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Preliminary Investigation

Saline versus Gadolinium-enhanced Magnetic Resonance Arthrography of Porcine Cartilage

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Rationale and Objectives. The authors compared saline and dilute gadopentetate dimeglumine as injectants for magnetic resonance (MR) arthrography.

Methods. Sixty-three lesions were created on the joint surfaces of six pig patellas. MR arthrography (1.5 T) was performed with the specimens in saline and then in 2 mmol gadopentetate dimeglumine by using fat-saturated two-dimensional (2D) and three-dimensional (3D) sequences. Two musculoskeletal radiologists independently interpreted the images.

Results. At 2D MR arthrography, reader 1 performed equally well with saline and gadolinium solutes, whereas reader 2 had better sensitivity with the saline solute ($P < .05$); interobserver agreement was equivalent for saline and gadolinium solutes. With 3D MR arthrography, reader 2 performed equally well with saline and gadolinium solutes, whereas reader 1 had better sensitivity ($P < .0001$) but poorer specificity ($P < .001$) with the gadolinium solute; interobserver agreement was significantly better for saline than for gadopentetate dimeglumine ($P < .05$).

Conclusion. In this initial evaluation, there was no clear advantage to using gadolinium-enhanced MR arthrography over saline MR arthrography for detecting lesions in porcine hyaline cartilage.

Key Words. Arthrography; cartilage, MR; gadolinium.

Magnetic resonance (MR) arthrography has been reported to be more accurate than conventional MR imaging for the diagnosis of lesions of the joint surface, improving the assessment of chondromalacia, chondral defects, and osteochondritis dissecans [1-3]. In the absence of a joint effusion, an intraarticular injection affords joint distention and can improve image contrast along the joint surface.

High-quality MR arthrographic images can be acquired with the intraarticular administration of saline alone. Intraarticular injection of saline affects joint distention, and saline has signal intensity characteristics sufficiently different from those of hyaline and fibrocartilage to act as an MR contrast agent. Initial experience in cadavers has suggested that gado-

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linium-enhanced MR arthrography is superior to saline MR arthrography for the detection of cartilage defects, at least with two-dimensional (2D) spin-echo (SE) sequences [1]. To date, however, the intraarticular administration of gadolinium chelates is not approved by the U.S. Food and Drug Administration, carries potential unknown risks, and increases cost. Meanwhile, new and faster MR techniques such as fast SE and three-dimensional (3D) gradient-echo (GRE) imaging have improved the MR evaluation of cartilage.

In this study, we compared a dilute gadolinium chelate to saline as potential injectants for the detection of experimentally created lesions in porcine cartilage with MR arthrography.

MATERIALS AND METHODS

Six patellas were harvested from three freshly sacrificed pigs. Ten lesions each were created with a motorized drill on the joint surfaces of four patellas, and 12 lesions each were created on the surfaces of two patellas. Lesion diameters were 1.6, 2.0, 2.4, 2.8, or 3.2 mm. Partial-thickness cartilage lesions of differing depths were created at each diameter. This procedure yielded a total of 63 analyzable lesions (one lesion was incompletely imaged).

MR imaging was performed at 1.5 T (Signa, version 5.3; GE Medical Systems, Milwaukee, WI) with a round, three-inch receiver coil. Two patellas were imaged at a time. The 2D sequences included fast SE with spectral fat saturation, an echo train length of eight, a repetition time of 2,500 msec, effective echo times of 25 and 125 msec, 3-mm-thick sections (interleaved), two signals acquired, and a 192×256 matrix. T1-weighted conventional, 2D SE images were acquired with spectral fat saturation, a repetition time of 500 msec, an echo time of 20 msec (500/20), 3-mm-thick sections (interleaved), two signals acquired, and a 192×256 image matrix. The 3D images were obtained with a spoiled gradient-recalled (SPGR) sequence by using spectral fat saturation, 55/10, a flip angle of 50° , 2-mm-thick sections, two signals acquired, and a $32 \times 192 \times 256$ matrix. The field of view was 6×8 cm for all sequences.

