Cartilage Morphology at 3.0T: Assessment of Three-Dimensional MR Imaging Techniques

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Introduction: Many new three-dimensional MR imaging methods are available for musculoskeletal imaging. Fast-spin-echo Cube (FSE-Cube) with 2D-accelerated auto-calibrated parallel imaging [1] uses refocused flip angle modulation and k_y-k_z centric view ordering to constrain T2 decay. Vastly undersampled isotropic projection reconstruction balanced steady-state free precession (VIPR-bSSFP) [2] has a 3D radial k-space trajectory that produces fat-water separation images with mixed T2/T1 contrast and high isotropic resolution. IDEAL [3] is a chemical-shift based water-fat separation technique that is robust to B_0 and B_1 field inhomogeneities. It can be combined with SPGR (IDEAL-SPGR) [4] for T1-weighted contrast commonly used in cartilage thickness and volume [5]. We also acquired IDEAL with unspoiled gradient recalled-echo acquired in the steady-state (IDEAL-GRASS) [6] for bright synovial fluid. Multi-echo in the steady-state acquisition (MENSA) averages 2 echoes acquired within the same repetition time (TR) for high fluid signal [7]. Coherent Oscillatory State Acquisition for the Manipulation of Image Contrast (COSMIC) [8] is a balanced coherent sequence that utilizes segmented multi-shot centric acquisition to achieve mixed T2/T1-weighted contrast. In this study, we qualitatively and quantitatively compared 6 new magnetic resonance (MR) methods for evaluating knee cartilage at 3.0T.

Methods: All 5-minute sequences were sagittally acquired with a 3.0T MR unit (Signa Excite HDx; GE Healthcare, Waukesha, WI), transmit-receive 8-channel phased-array extremity coil, and voxel volumes ranging from 0.18mm^3 to 0.26mm^3. Each sequence was performed twice on 10 healthy volunteers, and once on 5 osteoarthritis (OA) patients. Images of 5 volunteers and the 5 OA patients were ranked by 3 radiologists on tissue contrast, articular surface clarity, reformat quality, and cartilage lesion conspicuity. Exact binomial tests were used to compare differences in the rankings of the sequences. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured from all of the volunteers. Muscle and bone SNR were measured using the double acquisition difference method previously described with parallel imaging [9]. To avoid errors due to subject motion, cartilage and fluid SNR were estimated from 5 regions of interest (ROI) placed throughout the image sets to better account for the spatial variation of noise in parallel imaging and the multi-channel coil. Paired t-tests were used to compare SNR and CNR. FSE-Cube and VIPR-bSSFP were compared with IDEAL-SPGR for their ability in measuring cartilage volume. The femoral, tibial, and patellar cartilage of all volunteers were manually segmented. Accuracy of FSE-Cube and VIPR-bSSFP for cartilage volume measurement was assessed relative to IDEAL-SPGR by calculating the concordance correlation coefficient (CCC), 95% confidence interval, the Bland-Altman 95% limits of agreement (LoA), and the mean and standard deviation (SD) of the difference between the test and reference sequences' measured volumes. Precision was evaluated by mean coefficients of variation (COV) for intraobserver and interobserver variabilities, with interobserver variability assessed by having an additional observer segment the femoral cartilage of 5 volunteers. To assess intraobserver variability, the femoral cartilage of a volunteer was segmented 3 separate times by both observers. The ICC reported by sequence type was calculated by a random-effects regression of observer and volunteer.

Results: FSE-Cube had the best performance overall, with top rankings for cartilage lesion conspicuity and reformatting ability. FSE-Cube had the highest cartilage SNR, fluid SNR, muscle SNR, fluid-cartilage CNR, bone-cartilage CNR, and muscle-cartilage CNR ($P<0.02$ except for muscle-cartilage CNR, Fig. 1). VIPR-bSSFP ranked second, with top rankings in overall tissue contrast, reformatting ability, and clarity of articular surface. Both FSE-Cube and VIPR-bSSFP compared favorably to IDEAL-SPGR in accurate (CCC>0.998) and reproducible (COV<2%) cartilage volume measurements of the knee (Tables 1-2). All sequences, except for IDEAL-SPGR, had bright synovial fluid that highlighted cartilage surface lesions (Fig. 2).

