthrographically normal patient with unexplained shoulder pain. (a) Sagittal and coronal oblique fat-suppressed 3D VIBE MR arthrography images reveal rotator interval volume measurement levels. Volume measurements were performed superiorly from the anterior border of the supraspinatus tendon inferiorly to the superior aspect of the subscapularis tendon and medially from the base of the coracoid process laterally to the biceps pulley. (b) Coronal and sagittal oblique and axial fat-suppressed 3D VIBE MR arthrography images reveal axillary pouch volume measurement levels. The volume measurements were performed inferiorly from the bottom of the axillary recess superiorly to the inferior glenoid margin. 3D, VIBE, volumetric interpolated breath-hold examination.

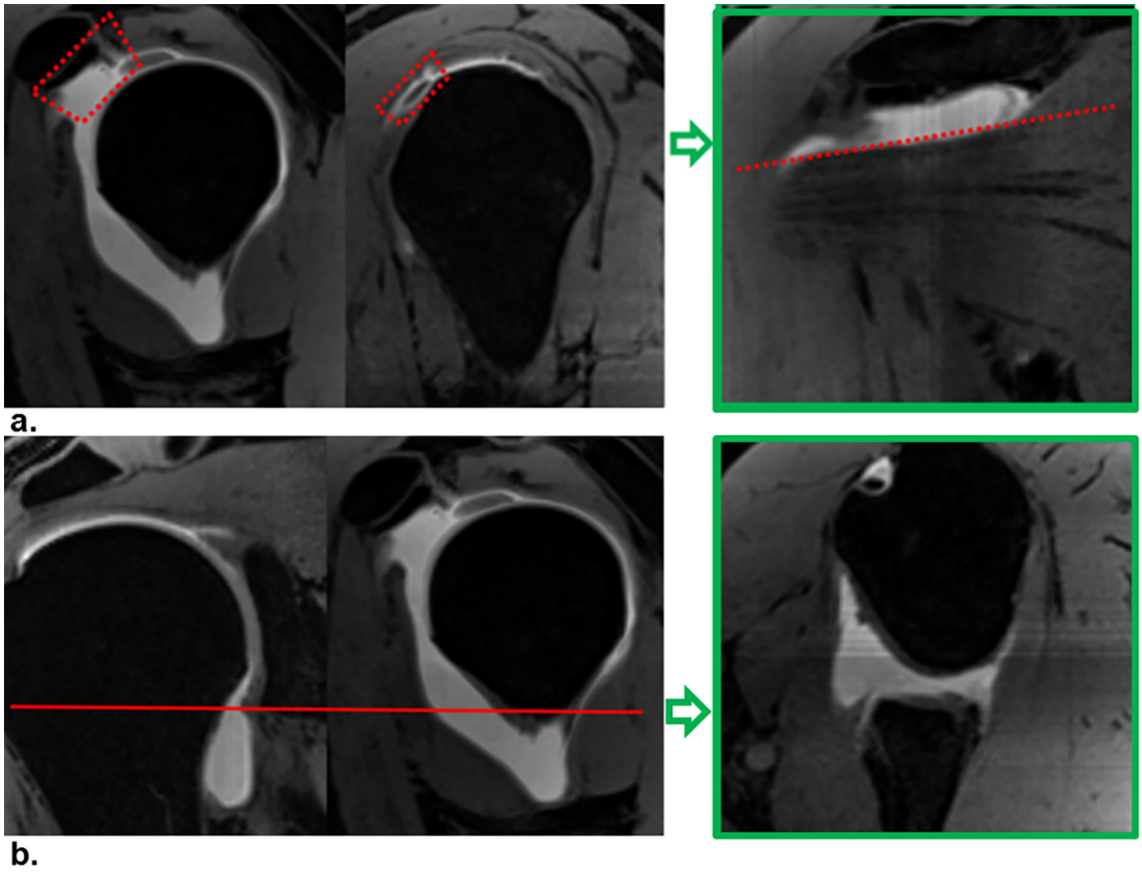
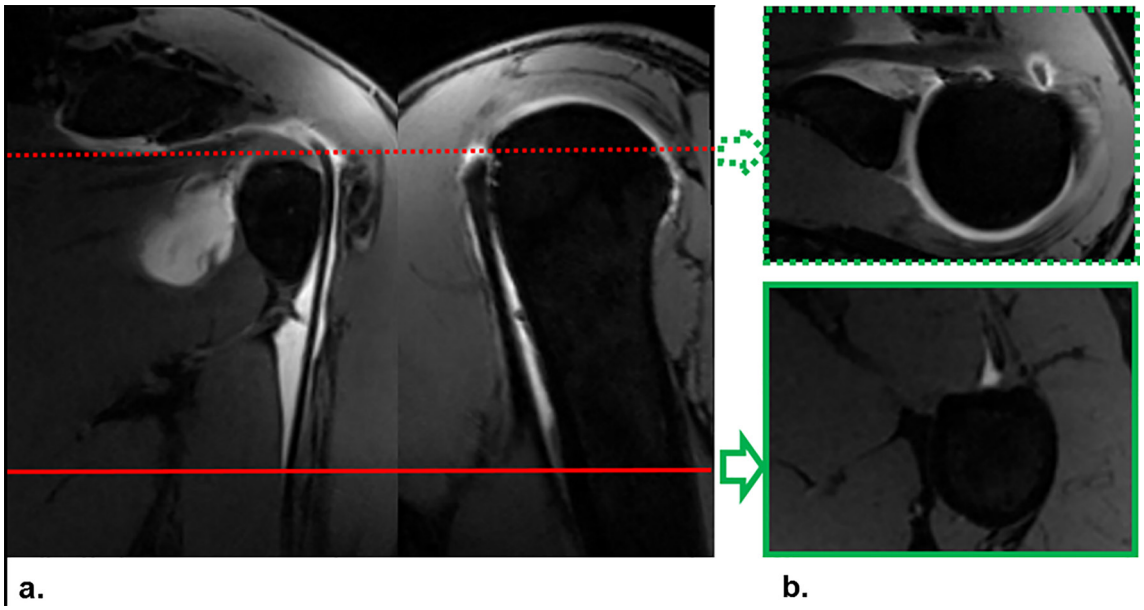


