Technical Note

Direct MR Arthrography of the Shoulder at 3 Tesla: Optimization of Gadolinium Concentration

Yao Shang, MD, Zhuo-zhao Zheng, MD,* and Xuan Li, MD

Purpose: To determine the optimal concentration of gadopentetate dimeglumine for direct shoulder MR arthrography at 3T in vivo.

Materials and Methods: Sixty-eight consecutive shoulder MR arthrograms were obtained with 1 mmolGd/L (n = 12), 2 mmolGd/L (n = 12), 4 mmolGd/L (n = 12), 6 mmolGd/L (n = 12), 9 mmolGd/L (n = 10) and 12 mmolGd/L (n = 10). All postinjection fat-suppressed T1-weighted and T2-weighted images were analyzed retrospectively. For qualitative evaluation, image contrast was graded on a subjective three-level scale (excellent, moderate, and poor). For quantitative analysis, the contrast-to-noise ratio (CNR) of intra-articular fluid to muscle was measured.

Results: All postinjection T1-weighted images and T2-weighted images with 1 mmolGd/L, 2 mmolGd/L, 4 mmolGd/L, and 6 mmolGd/L were qualitatively evaluated as excellent or moderate. Two of the ten 9-mmolGd/L images and seven of the ten 12-mmolGd/L images were rated as poor with regard to the T2 image contrast. On the T1-weighted images, no significant difference existed between the CNRs of the six concentrations, but a peak CNR was seen at the concentration of 6 mmolGd/L. On the T2-weighted images, CNRs at concentrations of 1 mmolGd/L, 2 mmolGd/L, 4 mmolGd/L, 6 mmolGd/L, and 9 mmolGd/L showed no statistical difference, but were all significantly higher than that with 12 mmolGd/L.

Conclusion: The acceptable concentration of gadopentetate dimeglumine for shoulder MR arthrography at 3T was found to be in the range of 1 mmolGd/L to 6 mmolGd/L. 6 mmolGd/L may be the optimal concentration.

Key Words: magnetic resonance imaging; shoulder; arthrography; gadopentetate dimeglumine
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DIRECT MR ARTHROGRAPHY with gadopentetate dimeglumine has been proven to be an effective method in assessing internal derangements of the major joints, particularly for partial-thickness rotator cuff tears, glenoid labral tears, re-tear of the meniscus postoperation, acetabular labrum tears, injuries of the triangular fibrocartilage complex, and osteochondral lesions (1–4). The optimized concentration of gadopentetate dimeglumine for MR arthrography at 1.5T has been suggested to be 2 mmolGd/L (5–8). However, optimization studies for gadopentetate dimeglumine concentrations at 3T in vivo have not previously been performed in depth. In several recent in vitro studies, the optimal concentrations for direct MR arthrograms at 3T were reported (9–11), but results of phantom studies may differ from those obtained in vivo.

In addition, direct MR arthrograms with gadolinium may be performed without preceding conventional MR examinations in clinical practice. Under these circumstances, supplemental T2-weighted images are indispensable because these images aid in the identification of extra-articular fluid collections, periarticular masses, bone marrow lesions, and certain specific injuries. For example, in the shoulder, the bursal-sided or intrasubstance partial-thickness tears of the rotator cuff can only be well-assessed by T2-weighted images. Therefore, during MR arthrography, it is advisable to consider the influence of intra-articular gadopentetate dimeglumine on T2-weighted images as well. This influence, however, has not been fully evaluated in vivo.

The purpose of the present study was to evaluate the influence of intra-articular gadopentetate dimeglumine qualitatively and quantitatively on both postinjection T1-weighted and T2-weighted images to determine the optimum concentration of gadolinium for the shoulder at 3T in vivo.

MATERIAL AND METHODS

Patients

Sixty-eight consecutive patients (21 female, 47 male; age range, 16–62 years; mean age, 34 years) referred for MR arthrography of the glenohumeral joint were included in this prospective study. The only exclusion criterion was in the patient had prior shoulder surgery or arthroscopy. These patients were examined for suspected labrum disorders (n = 36), suspected rotator cuff disorders (n = 24), or shoulder pain with unknown cause (n = 8). This project was approved by the investigational review board of our hospital, and informed consent was obtained from all patients.