The patellas were immersed in saline for fat-saturated 2D fast SE and 3D SPGR imaging, and then in a 1:250 dilution (2 mmol) of gadopentetate dimeglumine (Magnevist; Berlex, Wayne, NJ) in saline solution for fat-saturated 2D T1-weighted SE and 3D SPGR imaging. The same patellar orientation was maintained between

TABLE 1: Summary of Results for Two Readers

Imaging Technique	Reader 1 (%)	Reader 2 (%)
2D MR arthrography		
Saline-enhanced		
Sensitivity	48 of 63 (76)	54 of 63 (86)*
PPV	48 of 54 (89)	54 of 63 (86)
Gadolinium-enhanced		
Sensitivity	46 of 63 (73)	45 of 63 (71)*
PPV	46 of 48 (96)	45 of 48 (94)
3D MR arthrography		
Saline-enhanced		
Sensitivity	44 of 63 (70) [†]	50 of 63 (79)
PPV	44 of 44 (100) [‡]	50 of 51 (98)
Gadolinium-enhanced		
Sensitivity	60 of 63 (95) [†]	50 of 63 (79)
PPV	60 of 72 (83) [‡]	50 of 53 (94)

Note.—Numbers in parentheses are percentages. PPV = positive predictive value.

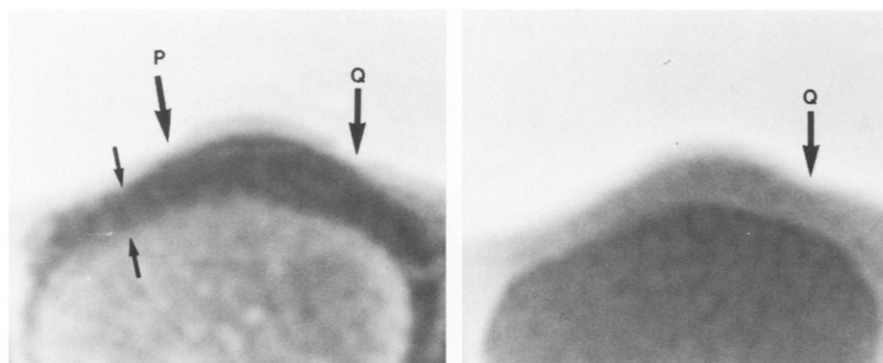
* $P < .05$ (for differences in specificity).

[†] $P < .0001$ (for differences in specificity).

[‡] $P < .001$ (for differences in specificity).

the two sets of images by embedding the specimens in nontoxic plumber putty.

Images were interpreted by two experienced musculoskeletal radiologists (A.G., L.L.S.) in independent readings. Readers interpreted each technique (2D saline and gadolinium-enhanced MR arthrography, 3D saline MR arthrography and gadolinium-enhanced MR arthrography) on separate occasions. Only the T2-weighted images from the fast SE acquisitions were interpreted for 2D saline MR arthrography. Reading sessions were separated by at least 3 days. Readers scored suspicious lesions along the patellar joint surface as follows: 1 = probably not a lesion, 2 = probably a lesion, or 3 = definitely a lesion. The scores were marked on the hard copy. A third reader tabulated the independent readings, comparing them to detailed maps of lesion size and location. Scores of 2 or 3 were considered positive responses. A score of 1 or no score were considered negative responses. This scoring system permitted an efficient, paired comparison of the sensitivity and specificity of the arthrographic techniques but precluded a global tabulation of true-negative findings. Thus, although specificity was not specifically calculated, the sensitivity and specificity of sequences performed with saline could be compared with those of sequences performed with dilute gadolinium solution by tabulating the discordant readings for each reader (McNemar test). A probability of .05 was taken as the



A.

B.

FIGURE 1. **A.** 2D saline MR arthrogram (T2-weighted fast SE sequence with spectral fat saturation) shows two lesions (*P* and *Q*) that were detected by both readers. Note the distinct bilaminar appearance of the hyaline cartilage, which has a broad, low-signal-intensity basal zone (arrows). **B.** 2D gadolinium-enhanced MR arthrogram (T1-weighted SE sequence with spectral fat saturation) obtained at the same location as **A.** Lesion *Q* is less well depicted than on the 2D saline MR arthrogram but was detected by both readers, whereas lesion *P* was missed by both readers.

threshold for a type I error in reporting a statistically significant difference in the rate of discordant observations. Interobserver variability was expressed for two response categories (lesion, no lesion) with kappa as defined by Cohen.

RESULTS

Results for the two readers are summarized in Table 1 and detailed below.

2D MR Arthrography

Reader 1 identified 48 of the 63 lesions with saline MR arthrography and 46 with gadolinium-enhanced MR arthrography. A tabulation of discordant readings for reader 1 revealed the following: Nine lesions were detected only with saline MR arthrography and seven only with gadolinium-enhanced MR arthrography, indicating no statistically significant difference in sensitivity (Fig 1). Five false-positive findings occurred only with saline MR arthrography and one false-positive finding occurred only with gadolinium-enhanced MR arthrography, indicating no statistically significant difference in specificity.