Figure 3. The biceps sheath volume measurement method in an MR arthrographically normal patient with unexplained anterior shoulder pain. Coronal and sagittal oblique fat-suppressed 3D VIBE MR arthrography images reveal biceps sheath volume measurement levels. The volume measurements were performed inferiorly from the bottom of the biceps sheath superiorly to the upper margin of the biceps pulley. 3D, three-dimensional; VIBE, volumetric interpolated breath-hold examination.



RESULTS

The retrospective study included a patient group of 28 consecutive patients with primary adhesive capsulitis comprising 14 (50%) females and 14 (50%) males with a mean age of 44.5 ± 9.3 (range, 30–62) years and a control group of 25 patients without adhesive capsulitis comprising 10 (40%) females and 15 (60%) males with a mean age of 40.1 ± 9.2 (range, 27–57) years. Demographic data were summarized in Table 1.

In both groups, no significant relationship was found between age and volumetric measurements ($p = 0.234$) and between sex and volumetric measurements ($p = 0.189$).

Mean volume of the rotator interval was significantly lower in the patient group compared to the control group (7.67 ± 2.6 cm^3 *vs* 12.31 ± 2.5 cm^3) ($p < 0.0001$). Similarly, mean volume of bicipital groove was significantly lower in the patient group compared to the control group (1.67 ± 0.9 cm^3 *vs* 2.88 ± 0.9 cm^3) ($p < 0.0001$). However, although mean volume of axillary recess was lower in the patient group compared to the control group (3.21 ± 1.1 cm^3 *vs* 4.04 ± 1.7 cm^3), no significant difference was established ($p = 0.123$).