Department of Radiology, Peking University Third Hospital, Haidian District, Beijing, China.
*Address reprint requests to: Z.-z.Z., Department of Radiology, Peking University Third Hospital, 49 North Garden Road , Haidian District, Beijing 100191, P.R. China. E-mail: zzhuozhao@yahoo.com.cn
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MR Arthrography

Joint puncture was performed with fluoroscopic guidance by a musculoskeletal radiologist with 10 years of experience in arthrography. A 21-gauge needle was placed into the glenohumeral joint by means of a rotator interval approach. This was used to inject 10–12 mL of prepared contrast material into the shoulder after aspiration of any joint fluid. On the basis of our previous experience, this procedure was performed with only minor pain or discomfort of the patient, so local anesthesia was not necessary.

The contrast material injected was a mixture of diluted Magnevist solution(Schering, GuangZhou, China), iodine-based contrast (Omnipaque 300 mg I/mL; AnSheng, ShangHai, China), and lidocaine hydrochloride injection. The admixture was prepared as follows: first, a variable amount of Magnevist was added to 250 mL of normal saline, then 5 mL of this solution was mixed with 5 mL of iodinated contrast and 5 mL of lidocaine using a 20-mL syringe before injection (12). The final gadolinium concentration of the contrast material was adjusted to 1 mmolGd/L (n = 12), 2 mmolGd/L (n = 12), 4 mmolGd/L (n = 12), 6 mmolGd/L(n = 12), 9 mmolGd/L(n = 10), and 12 mmolGd/L(n = 10).

All patients underwent MR imaging of the shoulder on a 3.0 Tesla (T) scanner (Magnetom Trio with TIM system, Siemens, Erlangen, Germany) with a maximum gradient amplitude of 45 mT/m and a maximum slew rate of 200 mT/m/s. The time interval between joint injection and initiation of imaging was strictly controlled to be within 30 min (13). The patient was placed in a supine position, with the affected shoulder wrapped by a dedicated flexible surface coil (4-Channel Flex Coil, Large) supplied by the MR manufacturer. The arm position was standardized, with the thumb pointing upward. Fat saturation T1-weighted turbo spin-echo images were obtained in the transverse plane and in the coronal oblique plane, parallel to the long axis of the supraspinatus tendon (700 ms / 12 ms [repetition time / echo time], 3.5 mm section thickness, 160 mm × 160 mm field of view, 2 turbo factors). Fat saturation T2-weighted turbo spin-echo images (3200/78, 4 mm section thickness, 160 mm × 160 mm field of view, 11 turbo factors) were obtained routinely in the coronal oblique plane. T1-weighted turbo spin-echo images were also obtained in the sagittal oblique plane, perpendicular to the long axis of the supraspinatus tendon (650/11, 4-mm section thickness, 160 mm × 160 mm field of view). The total MR examination time was approximately 13 minutes long.

Qualitative Assessment of Images

Two musculoskeletal radiologists, blinded to the exact gadolinium concentration used, reviewed all MR images independently by an image processing workstation (Leonardo, Siemens Medical Systems). Qualitative evaluation of image contrast between intra-articular fluid and adjacent structures on fat-suppressed T1-weighted sequence and fat-suppressed T2-weighted sequence was graded on a subjective three-level scale: "excellent" meant a homogenous high signal of the intra-articular fluid, distinct contrast between the intra-articular fluid and other relevant structures, and completely satisfactory for diagnostic purposes; "moderate" meant a nonhomogenous high signal of the intra-articular fluid with vague low signal intensity regionally, but contrast still sufficient for diagnosis; "poor" meant a nonhomogenous signal of the intra-articular fluid with obvious low signal intensity regionally or a homogenous low signal of the intra-articular fluid, and diagnosis may be confused.

Quantitative Assessment of Images

On the axial fat-suppressed T1-weighted images through the middle-lower part of the glenohumeral joint, the contrast-to-noise ratios (CNRs) between the intra-articular contrast material and the teres minor muscle were calculated. Signal intensities were measured by region of interest (ROI) using the same image processing workstation mentioned above. All ROI measurements were performed by the same analyst. Oval ROIs were drawn in the areas of the contrast-enhanced posterior joint cavity and the muscle belly of the teres minor behind the glenoid neck, as large as possible without including adjacent structures. The standard deviation (SD) of the background signal intensity was obtained by placing a ROI no less than 100 mm^2 in the air anterior to the body along the phase-encoding direction. CNRs were then calculated by dividing the difference in mean signal intensity of intra-articular contrast material and the muscle belly by the SD of the air (14).

