Diagnostic performance of a 3D FSE T2 and T1rho sequence for quantitative mapping of articular cartilage composition for the detection of morphological internal knee derangements

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Purpose: Novel quantitative MRI techniques for articular cartilage composition show promise for early detection of osteoarthritis (OA) and may offer additional information for routine clinical MRI evaluation to assess morphological knee derangements. [1] However, large-scale application of quantitative MRI techniques in routine clinical patient care or in clinical OA research studies is hampered by long scan times. Implementation of quantitative MRI techniques may become more widespread if they can be applied as a replacement of routine morphological knee MRI pulse sequences rather than an extension of the MRI protocol. Therefore, the purpose of this study was to assess the diagnostic performance of a novel 3D FSE T2 and T1rho sequence for quantitative mapping of articular cartilage composition for the detection of internal knee derangements. We focused on cruciate ligament and meniscal tears, which are among the most common internal knee derangements on MRI and have a reported association with (early) OA. [2,3] In addition, we determined the performance for diagnosis of bone marrow lesions and cartilage defects, which are morphological features of established OA.

Methods: 39 patients referred for routine clinical MRI of the knee were studied. All images were acquired on a 3T whole body MRI scanner (Discovery MR750, General Electric Healthcare, Waukesha, WI) using a 16-channel flexible wrap-around coil (GEM Flex Coil, NeoCoil, Pewaukee, WI). The MRI protocol (Table 1) consisted of routine 2D fast spin-echo (FSE) clinical knee MRI pulse sequences, and was extended with novel 3D pseudo-steady-state FSE sequences with magnetization-preparation for the purpose of quantitative T2 and T1rho mapping of the articular cartilage. [4] Three separate de-identified MRI datasets with randomized patient order were created consisting of morphological images, quantitative T2, and T1rho images. An experienced musculoskeletal radiologist evaluated all MRIs for the presence or absence of anterior cruciate ligament (ACL) complete tears (native ACL or re-ruptured ACL reconstruction), posterior cruciate ligament (PCL) complete tear, medial meniscal tear, and lateral meniscal tear. Bone marrow lesions (BMLs) and cartilage defects were also assessed in 15 and 14 sub-regions of the knee, respectively, according to the semi-quantitative MRI Osteoarthritis Knee Score (MOAKS). [5] In patients who subsequently underwent knee arthroscopy, the orthopaedic surgeon systematically assessed intra-articular pathology using the International Cartilage Repair Society (ICRS) scoring system. [6] Diagnostic performance statistics were calculated for aforementioned morphological abnormalities on the T2 mapping and T1rho mapping sequence separately, only including lesions with a frequency of 5 more in our study population. Arthroscopic findings were used as the reference standard for the 23 patients that underwent arthroscopy, whereas for the other 16 patients we used routine morphological MRI as the reference.

Table 1: MRI protocol

Imaging plane and weighting	TR/TE* (ms)	Fatsat	NEX	Slice thickness /spacing (mm)	Matrix	FOV (cm)	Scan time (min: sec)
Routine clinical sequences (all 2D FSE)							
Sagittal PDw	3775/35	No	3	2.5/0.5	512x320	14.0	4:06
Sagittal T2w	5000/54	Yes	2	2.5/0.5	416x320	14.0	2:55
Coronal T1w	1000/	No	1	2.5/0.5	384x192	14.0	1:31
Coronal PDw	3000/25	Yes	2	2.5/0.5	416x320	14.0	2:12
Axial PDw	4200/30	Yes	3	2.5/0.5	416x320	14.0	4:29
Quantitative sequences for cartilage composition (3D FSE)							
Sagittal T2	2700/6,12,25,38,64	Yes	0.5	3.0/0.0	384x256	15.0	6:49
Sagittal T1rho	1700/1,10,30,60,80	Yes	0.5	3.0/0.0	384x256	15.0	6:37

PD=proton density; TR=repetition time; TE=echo time; NEX= number of excitations; FOV=field-of-view;
* Spin lock time for 3D FSE T1rho sequence