In contrast, mean volume of extra-articular contrast material extravasation was higher in the patient group compared to the

Table 1. Demographic factors and clinical variables

	Study group	Control group
Gender	14F, 14M	10F, 15M
Shoulder side	11L, 17 R	15L, 10R
Mean age	44.5 ± 9.3 (range, 30–62)	40.1 ± 9.2 (range, 27–57)
Arthrographic diagnosis	MR arthrographic findings of idiopathic adhesive capsulitis without other arthrographic pathology ($n = 28$)	Arthrograpically normal ($n = 5$), SLAP lesion ($n = 10$), undersurface partial rotator cuff tear ($n = 5$), GHL tear ($n = 4$), glenoid cartilage defect ($n = 1$)
Clinic diagnosis	Clinic findings of idiopathic adhesive capsulitis associated with diabetes mellitus ($n = 10$), clinic findings of idiopathic adhesive capsulitis associated with thyroidopathy ($n = 6$), clinic findings of idiopathic adhesive capsulitis associated with connective tissue disease ($n = 4$), clinic findings of idiopathic adhesive capsulitis without other clinic entity ($n = 8$)	Non-specific shoulder pain ($n = 15$), clinic findings of SLAP lesion and rotator cuff tendinopathy ($n = 10$)
Therapy	Arthroscopic capsulotomy ($n = 8$), physical therapy, and medical therapy ($n = 20$)	Arthroscopic SLAP lesion repair ($n = 8$), arthroscopic rotator cuff tear repair ($n = 3$), medical therapy with NSAID (14)

SLAP, superior labral anterior posterior; NSAID, Non Steroidal anti inflamatuar drug;GHL, glenohumeral ligament;

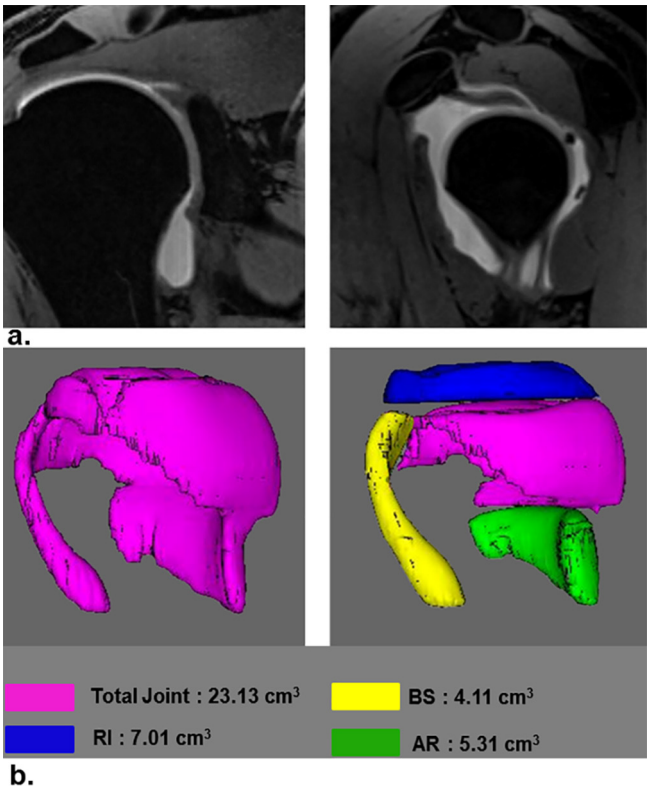
Table 2. The mean volumetric measurements in both study and control groups

