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ScienceDirect

Journal of the Chinese Medical Association 80 (2017) 662−668

www.jcma-online.com

Original Article

Assessment of factors that could affect the success of US-guided contrast injection for hip MR arthrography

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Received January 13, 2017; accepted April 30, 2017

Abstract

Background: To retrospectively evaluate the association between possible influencing factors and failed first attempts to inject a contrast agent intra-articularly under ultrasound (US)-guidance for direct magnetic resonance (MR) arthrography of the hip joint.
Methods: Ninety consecutive patients (38 women and 52 men; mean age, 42 years) undergoing US-guided hip MR arthrography (3 bilaterally) were retrospectively included in this study. The potential influencing factors were sex, age, body mass index (BMI), side of injection, target site, trajectory of the needle, additional use of needle tip rotation, failed first-attempt, and capsule elongation at the site of needle insertion.
Results: First-attempt failure was significantly associated with reduced capsule elongation at the target site and no additional use of needle tip rotation (OR 10.708; 95% CI 1.847−62.059; OR 3.518; 95% CI 1.120−11.047). Capsule elongation (sufficient for needle bevel insertion) was significantly larger at the femoral head-neck junction (5.2 ± 1.5 mm) than at the femoral head (2.9 ± 1.3 mm) ($p < 0.001$).
Conclusion: Less capsular elongation of the femoral head and no additional use of needle tip rotation to reduce the difficulty in contrast material delivery can increase the first-attempt failure rate in patients undergoing US-guided hip arthrography.

Keywords: Arthrography; Hip; Magnetic resonance image; Ultrasonography; Ultrasound-guided

1. Introduction

Magnetic resonance (MR) arthrography of the native hip is a well-proven and useful technique for the diagnosis of intra-articular lesions, especially lesions of the acetabular labrum.[1,2] As the number of intra-articular contrast injections increase, hip injection efficacy increases.

Various injection techniques have been described for MR imaging-guided arthrography targeting the femoral head or head-neck junction.[3−5] The use of US guidance is less common than the use of conventional fluoroscopic guidance. However, fluoroscopy is unable to visualize soft tissue structures (such as the femoral neurovascular bundle and distended hip capsule) and inflammatory reactions such as intra-articular effusion. Compared with the most commonly described fluoroscopy guidance technique, the most popular alternative (i.e., injection of a contrast agent into the hip joint under US-guidance) permits direct visualization of intra-articular needle placement and adjacent vascular structures, and involves no exposure to radiation[3−7] Nevertheless, failed injection attempts have occasionally been reported in patients undergoing US-guided hip arthrography.[8]

The advantages of knowing the factors influencing failed attempts at US-guided injection are two-fold. First, the operator can choose the more appropriate technique before injection. Second, avoiding failure reduces the procedure time and discomfort of the patient. Recently, Kantarci et al.[8] reported no

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

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http://dx.doi.org/10.1016/j.jcma.2017.05.008

difference in the rate of failed first attempts under US-guidance targeting the femoral head and the rate of failed first attempts targeting the femoral head-neck junction, but more contrast media extravasation was noted when the femoral head was targeted. However, the factors possibly associated with failed first attempts during direct hip MR arthrography have never been assessed. The purpose of our study was to retrospectively determine which of these factors are associated with failed attempts to inject contrast into the native hip joint.

2. Methods

The protocol of this retrospective study was approved by the Institutional Review Board for Human Investigation (TSGHIRB 2-102-05-031) and required full de-identification/anonymization of the patients' records.

2.1. Patients

From February 2010 to March 2013, a total of 105 consecutive patients were referred to our hospital for MR arthrography of the hip joint and included in this study. Joint effusion was not apparent on hip US in any patient before hip arthrography. Inclusion criteria were adult age and receipt of US-guided injection for MR arthrography of the hip. Exclusion criteria were history of hip surgery or extra-articular pathology of the hip joint. Eleven patients with prior hip arthroscopy, 2 patients with communication between the hip joint and iliopsoas bursa, and 1 patient with osteochondroma-related posterior capsular rupture were excluded. One patient refused to take an MR examination because she was claustrophobic. Ninety patients (38 women, 52 men; mean age, 41 years; age range, 20–69 years) received US-guided injections for MR arthrography of the hip. Three patients underwent bilateral MR arthrography. A total of 93 native hips were enrolled in this study.

