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3.0 vs 1.5 T MRI in the detection of focal cartilage pathology – ROC analysis in an experimental model

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Summary

Objective: To use receiver operator characteristics (ROC) analysis for assessing the diagnostic performance of three cartilage-specific MR sequences at 1.5 and 3 T in detecting cartilage lesions created in porcine knees.

Design: Eighty-four cartilage lesions were created in 27 porcine knee specimens at the patella, the medial and lateral femoral and the medial and lateral tibial cartilage. MR imaging was performed using a fat saturated spoiled gradient echo (SPGR) sequence (in plane spatial resolution/slice thickness: $0.20 \times 0.39\ mm^2$/1.5 mm) and two fat saturated proton density weighted (PDw) sequences (low spatial resolution: $0.31 \times 0.47\ mm^2$/3 mm and high spatial resolution: $0.20 \times 0.26\ mm^2$/2 mm). The images were independently analyzed by three radiologists concerning the absence or presence of lesions using a five-level confidence scale. Significances of the differences for the individual sequences were calculated based on comparisons of areas under ROC curves (A_Z).

Results: The highest A_Z-values for all three radiologists were consistently obtained for the SPGR ($A_Z = 0.84$) and the high-resolution (hr) PDw ($A_Z = 0.79$) sequences at 3 T. The corresponding A_Z-values at 1.5 T were 0.77 and 0.69; the differences between 1.5 and 3 T were statistically significant ($P < 0.05$). A_Z-values for the low-resolution PDw sequence were lower: 0.59 at 3 T and 0.55 at 1.5 T and the differences between 1.5 and 3 T were not significant.

Conclusion: With optimized hr MR sequences diagnostic performance in detecting cartilage lesions was improved at 3 T. For a standard, lower spatial resolution PDw sequence no significant differences, however, were found.

Key words: Cartilage imaging, MRI, High field, ROC-analysis, Experimental study, Focal cartilage pathology.

Introduction

Optimization of cartilage imaging with magnetic resonance imaging (MRI) has evolved in two directions: (1) Quantitative techniques such as dGEMRIC imaging, T1-rho and T2-mapping aim at quantifying the cartilage matrix including glycosaminoglycans and water content as markers of early cartilage degeneration[1–4] and (2) morphologic techniques based on new imaging sequences and higher field strength directly visualize cartilage structure and defects[5–11]. While assessing cartilage biochemistry is important in better understanding degeneration and, potentially, in early treatment of osteoarthritis, morphologic techniques are extremely important in guiding the orthopedic surgeon to better perform cartilage repair such as autologous chondrocyte transplantation and osteochondral autograft transfer[11–18].

Based on promising results in a previous pilot study[19], the purpose of this research project was to assess whether 3 vs 1.5 T provided consistently a better visualization and diagnostic evidence of focal cartilage pathology in fat saturated proton density weighted (PDw) and spoiled gradient echo (SPGR) sequences using receiver operator characteristics (ROC) analysis. A porcine model was used to have optimal control over lesion size, shape and depth. All images were analyzed independently by three radiologists to assess for consistency between different observers.

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Method

PORCINE MODEL AND FOCAL LESION CREATION

The study population consisted of 27 porcine knees that were obtained fresh from a local meat market and frozen for storage at −80 °C. Twenty hours prior to the imaging studies the specimens were thawed to room temperature. A lateral parapatellar approach was used to access the joint space and care was taken to reduce damage of the internal knee structures to a minimum, i.e., the cruciate and collateral ligaments as well as the patellar tendon were preserved. Focal cartilage lesions were created with a ceramic scalpel (Fine Science Tools, San Francisco, CA) to avoid metal artifacts. Cartilage lesions were created analogous to *in vivo* cartilage defects as visualized with arthroscopy and described by McGinty[20] (Fig. 1). In each joint five areas were defined: the patellar surface, the medial and lateral femoral and the medial and lateral tibial joint surfaces. In these 135 joint surfaces, 84 cartilage lesions were created, 81 focal defects and 3 fissure-like defects. Focal lesions were created as (1) full thickness lesions ($n = 39$), (2) lesions with a depth of more than 50% of the total cartilage thickness ($n = 22$) and (3) lesions with a depth of less than 50% of the total cartilage thickness ($n = 23$). Because the lesions