	Study group (with adhesive capsulitis)	Control group (without adhesive capsulitis)	*p* values
Axillary recess volume	[a]3.21 ± 1.1 cm^3 (range, 1.1–5.6 cm^3)	[a]4.04 ± 1.7 cm^3 (range, 1.3–8.2 cm^3)	$p = 0.123$
Rotator interval volume	[a]7.67 ± 2.6 cm^3 (range, 3.3–13.1 cm^3)	[a]12.31 ± 2.5 cm^3 (range, 6.4–15.5 cm^3)	***p < 0.0001***
Bicipital groove volume	[a]1.67 ± 0.9 cm^3 (range, 0.0–2.8 cm^3)	[a]2.88 ± 0.9 cm^3 (range, 1.1–4.2 cm^3)	***p < 0.0001***
Extravasation volume	[a]9.93 ± 1.7 cm^3 (range, 6.7–13.6 cm^3)	[a]5.1 ± 1.4 cm^3 (range, 0.0–18.6 cm^3)	***p = 0.002***
Total glenohumeral joint capacity	[a]22.52 ± 1.1 cm^3 (range, 16.0–30.3 cm^3)	[a]26.01 ± 1.2 cm^3 (range, 14.0–31.6 cm^3)	***p = 0.003***

[a]The mean volume values for each comparison between the study and control group.

control group (9.93 ± 1.7 cm^3 *vs* 5.1 ± 1.4 cm^3) (p = 0.002). However, mean total glenohumeral joint volume was lower in the patient group compared to the control group (22.52 ± 1.1 cm^3 *vs* 26.01 ± 1.2 cm^3) (p = 0.003). Table 2 presents volumetric measurements for both groups. Figures 4–6 illustrate 3D volumetric MR arthrography measurements for both groups.

Figure 4. A 40-year-old female with anterior shoulder pain (a patient from the control group). (a) Coronal and sagittal oblique fat-suppressed 3D VIBE MR arthrography images show the axillary recess and rotator interval capsules at normal thickness. The images also reveal an intact subcoracoid triangle fat pad. (b) 3D volume-rendering MR arthrography images reveal volumes of the glenohumeral joint and its components. 3D, three-dimensional; VIBE, volumetric interpolated breath-hold examination.



DISCUSSION

Adhesive capsulitis or "frozen shoulder" is a clinical condition defined as painful restriction of both active and passive shoulder motion. The disease concludes with progressive fibrosis and eventual contracture of the shoulder joint capsule.[8,9] Therefore, some investigators have advocated the idea that the shoulder joint capacity decreases in adhesive capsulitis.[10,11] However, this

Figure 5. A 48-year-old male with a clinical diagnosis of adhesive capsulitis. (a) Coronal and sagittal oblique fat-suppressed 3D VIBE MR arthrography images show markedly thickened axillary recess and rotator interval capsules. The images also reveal complete obliteration of the subcoracoid triangle fat pad. (b) 3D volume-rendering MR arthrography images reveal volumes of the glenohumeral joint and its components. The images also show pericapsular contrast material extravasation and decreased bicipital groove and axillary recess volumes.