2.2. Imaging and probe placement techniques

US-guidance was provided using a scanner (Nemio XG; Toshiba, Tokyo, Japan) with a 3–4 MHz transducer (PLF-308P). The linear transducer was sterilized by CIDEX® OPA solution before injection. After cleaning the skin and transducer with alcohol, we slid the probe laterally through the femoral vessels to the most lateral edge of the superior acetabulum and placed it vertical to the most lateral edge of the superior acetabulum using a parasagittal approach. Under in-plane US-guidance, the needle was advanced toward the hip joint (Fig. 1) until the bone of the femoral head or head-neck junction was reached.

The patient's leg was placed in a neutral position, and the skin over the anterior hip was cleaned with alcohol. With regard to this leg position, we checked with the patients before injection to make sure they were comfortable. A 3.5-inch long 22-gauge spinal needle was used for all procedures. Ten ml of diluted (2 mmol/l) gadopentetate dimeglumine (Magnevist; Bayer Schering Pharma AG, Berlin, Germany) was injected according to a standard protocol.[7]

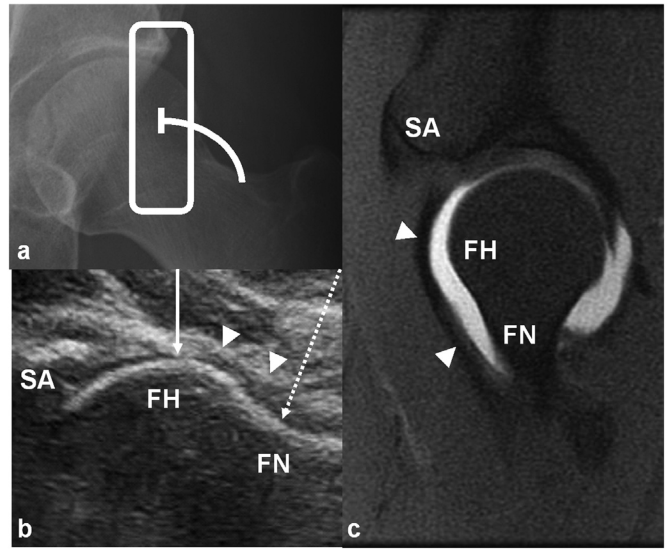

Fig. 1. A desirable probe position for US-guided hip joint injection as highlighted by the rectangle in (a). Major anatomical landmarks used for intra-articular injection on an ultrasonogram (b) and subsequent sagittal fat-saturated T1-weighted MR image (c). A parasagittal sonogram obtained at the anterior aspect of the hip joint and vertically along the most lateral edge of the superior acetabulum shows the femoral head (FH), femoral neck (FN), superior acetabulum (SA), and anterior hip joint capsule (arrowheads). The orientation of the needle for the US-guided technique is indicated by the long, white arrows (unbroken arrow: oblique trajectory of needle; dashed arrow: straight trajectory of needle).

When the procedure was performed under US guidance, a test injection of 2 ml of contrast agent was administered to confirm accurate needle placement, and was followed by intra-articular injection of approximately 8 ml of contrast agent into the hip joint using the end of the extension tube as a port. Needles encountered low resistance when in the joint space, and high resistance when embedded in articular cartilage. In the latter case, the needle was retracted just a few millimeters while injection pressure was maintained.[9] As soon as the tip of the needle reached the joint space, resistance immediately diminished. However, the maneuver of needle retraction sometimes failed to facilitate injection. Since August 2011, we used needle tip rotation, in addition, as described previously by Zwar et al.[10] We rotated the bevel of the needle counterclockwise while continuing to test for resistance to injection of the contrast agent until no resistance was encountered. If rotation was ineffective, the needle tip would then be advanced or withdrawn or both very slightly, and then rotated in successive small steps before again attempting to inject. If the test injection was still difficult and there was no accumulation of contrast in the joint, the needle was withdrawn from the joint capsule and a second insertion was attempted under freehand US-guidance. Each injection attempt was recorded on different US images. A US-guided technique was considered successful if no accumulation of contrast agent was found during the early stages of injection around the needle tip and if, later, a sufficiently large volume of fluid had been instilled, the anterior recess at the anterior femoral head-neck junction had begun to distend, and the anterior capsule had moved away from the femoral head.[3,5]

The injections were performed in a standardized fashion during a 37-month period (February 2010 to March 2013) by a musculoskeletal radiologist (Y. C. H.) with 10 years of experience in US and arthrography. Time from the injection to the onset of the MR scan was within 30 min.