On the coronal oblique fat-suppressed T2-weighted image through the long axis of the supraspinatus tendon, oval ROIs were drawn in the areas of the axillary recess, the musculotendinous junction of the supraspinatus, and the air lateral to the body. The ROI sizes in the axillary recess and supraspinatus were made as large as possible without including adjacent structures. The ROI in the air was no less than 100 mm^2. CNRs of the intra-articular fluid to the supraspinatus were then calculated by the method described earlier.

Statistics Evaluation

One-way analysis of variance (ANOVA) was used to compare the CNRs of the six concentrations on both the T1-weighted images and the T2-weighted images. If the difference was determined to be significant, least-significance-difference (LSD) method was then used to compare each two concentrations. Statistical analysis was performed by SPSS 11.5 software (SPSS Inc., Chicago, IL), and a P value less than 0.05 was considered to be statistically significant.

RESULTS

Qualitative Assessment

Table 1 gives an overview of the frequency distribution of the different quality ratings made by the two readers. When examining the T1-weighted sequence, all MR arthrograms obtained with 1 mmolGd/L to 6 mmolGd/L were graded as excellent by both readers. A few discrepancies between the readers existed in the grading of MR

Table 1
Overview of Frequency Distribution of Image Contrast Ratings

	FS T1-Weighted			FS T2-Weighted		
	Excellent	Moderate	Poor	Excellent	Moderate	Poor
1 mmolGd/L	12 (12)	0 (0)	0 (0)	12 (12)	0 (0)	0 (0)
2 mmolGd/L	12 (12)	0 (0)	0 (0)	12 (12)	0 (0)	0 (0)
4 mmolGd/L	12 (12)	0 (0)	0 (0)	12 (12)	0 (0)	0 (0)
6 mmolGd/L	12 (12)	0 (0)	0 (0)	12 (10)	0 (2)	0 (0)
9 mmolGd/L	10 (9)	0 (1)	0 (0)	6 (4)	4 (4)	0 (2)
12 mmolGd/L	6 (7)	4 (3)	0 (0)	0 (1)	3 (2)	7 (7)

The numbers outside the parentheses are the grading results of reader 1, and the numbers within the parentheses are the grading results of reader 2.

arthrograms obtained with 9 mmolGd/L and 12 mmolGd/L, but all of them were still rated as sufficient for diagnosis (excellent or moderate) (Fig. 1).

Both readers agreed on the fat suppressed T2-weighted images with 1 mmolGd/L, 2 mmolGd/L, and 4 mmolGd/L, which were all rated as excellent. A few discrepancies were noted for T2-weighted images with a concentration of 6 mmolGd/L, but were still rated as sufficient for diagnostic purposes. Two patients with 9 mmolGd/L were graded as poor by reader 2, but not by reader 1, and seven with 12 mmolGd/L were graded as poor by both readers (Fig. 2).

Quantitative Assessment

With the fat suppressed T1-weighted MR arthrograms, there was no statistically significant difference of CNRs among the six concentrations ($F = 2.26$; $P = 0.064$). The highest mean CNR was obtained with 6 mmolGd/L (Fig. 3).

With the fat suppressed T2-weighted images, a statistically significant difference of CNRs was seen among the six different concentrations ($F = 8.11$; $P < 0.001$). Further analysis by LSD revealed that the CNRs for concentrations of 1 mmolGd/L, 2 mmolGd/L, 4 mmolGd/L, 6 mmolGd/L, and 9 mmolGd/L showed no significant difference for each two concentrations, but were all statistically higher than the CNR with a concentration of 12 mmolGd/L (Fig. 4).

DISCUSSION

When performing direct MR arthrography of the shoulder at 3T in vivo, this study found that the acceptable concentration of gadopentetate dimeglumine could range from 1 mmolGd/L to 12 mmolGd/L if only postinjection T1-weighted images were taken into account. All MR arthrograms with these concentrations were sufficient for diagnosis with regard to image contrast and had similar CNRs of intra-articular contrast material to the surrounding muscles. In addition, the concentrations from 1 mmolGd/L to 6 mmolGd/L were found to be superior, due to the possibility of a slightly deteriorated image contrast with higher gadolinium concentrations.