Reader 2 identified 54 of the 63 lesions with saline MR arthrography and 45 with gadolinium-enhanced MR arthrography. A tabulation of discordant readings for reader 2 revealed the following: 14 lesions were detected only with saline MR arthrography and five only with gadolinium-enhanced MR arthrography (Fig 1), in-

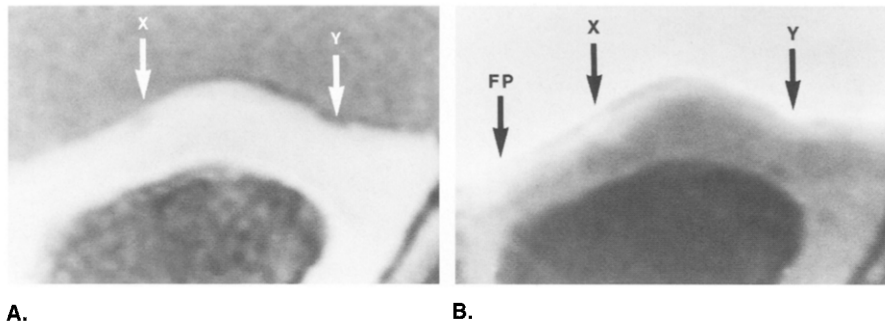
dicating a significantly higher sensitivity for saline MR arthrography ($P < .05$). Eight false-positive findings occurred only with saline MR arthrography and two occurred only with gadolinium-enhanced MR arthrography, indicating no statistically significant difference in specificity.

There were 77 composite responses for 2D saline MR arthrography, and kappa for the two readers was 0.27 (95% confidence interval [CI] = 0.03, 0.50). There were 69 composite responses for 2D gadolinium-enhanced MR arthrography, and kappa for the two readers was 0.38 (95% CI = 0.17, 0.60). Thus, the difference between the interobserver agreements for 2D saline and gadolinium-enhanced MR arthrography was not statistically significant.

3D MR Arthrography

Reader 1 identified 44 of the 63 lesions with saline MR arthrography and 60 with gadolinium-enhanced MR arthrography. A tabulation of discordant readings for reader 1 revealed the following: No lesions were detected with saline MR arthrography alone and 16 were detected only with gadolinium-enhanced MR arthrography, indicating a significantly higher sensitivity for gadolinium-enhanced MR arthrography ($P < .0001$). Reader 1 had no false-positive findings with saline MR arthrography and 12 with gadolinium-enhanced MR arthrography (Fig 2), indicating a significantly higher specificity for saline MR arthrography ($P < .001$).

Reader 2 identified 50 of the 63 lesions with saline



A. **B.**
FIGURE 2. **A**, 3D saline MR arthrogram (SPGR sequence with spectral fat saturation) shows two lesions (X and Y) that were detected by both readers. There is good contrast along the cartilage surface with this “dark fluid” technique. **B**, 3D gadolinium-enhanced MR arthrogram (SPGR sequence with spectral fat saturation) obtained at the same level as **A** depicts the two lesions (X and Y), although contrast is poorer along the cartilage surface than with 3D saline MR arthrography. Reader 1 detected both lesions, whereas reader 2 detected only lesion Y. Reader 1 also interpreted a vague area of higher signal intensity along the joint surface (FP) as a lesion, although none existed.

MR arthrography and 50 with gadolinium-enhanced MR arthrography. A tabulation of discordant readings for reader 2 revealed the following: Seven lesions were detected only with saline MR arthrography and seven only with gadolinium-enhanced MR arthrography, indicating no statistically significant difference in sensitivity. One false-positive finding occurred only with saline MR arthrography and three false-positive findings occurred only with gadolinium-enhanced MR arthrography, indicating no statistically significant difference in specificity.

There were 66 composite responses for 3D saline MR arthrography, and kappa for the two readers was 0.74 (95% CI = 0.57, 0.92). There were 79 composite responses for 3D gadolinium-enhanced MR arthrography, and kappa for the two readers was 0.05 (95% CI = -0.13, 0.23). Thus, interobserver agreement was significantly better for 3D saline MR arthrography than for 3D gadolinium-enhanced MR arthrography.