2.3. MR arthrography

All MR imaging studies were performed with a 1.5-T unit (Signa HDx, GE Medical Systems, Milwaukee, WI, USA) using a surface coil for image acquisition within 30 min after arthrography. MR imaging was performed with the patient in a supine position. Fat-saturated spin-echo T1-weighted MR images (repetition time [ms]/echo time [ms], 400−700/8−12; field of view, 16 cm; matrix, 256−320 × 192−256; section thickness, 3−4 mm; number of signals acquired, 2) of the hip were obtained in the transverse-oblique (parallel to the femoral neck), coronal, and sagittal planes. Non-fat-saturated T1-weighted MR images with the same parameters were obtained in the coronal plane. A fast spin-echo T2-weighted sequence (4500/100; field of view, 16; matrix, 256−320 × 192−256; section thickness, 3−4 mm; number of signals acquired, 2, and echo train length, 8−10) was performed in the coronal and sagittal planes.

2.4. Data collection

The patients' medical records were reviewed. Routinely, we recorded clinical data (including sex, age, side of injection, and height and weight [which were used to estimate BMI]), the use of the needle tip rotation maneuver, first attempt successes, needle insertions targeting the head or head-neck junction, trajectory of the needle, and incapability of a complete evaluation on MR arthrography related to insufficient joint distention.

Capsular elongation (relative to the most lateral edge of the superior acetabulum) was measured at the anterior femoral head and femoral head-neck junction on sagittal fat-saturated T1-weighted MR images (Fig. 1) by two of the authors (Y.C.W. and K.H.K.), who were blinded to the US imaging results. The lateral edge of the superior acetabulum, which is used as a surrogate bony marker for US-guided injection and MR assessment,[7] served as a positional reference point for measurement of capsular elongation in different subjects. The protocol used to outline the anterior contour of the femoral head-neck junction, which has shown high reliability in US and MR examinations,[11,12] was applied to ensure that measurement by different operators is repeatable. A circle was defined by 3 points on the contour of the femoral head. To prevent measurement errors due to a femoroacetabular cam deformity, all three points were positioned on the spherical portion of the proximal femoral head contour. The femoral head-neck junction was defined as the intersection of the circle and femoral neck. According to previous reports,[13−16] the linear distance (defined manually as the shortest, perpendicular distance from the inner capsule to the cortex of bone with a line to point method) is an effective and repeatable measure of joint elongation (Fig. 2). We determined the capsular elongation at the femoral head and head-neck junction by measuring linear distances (recorded to the nearest 0.1 mm) on sagittal MR arthrography sequences. Each rater performed duplicate measurements, with the second measurement obtained 2 weeks after the first. All measurements were performed with the aid of a picture archiving and communications system (PACS), a mouse pointer (cursor), and automated computer calculation. The mean of two measurements was considered to be the final value.

We also determined the extra-articular contrast leakage.[8] Leakage of contrast material was graded as none, minimal, moderate, or severe according to the MR images. Minimal contrast leakage was defined as contrast only around the needle track. It was not extra-articular. Moderate leakage was defined as contrast around the needle track and between fascial planes or muscle fascicles. Severe leakage was defined as localized fluid collection outside the joint capsule. Moderate leakage and severe leakage were considered extra-articular.