However, when fat suppressed T2-weighed images were integrated to the consideration concomitantly, this study indicated that 12 mmolGd/L and 9 mmolGd/L should not be used for direct MR arthrography. These two concentrations may lead to a severe loss of signal intensity of the intra-articular fluid on postinjection T2-weighed images in several cases, and a concentration of 12 mmolGd/L will also result in a significantly lower CNR of the intra-articular fluid to the supraspinatus. Fat suppressed T2-weighed images obtained using the other concentrations (1 mmolGd/L to 6 mmolGd/L) were found to be acceptable both qualitatively and quantitatively, despite a few cases using a concentration of 6 mmolGd/L might show a suboptimal T2 contrast.

Therefore, with consideration for both T1-weighted and T2-weighted images, the concentrations ranging from 1 mmolGd/L to 6 mmolGd/L were all found to be acceptable for direct shoulder MR arthrography at 3T. But which one would be the optimal concentration within this range? Due to the general concept of MR arthrography emphasizing the T1 contrast and the fact that concentration of 6 mmolGd/L provided the highest mean CNR on T1-weighed images, we consider 6 mmolGd/L to be the optimal concentration.

The acceptable range of gadolinium concentration defined by present study was not conflicted with values suggested by previous studies with lower scanner field strength, in which gadolinium concentrations ranging from 1 mmolGd/L to 10 mmolGd/L had been recommended for direct MR arthrography, with a concentration of 2 mmolGd/L being the most frequently used. For instance, 1 mmolGd/L was recommended by Hajek et al (15), 2 mmolGd/L by Palmer and Caslowitz (12), 2.5 mmolGd/L by Jacobson et al (16), 4 mmolGd/L by Czerny et al (17), 5 mmolGd/L by Brenner et al (13), and 10 mmolGd/L by Kopka et al (18).

However, the optimal concentration of 6 mmolGd/L, with a peak CNR for the T1-weighed images in this study, was unexpectedly higher than the concentrations recommended by previous phantom studies. For example, Montgomery et al (19) found that peak signal of gadolinium contrast diluted in saline for T1-weighted images was observed at 0.625–2.5 mmolGd/L at 0.2T and 2.5 mmolGd/L at 1.5T. Masi et al (9) and Andreisek et al (10) recommended the optimum gadolinium concentration in the range of 1.25–2 mmolGd/L and 0.7–3.4 mmolGd/L, respectively, in later phantom studies at 3T, based on the results of signal to noise ratio on T1-weighted sequences. The discrepancy of results between our study in vivo and those studies in vitro may be ascribed to many factors, such as interaction of