DISCUSSION

Our results suggest no clear advantage to the use of a gadolinium chelate for detecting focal lesions in hyaline cartilage with MR arthrography. With 2D imaging, one reader actually had a higher sensitivity with saline MR arthrography. With 3D imaging, one reader had a higher sensitivity but lower specificity with gadolinium-enhanced MR arthrography. With 3D imaging, interobserver agreement was significantly better with saline than with gadopentetate dimeglumine. Our study is admittedly an artificial diagnostic model with porcine

patellar specimens and a limited number of readers. This model may not be directly generalizable to daily MR imaging practice in human subjects.

Different results might also conceivably be obtained with other imaging parameters or pulse sequences. Our 2D sequences were “bright fluid” techniques. We used a dark fluid sequence for 3D saline imaging, whereas a bright fluid sequence was used for 3D gadolinium-enhanced imaging. Our choice of MR pulse sequences was based on prevailing recommendations in the literature [4–6] and on our own clinical experience.

2D gadolinium-enhanced MR arthrography is typically performed with T1-weighted SE sequences, often with spectral fat saturation. On these images, the injectant is hyperintense (bright) relative to cartilage and capsular structures. Chandnani et al [7] deemed fat-saturated T1-weighted SE images better than proton-density-weighted, T2-weighted, or non-fat-saturated T1-weighted SE images for the visualization of cartilage in cadaver knees after intraarticular saline injection. Tervonen et al [6], however, also evaluated cartilage lesions created in cadaver knees after intraarticular saline injection and found fast SE images to be far superior to conventional SE images, with or without spectral fat saturation. Fast SE sequences are time-efficient, and incidental magnetization transfer contrast in fast SE imaging of cartilage confers a potential advantage over GRE and conventional SE techniques [8, 9]. Thus, we chose a bright fluid, fat-saturated, fast SE sequence for 2D saline MR arthrography in this study.

Recht et al [5] found a fat-saturated 3D SPGR sequence (52/10, 60° flip angle) to be superior to 2D SE

imaging and 3D gradient-recalled acquisition in the steady state (GRASS; GE Medical Systems) (40/10, 30° flip angle) in the depiction of naturally occurring cartilage lesions in cadaveric human knees. Disler et al [4] optimized the contrast-to-noise ratio of knee cartilage to saline for a fat-saturated 3D SPGR sequence and found similar sequence parameters (60/5, 40° flip angle) to be best. Tervonen et al [6] also found 3D SPGR (30/9, 30° flip angle) to be superior to 3D GRASS and steady state free precession (SSFP) techniques in the detection of cartilage lesions created in human cadaver knees. Van der Linden [10] deemed a SPGR sequence (65/11.5; 30°–45° flip angle) preferable to other spoiled and steady-state GRE sequences at 0.5 T in the depiction of lesions created in pig cartilage. The studies by Recht et al [5], Tervonen et al [6], and Van der Linden [10] were all performed after the intraarticular injection of saline. Hence, the consensus is that dark fluid sequences are best for 3D saline MR arthrography of hyaline cartilage.

Because a gadolinium chelate injectant shortens T1, and previous studies indicate an advantage of spoiled (T1-weighted) over steady-state (T2*-weighted) GRE techniques for MR arthrography [6], we chose the same T1-weighted, fat-saturated SPGR sequence for both saline and gadolinium-enhanced 3D MR arthrography. One published clinical series used a T2*-weighted sequence for 3D gadolinium-enhanced MR arthrography without establishing its superiority over other 3D sequences [11]. Our unpublished experience suggests that spoiled, T1-weighted, gradient-recalled 3D sequences are superior to steady-state, T2*-weighted gradient-recalled sequences in this application.

The 3D image acquisition potentially offers higher signal-to-noise ratios and thinner image sections than 2D image acquisition and is likely more sensitive for small cartilage lesions [1, 5]. The 3D image acquisition, however, is currently limited to GRE sequences. GRE images offer good signal-to-noise ratios but may have poorer contrast than SE or fast SE techniques. One study [6] showed that GRE and conventional SE images

do not depict lesion size or contour as accurately as fast SE images. Given the sensitivity of 2D saline MR arthrography in our study, further improvements in saline MR arthrography may be anticipated with the advent of 3D fast SE sequences.

Our study addresses only the efficacy of MR arthrography for detecting lesions in hyaline cartilage. MR arthrography is often performed to evaluate capsuloligamentous and periarticular structures such as Bankart lesions of the shoulder, labral tears in the hip, and recurrent tears in the menisci of the knee after partial meniscectomy or meniscal repair. Additional studies are required to address the added value of gadolinium-enhanced arthrography and the optimal pulse sequences for these other indications.

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