We hypothesized that multiple independent factors may influence the success of injection during hip arthrography, including sex, age, patient BMI, side of injection, additional use of needle tip rotation, target site, trajectory of the needle, and capsular elongation. To evaluate the influence (relative risk) of independent factors on the success of injection during hip arthrography, we decided to convert these continuous variables into dichotomous variables. Subjects were divided into old and young groups on the basis of a cutoff age of 40 years, thin and obese groups on the basis of a cutoff BMI of 26, and straight alignment and non-straight alignment groups

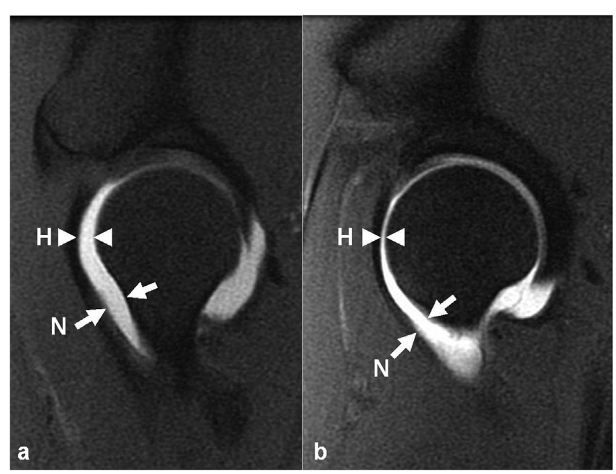

Fig. 2. MR arthrography shows US-guided injection with needle tip at the femoral head in a 41-year-old man (a) and at the femoral head-neck junction in a 27-year-old man (b). Sagittal fat-saturated, T1-weighted MR arthrogram depicts the capsular distension at the femoral head (H) and femoral head-neck junction (N). The capsular elongation width of distension is defined as the shortest, perpendicular distance from the capsule to the bone measured manually on the arthrogram. The first attempts in these two US-guided injections were successful.

on the basis of needle trajectory. Straight alignment of needle trajectory, which indicated the needle was perpendicular to the skin, meant the shortest distance from the skin to joint. Because the bevel of spine needle tip was approximately 2−3 mm in length, 3 mm was chosen as the cutoff point for capsular elongation.

2.5. Statistical analysis

All the measurements regarding capsular elongation were presented as mean ± standard deviation. Intra- and inter-rater agreement was evaluated using the intra-class correlation coefficient (ICC)[17] and Bland-Altman plots for measures of capsular elongation. In Bland-Altman plots, the presence of 5% of values outside the limits of agreement was considered sufficient to show clinically acceptable reproducibility.[18]

Multiple logistic regression analysis was used to determine the association between failure of the first attempt to inject during arthrography and independent factors. Odds ratios (used to measure the association) and their corresponding 95% confidence intervals were calculated using a multiple logistic regression model. In addition, if a relationship between first-attempt failure and capsular elongation in the head and head-neck junction was significant, a Student *t* test was used to clarify the difference in capsular elongation between the head and head-neck junction. Statistical analyses were performed using SPSS software (v. 16; SPSS, Inc. Chicago, IL, USA). Significance testing was conducted using a two-tailed alternative hypothesis. Differences were considered statistically significant for a p value of <0.05.

3. Results

Ninety-three US-guided arthrography procedures were performed on native hips of 90 patients. No complications (e.g., intense pain, bleeding, paresthesia, mobility restriction, syncope, allergic reactions, fever, or infection) were observed during or after the procedures. Moreover, the joints in all patients were distended enough to fully evaluate MR arthrography. No leakage of contrast was observed in 77 out of 93 hip punctures, and minimal leakage was observed in 16 hip punctures. No patient had moderate or severe contrast leakage from the puncture site.

Puncture was performed successfully at the first attempt in 71% of cases (66/93) and unsuccessfully at the first attempt in 29% of cases (27/93) (Table 1). The puncture was successful in all of the cases in the first two attempts of injection. There was no initial failed attempt changing to aim at another site. The height and weight ranges were 148−188 cm (mean, 167 cm) and 38−104 kg (mean, 65 kg), respectively, and the mean BMI was 23 kg/m^2. Arthrography was performed in 57 right hips and 36 left hips. Needle tip rotation was performed in 53 examinations, trajectory of the needle was straight in 49 examinations, and the femoral head was the target in 34 examinations. Trajectory of the needle was oblique in 44 examinations, and the femoral head-neck junction was the target in 59 examinations. Capsular elongation in the head was less than 3 mm in 24 patients.