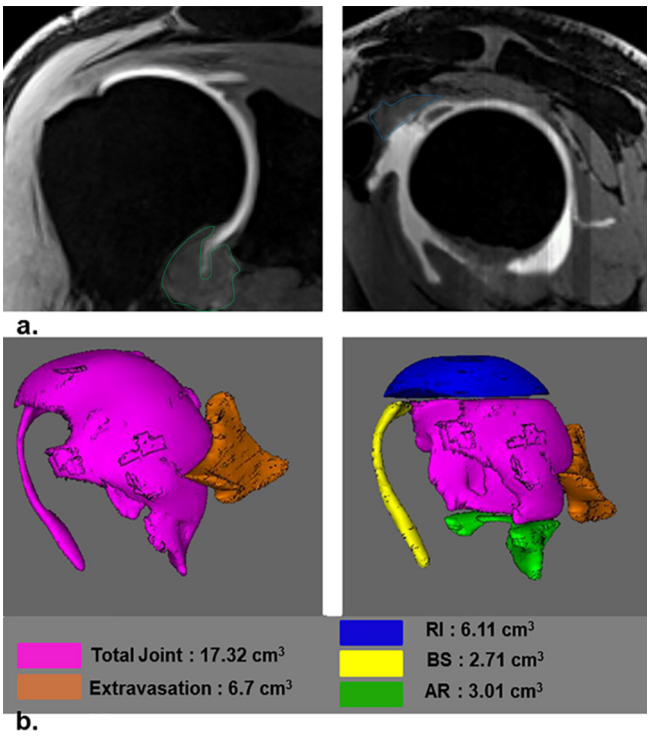
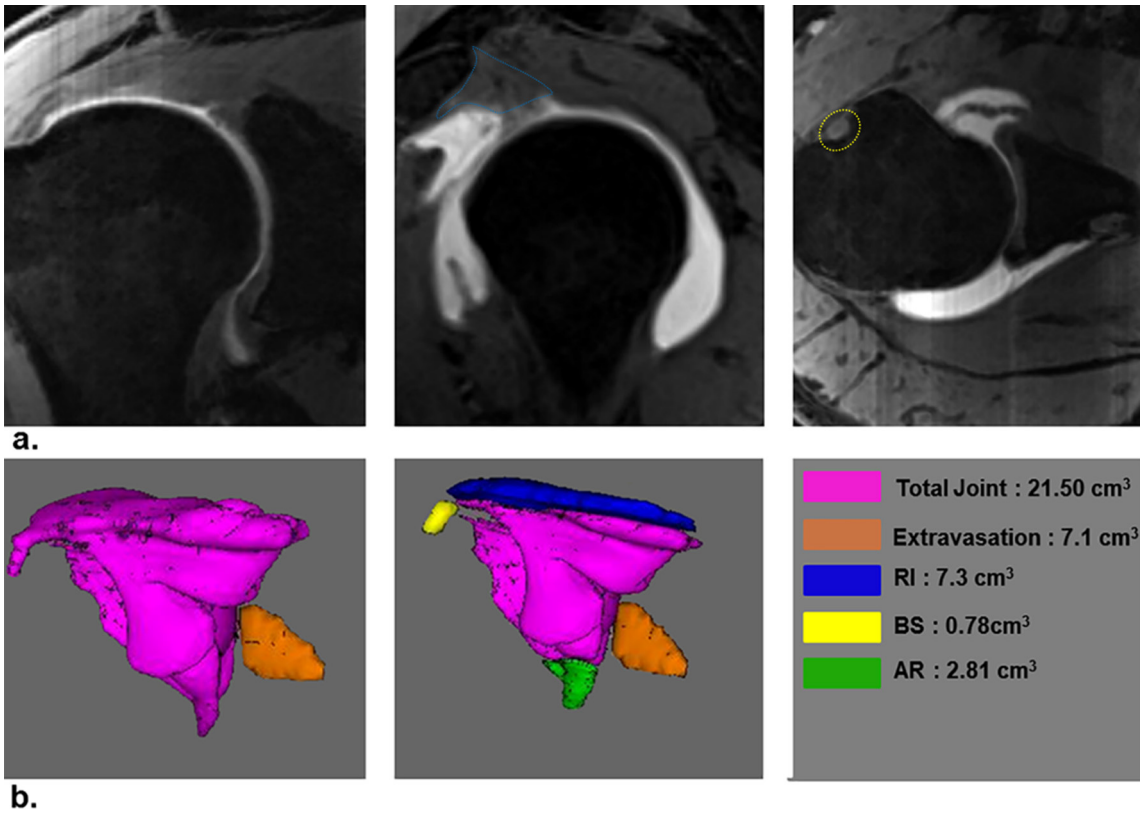