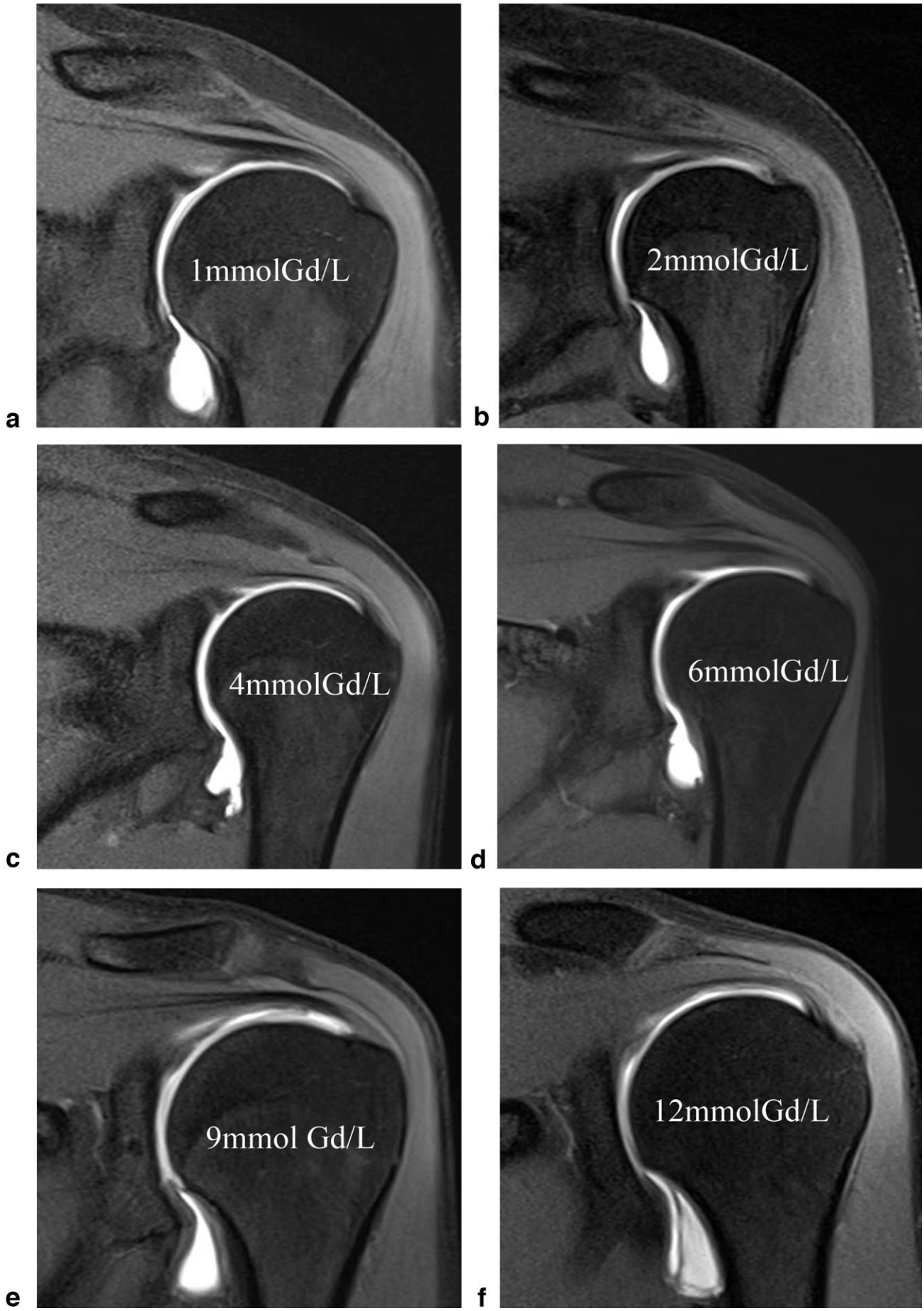

Figure 1. Coronal oblique fat-suppressed T1-weighted MR arthrograms obtained with different concentrations of gadopentetate dimeglumine. The panels **a–e** have excellent image contrast, however, **f** is graded moderate due to inhomogeneous signal intensity of the contrast material.

Figure 2. Coronal oblique fat-suppressed T2-weighted MR arthrograms obtained with different concentrations of gadopentetate dimeglumine. The panels **a–d** have excellent image contrast, however, **e** is sorted moderate due to inhomogeneous signal intensity of the fluid, and **f** is graded poor due to marked low signal intensity of the fluid.

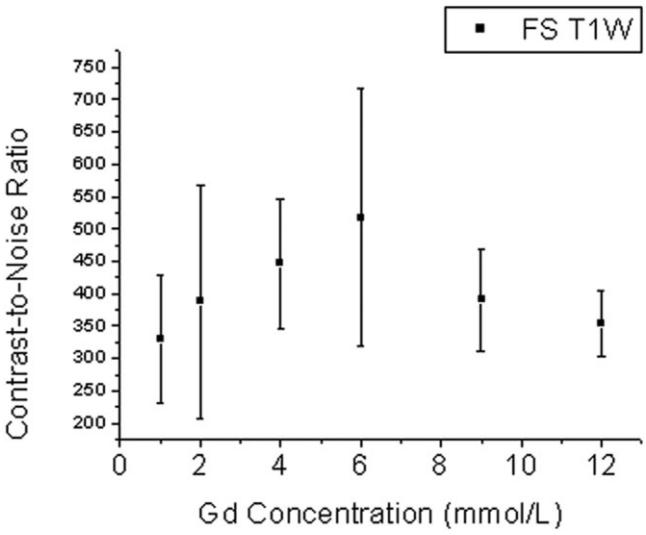

Figure 3. Graph of contrast-to-noise ratios on fat-suppressed T1-weighted MR arthrograms (mean value ± standard deviation) obtained with six concentrations (1 mmolGd/L, 2 mmolGd/L, 4 mmolGd/L, 6 mmolGd/L, 9 mmolGd/L, and 12 mmolGd/L).

contrast material with articular synovium, higher body temperatures than the ambient conditions, delay time between injection and imaging, and dilution by preexisting joint effusion. In addition, this discordance also suggested that results in vitro needed to be further verified before being applied in vivo.