Table 2: Diagnostic performance results

	T2		T1rho	
Lesion type (no. of lesions)	Sensitivity	Specificity	Sensitivity	Specificity
ACL tears (5)	0.75	0.91	0.80	0.97
Medial meniscal tear (11)	0.46	0.96	0.80	0.93
Bone marrow lesions (48)	0.52	0.99	0.51	0.99
Cartilage lesions (all) (63)	0.08	0.99	0.38	0.99
Cartilage lesions (full-thickness) (31)	0.10	0.99	0.45	0.99

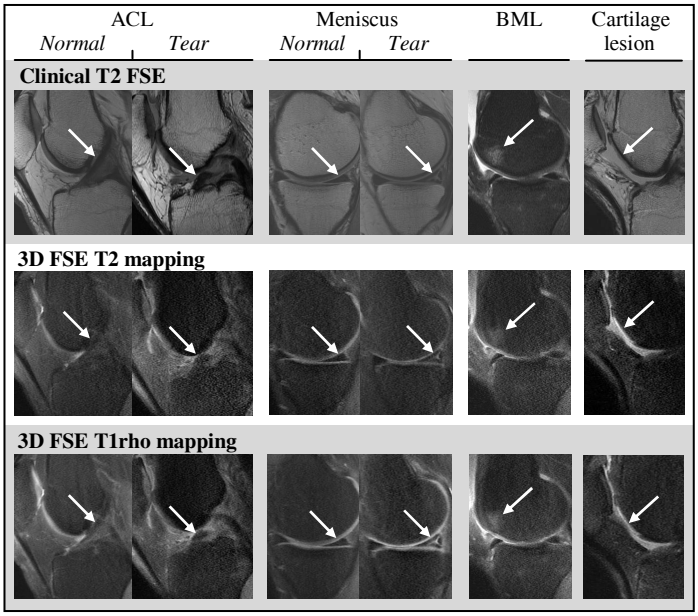

Figure 1: Examples of normal vs. abnormal knee structures:
Normal and torn anterior cruciate ligament (ACL) and meniscus, bone marrow lesions (BML) and cartilage lesions depicted on clinical T2 FSE as well as 3D FSE T2 and T1rho mapping sequences (arrows).

Results: Only a very small number of lateral meniscal tears (n=4) and no PCL tears were diagnosed. The 3D FSE T1rho sequence demonstrated good sensitivity and excellent specificity for the diagnosis for ACL tears and medial meniscal tears, and generally showed better diagnostic performance than the T2 mapping 3D FSE sequence (Table 2). For both sequences, sensitivity was poor for the detection of cartilage lesions, bone marrow lesions, and lateral meniscal tears. Illustrative examples of normal and abnormal internal knee structures are shown in Figure 1.

Discussion: The 3D FSE T1rho mapping sequence for quantitative mapping of articular cartilage composition showed good sensitivity and excellent specificity for the anatomic diagnosis of ACL tears and medial meniscal tears, which are significant intra-articular knee abnormalities associated with early osteoarthritis. The diagnostic performance of the 3D FSE T1rho mapping sequence was generally better than for T2, suggesting that the 3D FSE T1rho mapping sequence may be more useful for the assessment of these lesions. Our finding that the diagnostic performance for bone marrow lesions and cartilage lesions is poor for both sequences may be less relevant in light of the availability of more sensitive indicators of osteoarthritis status provided by these sequences, i.e. quantitative information on cartilage composition and quality. Examining quantitative T2 or T1rho information from these sequences along with the underlying morphologic images could enhance detection of cartilage and bone marrow lesions. As we primarily used sagittal images with a slice thickness of 3 mm to evaluate morphological abnormalities on the T2 and T1rho mapping sequences, we expect that diagnostic performance would benefit from isotropic acquisition methods that enable multi-planar reconstructions.

Conclusion: A 3D FSE T1rho sequence for quantitative mapping of articular cartilage composition may be used for the assessment of ACL tears and medial meniscal tears with good diagnostic performance. In MRI studies focused on these OA associated internal knee derangements, this sequence may replace routine clinical pulse sequences, enhancing scan time efficiency and potentially accelerating large-scale application in clinical OA research and routine clinical patient care.

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