Table 1
Comparison of demographic data of the success vs. failure of the first attempted injection during arthrography.

Number of patients		First attempted injection during arthrography		Total
Parameter		No. of successes	No. of failures	
Sex	Male	36	17	53
	Female	30	10	40
Age (y) > 40	Yes	38	12	50
	No	28	15	43
Body mass index (kg/m^2) > 26	Yes	11	2	13
	No	55	25	80
Side of injection	Right	41	16	57
	Left	25	11	36
Capsular elongation at the site of needle insertion (mm) < 3	Yes	13	11	24
	No	53	16	69
Target site	Head	16	18	34
	Head-neck junction	50	9	59
Needle trajectory	Straight	39	10	49
	Oblique	24	17	44
Additional use of needle tip rotation	Yes	43	10	53
	No	23	17	40

Capsular elongation was measured on MR images in about 5 s and was significantly less at the femoral head (2.9 ± 1.3 mm) than at the femoral head-neck junction (5.2 ± 1.5 mm) ($p < 0.001$). Intra-rater and inter-rater agreement, calculated according to Landis and Koch, was good (with the intraclass correlation coefficient [ICC] ranging from 0.918 to 0.972). Bland-Altman plots (Fig. 3) also demonstrated the high reliability of capsular elongation measurement. In multiple logistic regression analysis, failure of the first attempt was significantly associated with less capsular elongation and no additional use of needle tip rotation (OR 10.708; 95% CI 1.847−62.059; OR 3.518; 95% CI 1.120−11.047) (Table 2). There was no significant association with sex, age, BMI, side of injection, target site, and needle trajectory ($p > 0.05$).

4. Discussion

The use of intra-articular contrast improves the detection of internal structures of the hip joint by distending the capsule and increasing the definition of structures that are usually in intimate contact. Without sufficient volumes of contrast material the joint capsule may not be distended enough to permit evaluation and diagnosis. This is the first study to investigate factors potentially leading to failure of attempted US-guided arthrography.

Because the most lateral edge of the superior acetabulum is an easily-recognized surrogate bony landmark for both US-guided injection and MR arthrography,[7] sagittal fat-saturated T1-weighted MR images were employed to measure capsule elongation after contrast injection into the hip under US-guidance. Previous reports addressing this issue in shoulder