Figure 6. A 39-year-old female with a clinical diagnosis of adhesive capsulitis. (a) Coronal and sagittal oblique fat-suppressed 3D VIBE MR arthrography images show mildly thickened axillary recess capsule and markedly thickened rotator interval capsule. The images also reveal complete obliteration of the subcoracoid triangle fat pad. Axial fat-suppressed 3D VIBE MR arthrography image shows stenosing tenosynovitis of the biceps tendon. (b) 3D volume-rendering MR arthrography images reveal volumes of the glenohumeral joint and its components. The images also show pericapsular contrast material extravasation and markedly decreased bicipital groove and axillary recess volumes. 3D, three-dimensional; VIBE, volumetric interpolated breath-hold examination.



idea is controversial since some other authors have claimed that the injection volume in patients with adhesive capsulitis may be normal or even increased in the presence of full-thickness rotator cuff tears.[2] In the present study, we compared the volume of other components of the shoulder joint and the total shoulder joint capacity in patients with and without primary adhesive capsulitis by using thin-section 3D volumetric MR arthrography. The results indicated that total shoulder joint capacity and both the rotator interval and biceps sheath volumes showed statistically significant differences between the patients and the control subjects.

In a previous arthrographic study, Neviaser described decreased joint capacity in addition to variable obliteration of the axillary pouch, rotator interval, and bicipital groove.[10] Moreover, the authors also arthrographically defined an irregular internal capsular border and synovial septal formation associated with reduced capsular distension. The study also showed contrast material extravasation through the synovium of the biceps and the subscapular recess. Although conventional arthrography is considered the "golden standard" for adhesive capsulitis, extravasation may obscure the characteristic arthrographic findings described for adhesive capsulitis. Additionally, other common shoulder lesions such as SLAP lesion may reveal similar arthrographic findings.[6] In our series, contrast material extravasation was detected in 20 (71%) out of 28 patients as opposed to 12 (48%) out of 25 control subjects. These findings support our hypothesis.

Other arthrographic criterion for the diagnosis of adhesive capsulitis is anterior capsular insertion irregularity at the neck of the humerus.[12,13] However, the same arthrographic findings may also indicate humeral avulsion of the glenohumeral ligament lesion. Therefore, these findings can lead to diagnostic errors.

Another arthrographic finding described for adhesive capsulitis is an injection solution volume of <10 cc in the shoulder joint.[12–15] However, although this finding has been defined as a reference standard for adhesive capsulitis, some authors have reported contradictory evidence.[2,16,17] In a previous MR arthrographic study, Mengiardi et al claimed that the injected diluted contrast volume in patients with adhesive capsulitis may be normal (standard) or even increased in the presence of full-thickness rotator cuff tears. The authors suggested that the injection volume may be increased when there is contrast material extravasation through the subscapular recess.[2] As mentioned by Mengiardi et al we do not consider that an adhesive capsulitis diagnosis should be made on the basis of reduced injection volume. In the present

study, an injection solution volume of <10 cc was not detected in any patient with primary adhesive capsulitis. Moreover, contrast material extravasation was detected in 71% of the patients with adhesive capsulitis.

In another MR arthrographic study performed by Ogul et al the authors evaluated the localization, frequency, and amount of extravasation in patients with extra-articular contrast material extravasation into locations unrelated to the injection path in shoulder and shoulder-associated pathologies.[6] The authors showed that massive subscapular extravasations were most frequently associated with adhesive capsulitis and SLAP lesions. Similar to the results of this study, our study also showed that 10 out of 25 control subjects had a SLAP lesion. Moreover, massive subscapular extravasation was detected in the majority of these patients. On the other hand, since increased joint capacity is well known in the pathophysiology of shoulder instability and full-thickness rotator cuff tear, we did not include these patients in the control group. Moreover, due to the posterior capsular contracture in Type 2 SLAP lesions, it can be considered that these patients had decreased shoulder joint capacity.[18] These views explain the reason as to why contrast extravasation is frequently seen in patients with SLAP lesions. Therefore, we consider that using contrast extravasation as the only diagnostic criterion for adhesive capsulitis is not reasonable.