In this study, mixtures of diluted gadopentetate dimeglumine, Omnipaque, and lidocaine, each accounting for one-third volume of the injection admixture, was used for MR arthrography. Premixing these types of materials has been previously proved safe in vitro (20) and this mixing proportion was based on a previous study (12). The clinical experience of the study team has also demonstrated the amount of iodinated contrast used here was sufficient to verify correct needle placement under fluoroscopy and to guarantee the quality of conventional x-ray arthrography or CT arthrography. The administration of lidocaine was an effective way to relieve pain and improve the compliance of patients during the MR scanning.

The effect of adding iodinated contrast into gadolinium solution had been thoroughly investigated in phantom studies (9,10,19). In general, additional iodinated contrast decreased signal intensity of the gadolinium solution on all pulse sequences, and this decline was more obvious at 3T than at 1.5T and found to be more intensive on the T2-weighted images rather than on the T1-weighted images. In addition, it was found that if gadolinium was diluted in iodinated contrast, a lower concentration should be used due to the left shift of signal peak. Due to this, a minimal iodinated contrast during MR arthrography was advocated by these authors (9,19). Nevertheless, this view point was not unified in in vivo studies, where the use of high concentrations of iodinated contrast agents could be found frequently, such as 10 mL recommended by Jacobson et al (16), 5 mL by Palmer and Caslowitz (12), etc. The advantages of mixing high amount of iodine into gadolinium solution consists of ease of handling (not required to change syringe) and convenience in acquiring conventional x-ray arthrography or CT arthrography.

This study focused on the glenohumeral joint, because the shoulder MR arthrography is most frequently used in clinic. However, it does require the consideration of whether the results are applicable for the other major joints. When compared with other joints (such as a knee joint), at least one difference should be kept in mind, in the case of the shoulder, the pre-existing joint effusion is usually far less, and has a correspondingly smaller effect of dilution of the gadolinium-based contrast material on MR arthography. Therefore, a minute increase may be considered to further optimize gadolinium concentration during the performance of direct MR arthrography of other joints.

This study had several limitations. First, imaging of the shoulder did not take place directly after injection due to transportation and scheduling delays, so the injected gadolinium may have been partially resorbed by the synovium. Second, there was some variability in the time delay from shoulder injection to MR imaging, which might have different influence on the capsular resorption rate. However, all patients underwent imaging within 30 minutes of injection, and this time delay was considered reasonable for in clinic considerations. Third, turbo spin-echo T1-weighted sequence recommended by the manufacturer at 3T was used in this study, which may result in a mild difference of image contrast compared with spin-echo T1-weighted sequence or gradient echo sequence used in other studies. Finally, the injected contrast material was prepared on-site by the performing radiologist, so a little imprecision with the gadolinium concentration might exist in comparison to the level of precision that might be expected in a purely laboratory setting.

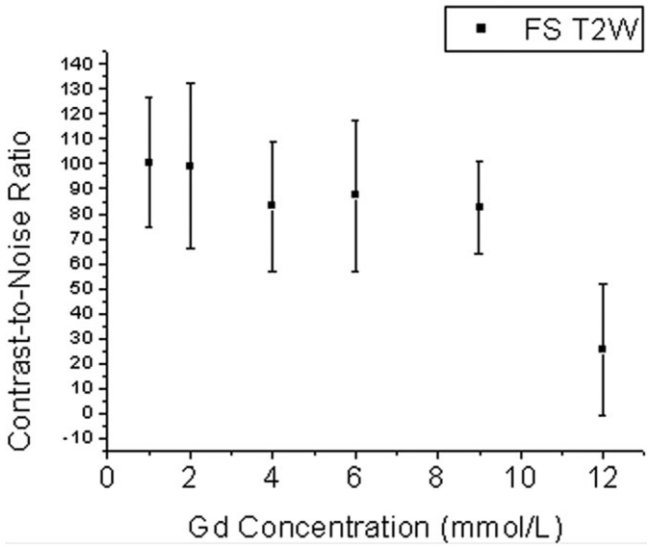

Figure 4. Graph of contrast-to-noise ratios on fat-suppressed T2-weighted MR arthrograms (mean value ± standard deviation) obtained with six concentrations (1 mmolGd/L, 2 mmolGd/L, 4 mmolGd/L, 6 mmolGd/L, 9 mmolGd/L, and 12 mmolGd/L).

In conclusion, with a focus on both T1-weighted and T2-weighted images, the acceptable concentration of gadopentetate dimeglumine for direct shoulder MR arthrography at 3T in vivo was found to be in the range of 1–6 mmolGd/L. The optimal concentration was determined to be 6 mmolGd/L.

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