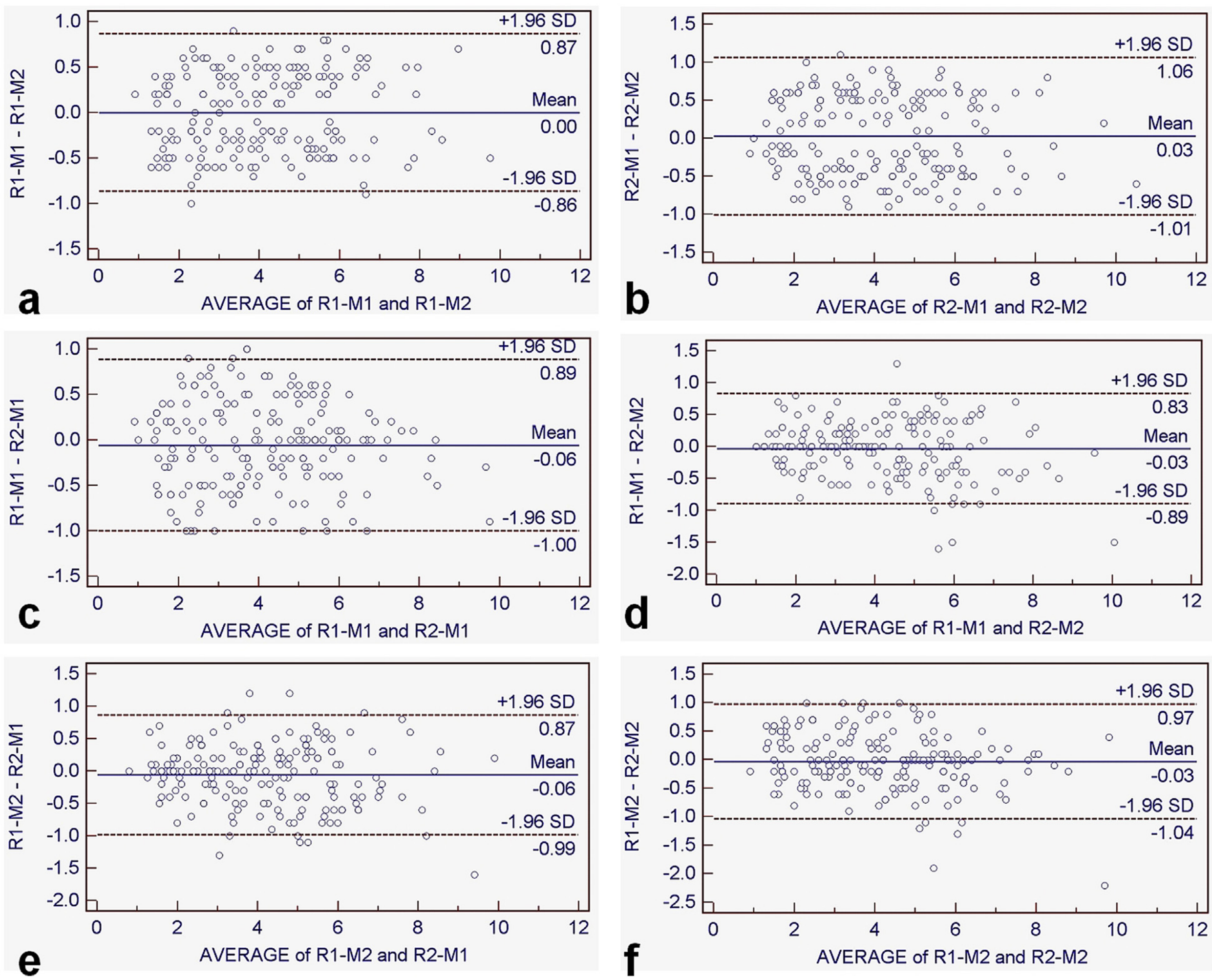

Fig. 3. Bland–Altman plots of the mean values of repeated measurements estimating capsular elongation relative to the difference between repeated measurements estimating capsular elongation in the femoral head and femoral neck obtained on the MR arthrograms. Measurements by the same rater (i.e., R1 [a] or R2 [b]) and by different raters (c–f). The three horizontal lines represent +1.96 SD, mean, and −1.96 SD differences between the repeated estimates of capsular elongation. Abbreviations: R1 = rater 1; R2 = rater 2; M1 = first measurement; M2 = second measurement.

Table 2
Multiple logistic regression analysis of contributing factors relating to failure of the first attempted injection during arthrography.

Parameter		Failure of the first attempt during arthrography		
		OR	95% CI	p
Non-technique-related factors	Age	0.818	0.246–2.726	0.744
	Sex	1.941	0.559–6.745	0.297
	Side of injection	1.164	0.354–3.822	0.802
	Body mass index	0.227	0.033–1.549	0.130
	Capsular elongation at the site of needle insertion	10.708	1.847–62.059	0.008[a]
Technique-related factors	Target site	1.041	0.208–5.217	0.961
	Needle trajectory	2.028	0.651–6.319	0.223
	Additional use of needle tip rotation	3.518	1.120–11.047	0.031[a]

[a] Statistically significant.

joints suggested that the linear distance between the capsule and bone cortex is a highly reliable and reproducible measure of the size of the recess beneath the joint capsule.[13–15] The same is true of hip joints.

In our study, the contrast media predominantly entered the posterior recess and anterior recess at the femoral head-neck junction rather than at the femoral head. Two phenomena can account for this observation. First, the effect of gravity on the injected contrast medium results in capsular elongation at the posterior recess. Second, in contrast to femoral-head junction with concave appearance, the femoral head at the hip joint has a convex appearance and (compared with the femoral head-neck junction) causes less anterior capsular elongation. Less capsular elongation at the femoral head can explain why the femoral head-neck injection technique (compared with the femoral head injection technique) results in less extra-articular contrast leakage.[8] In addition, our study demonstrated that the average capsular elongation at the femoral head-neck junction is 5.2 mm. Therefore, we suggest that the anterior recess at the femoral head-neck junction is large enough to accommodate the needle bevel and the volume of contrast medium.