Diluted contrast agent leak out of the shoulder joint capsule can obscure important anatomical structures (such as axillary pouch, bicipital groove, and subscapular recess) in the diagnosis of adhesive capsulitis performed with conventional arthrography and may prevent accurate diagnosis. Although conventional arthrographic techniques have been accepted as the golden standard for many years, they cannot be used to examine the changes in the joint synovium and perisynovial soft tissue in adhesive capsulitis. Therefore, we performed thin-section 3D volumetric MR arthrography in order to perform an optimal evaluation for both joints and/or their component volumes and capsular and/or pericapsular structures.

The MR arthrographic assessment of the rotator interval structures is important for diagnosis of adhesive capsulitis. Some MR arthrographic studies showed that there were no significant differences in the rotator interval width between the patients with and without adhesive capsulitis.[4,19,20] On the other hand, in an MR arthrographic study performed by Mengiardi et al[2] the authors described coracohumeral ligament thickening and rotator interval capsule and obliteration of the subcoracoid triangle as characteristic MR arthrographic features in adhesive capsulitis. In addition, the authors also showed synovial inflammation-like formation around the biceps tendon in many patients with adhesive capsulitis. Similarly, Jung et al[3] demonstrated a significant decrease in rotator interval width and capsular fibrosis in the rotator interval in MR arthrography of patients with adhesive capsulitis. In a similar study, Kim et al[17] also showed a significant decrease in rotator interval volume in patients with adhesive capsulitis.

In the majority of MR arthrographic studies, the rotator interval width was measured at the level of the coracoid process tip on oblique sagittal images. Due to extravasations through the subscapular recess and the anatomical variations in subcoracoid synovium, the joint capacity in this location varies widely among patients. Accordingly, these measurement techniques are not sensitive enough and are indirect volumetric measurements. Therefore, in the present study, we performed volumetric measurements using thin-section MR arthrography sequence (VIBE) on a 3D volume measurement workstation. Similar to the findings of Mengiardi et al, Jung et al, and Kim et al, [2,3,17] we found a significant decrease in the mean rotator interval volume in the patient group compared to the control group. Using the same measurement method, we also found that the mean bicipital sheath volume was also lower in the patient group compared to the control group. These findings suggest that decreased rotator interval and bicipital sheath volumes are useful diagnostic criteria for adhesive capsulitis on 3D volumetric MR arthrography.

Capsular thickness at the axillary recess of the patients with adhesive capsulitis has been previously demonstrated on conventional MRI and MR arthrography.[3,20,21] However, some authors showed no significant differences in capsular thickness between patients with and without adhesive capsulitis.[2,19] On the other hand, reduced axillary recess volume indirectly measured on MR arthrography has been evaluated as an imaging criterion for adhesive capsulitis by some authors, [2,20] while some other authors do not approve the use of this criterion.[19] In our patients, we found no significant difference between the patient and control groups in terms of axillary recess volume.

There were several potential limitations in our study. Our main limitation was the lack of a golden standard for the diagnosis of adhesive capsulitis. Since the use of conventional arthrography and arthroscopic examination for adhesive capsulitis diagnosis is controversial, we used a combination of physical examination and imaging findings as the diagnostic criteria. The patients in the adhesive capsulitis group met all the clinical criteria and at least one of the MR criteria defined for adhesive capsulitis in the literature. The majority of individuals in both groups were not arthroscopically confirmed. Another limitation was the retrospective nature of our study. However, there was no correlation between clinical disease staging and the MRI findings. Another potential limitation of our study was the absence of inter- or intra-observer correlation. Finally, due to the variable capsular anatomy, the injected diluted contrast material volume was variable in both groups.

In conclusion, obliterations in the biceps tendon sheath and rotator interval as well as decreased joint capacity on 3D volumetric MR arthrographic examination may be another useful imaging criteria for diagnosing primary adhesive capsulitis, in addition to the previously described characteristic MR findings, including thickened rotator cuff interval capsule and hypertrophic synovial tissue around the biceps anchor.

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