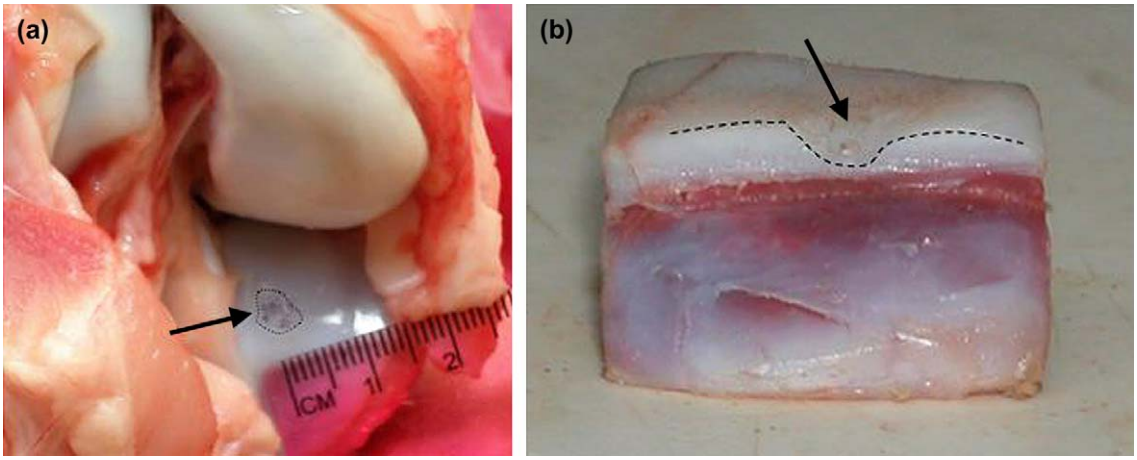

Fig. 1. Specimen photographs showing a full thickness cartilage defect at the medial tibia (a) and a femur section with a more than 50% thickness lesion (b).

varied in shape, the maximum diameter in a sagittal (anteroposterior) orientation was recorded in each case. After lesion creation and measurement, the joints were filled with a mixture of ultrasound gel and water carefully trying to remove remaining air as previously described[19]. In this previous study the signal intensity of the mixture was found to be similar to that of synovial fluid comparing it to clinical studies obtained with similar sequences. The knees were reassembled with special attention to restoring the proper physiological alignment of the articular surfaces and menisci. A transparent latex bag was pulled over the knee from the tibial side and the knee was flexed and extended to remove air from the joint. Finally, the knees were wrapped in parafilm. Care was taken to manually keep the patella in its normal alignment since the lateral retinaculum had been resected during the lesion creation procedure. Each knee was labeled and graphs of each knee were made indicating the exact location, shape, size and depth of the lesions. We also measured the lesions in five of the specimens directly after preparation and after all imaging procedures, when the specimens were dissected, to exclude changes of the lesions' size and depth during storage. But differences in the shape and depth of the lesions were not found.

MR IMAGING

All imaging procedures were performed at 1.5 and 3 T (Signa, GE Medical Systems, Milwaukee, WI, USA) and acquired with two phased array paddle coils (USA Instruments, Aurora, OH, USA for 1.5 T; Nova Medical, Wilmington, MA, USA for 3 T). Both magnetic resonance (MR) systems were equipped with 4 Gauss/cm gradients. Knees were placed in a supine orientation within the center of the coils lined up with the inferior margin of the patella during scanning. Great care was taken to position the specimens in the same way in both scanners. All scans at 1.5 and 3 T were performed immediately, back to back, to prevent changes of specimen condition induced by storage. Three sequences were used at each scanner: a fat saturated PDw standard sequence and fat saturated PDw high-resolution (hr) sequence as well as a hr fat saturated SPGR sequence. The imaging protocols at 1.5 and 3 T are shown in Table I. The low-resolution (lr) PDw sequence was a standard sequence used for imaging at 1.5 T while both hr sequences had been optimized for cartilage imaging at 3 T in a prior study[19]. The rationale to reduce the acquisition time of the SPGR sequence at 3 T was to obtain a clinically applicable SPGR sequence since a major disadvantage

Table I
Imaging sequences at 1.5 and 3 T performed in all specimens (PDw = proton density weighted, lr = low resolution, hr = high resolution, TR = repetition time, TE = echo time, NEX = number of acquisitions, ETL = echo train length, FOV = field of view, BW = band width, ST = slice thickness, Acqu. time = Acquisition time)

	Sequence					
	lr PDw		hr PDw		SPGR	
	Field strength					
	3.0 T	1.5 T	3.0 T	1.5 T	3.0 T	1.5 T
TR (ms)	2000	2000	4000	4000	22	32.9
TE (ms)	35	35	35	35	10	11.5
Flip angle	–	–	–	–	30	30
NEX	2	2	3	3	2	2
ETL	4	4	8	8	–	–
Matrix (pixels)	320 × 224	320 × 224	512 × 384	512 × 384	512 × 256	512 × 256
FOV (cm)	10	10	10	10	10	10
BW (kHz)	15.63	15.63	31.25	31.25	15.63	15.63
ST (mm)	3	3	2	2	1.5	1.5
Acqu. time (min)	3:40	3:48	9:44	9:44	6:33	9:07