In contrast to a hip joint with joint effusion, a native hip joint is more difficult to puncture exactly by real-time US. If the needle bevel is buried partially in the capsule and hip joint, the joint could become distended, requiring more contrast and contributing more extra-articular contrast leakage. That is why the injected volumes in previous hip arthrography reports vary widely.[3–6,8,16] Although our needle-manipulation technique led to a higher first attempt failure rate (29%) than previously reported (18%) for US-guided injection, the rate of moderate or severe contrast leakage during native hip arthrography, which is the primary reason for insufficient capsular distention and patient discomfort,[8] was diminished in our study. We can identify hypoechoic contrast pooling extra-articularly to prevent more extra-articular contrast leakage by real-time US. We hypothesize that the fixed volume (10 ml) of contrast injected into the hip joint may facilitate capsular elongation measurement and provide enough joint capsule distension for diagnosis of intra-articular lesions on subsequent hip MR arthrography.

Needle bevel orientation is considered important to the success of fluid injection. Zwar et al. have described a US-guided injection technique involving the additional maneuver of needle tip rotation when resistance is detected during intra-articular injection for shoulder arthrography.[10] Rotation of the needle with tip against the bone cortex can not only propel the needle bevel into the largest joint space, but also prevent needle tip withdrawal from the hip joint capsule, especially in obese patients where the needle tip itself is occasionally difficult to visualize.

The previous study mentioned above also revealed that targeting of the femoral head had no effect on the rate of US-guided hip injection failure.[8] For this reason, our study randomized patients to two groups differentiated by needle placement at the head or head-neck junction. Our result shows that the rate of hip injection failure (with the leg in a neutral position) is related to the amount of capsular elongation, which is significantly smaller at the femoral head than at the femoral head-neck junction. This contradiction may be explained by capsular elongation at the femoral head, which is not always sufficient for needle bevel insertion at the beginning of contrast injection. Consequently, we recommend needle insertion at the femoral head-neck junction to facilitate the success of hip joint injection.

In this retrospective study, we investigated a number of factors that potentially could result in a failed first attempt (sex, age, BMI, side of injection, and trajectory of the needle) in hip arthrography. Regardless of body build, the relevant anatomy of the anterior hip joint recess is consistently observable on sonograms.[10] Hence, the non-technique-related factors including sex, age, BMI, and side of injection had no influence upon the rate of first attempted hip joint injection success in our study. Kantarci et al. supposed that the tip of an obliquely inserted needle for US-guided hip injection could become dislodged and move to an extra-articular location during connection of an extension tube or during injection itself.[8] Manually stabilizing the needle after injection of 2 ml of contrast agent makes no significant difference in the rate of first-attempt failure between groups divided based on the trajectory of needle insertion (straight vs oblique).

The present study had several limitations. First, the study had a retrospective design and an imbalance between groups selected on the basis of potentially influential factors such as BMI and capsular elongation. Future studies of US-guided injection of the hip joint should therefore have a larger patient population or prospective design. Second, the overall size of the hip joint and the volume of the joint cavity were not taken into account in this study, as our aim was to determine whether capsular elongation at the femoral head and head-neck junction, not the laxity of the whole joint capsule, was a factor influencing the success of hip arthrography with a constant injected volume of contrast agent. Third, although BMI had no statistically significant influence, we think that BMI is an important factor and that our patient population (consisting mostly of young active patients and less overweight patients) may have been a limitation. Forth, the major limitation of ultrasound remains that it is operator dependent, with training and experience as well as inter-operator variability playing a role.

In conclusion, a US-guided anterior injection technique can be used to accurately place the needle tip into the hip joint. Failed first attempts at US-guided intra-articular hip injection are associated with less capsular elongation. US-guided anterior injection into the capsule at the femoral head-neck junction, where the capsule is more elongated, used with needle tip rotation can be an effective technique of needle placement before injection into the hip.

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