Conclusion: This was the first study that compared 6 promising, newly developed three-dimensional MR methods in the same cohorts of asymptomatic volunteers and patients with knee OA. VIPR-bSSFP and FSE-Cube produced high image quality with accurate and precise volume measurement of knee cartilage. A limitation of this study is that the difference method could not be used to calculate fluid-cartilage CNR, because the pockets of synovial fluid were too small for accurate ROI measurements in the setting of subject motion. In conclusion, FSE-Cube and VIPR-bSSFP show great promise for providing rapid, multi-planar evaluation of articular cartilage, and either may provide a single MR pulse sequence for comprehensive knee joint assessment for use in clinical practice and OA research studies.

	FSE-Cube			**VIPR-bSSFP**		
Region	*CCC (95% CI)*	*95% LoA (mL)*	*Volume Difference ±SD (mL)*	*CCC (95% CI)*	*95% LoA (mL)*	*Volume Difference ±SD (mL)*
Femur	0.993 (0.974, 0.998)	-0.64, 0.77	-0.06 ± (0.36)	0.997 (0.992, 0.999)	-0.46, 0.40	0.03 ± (0.22)
Patella	0.978 (0.916, 0.994)	-0.44, 0.25	0.09 ± (0.18)	0.979 (0.930, 0.994)	-0.44, 0.30	0.07 ± (0.19)
Tibia	0.988 (0.959, 0.997)	-0.29, 0.48	-0.09 ± (0.19)	0.980 (0.936, 0.994)	-0.50, 0.62	-0.05 ± (0.29)
Overall	0.998 (0.997, 0.999)	-0.49, 0.54	-0.02 ± (0.24)	0.999 (0.997, 0.999)	-0.47, 0.44	0.01 ± (0.23)

Table 1. FSE-Cube and VIPR-bSSFP compared favorably to IDEAL-SPGR in accurate cartilage volume measurements.

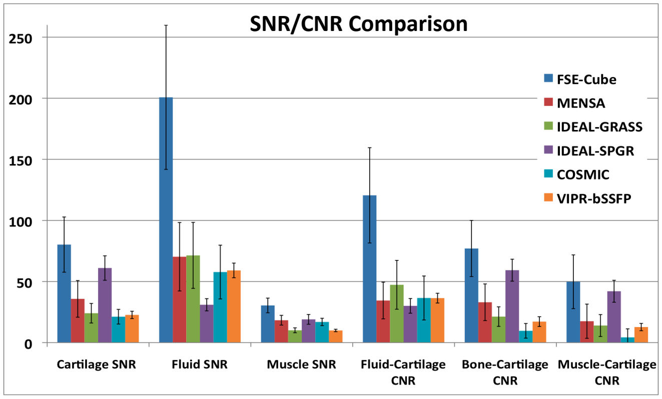

Figure 1. FSE-Cube had the highest SNR and CNR, except for bone SNR ($P< 0.02$). FSE-Cube had muscle-cartilage CNR was statistically equivalent to IDEAL-SPGR (P=0.2).

References: [1] Busse, et al. Magn Reson Med 2006;55(5):1030-1037. [2] Kijowski, et al. J Magn Reson Imaging 2006;24(1):168-175. [3] Yu, et al. Magn Reson Med 2005;54(4):1032-1039. [4] Reeder, et al. J Magn Reson Imaging 2007;25(3):644-652. [5] Kijowski, et al. ISMRM 2007, p. 3819. [6] Hardy et al. J Magn Reson Imaging 1996;6(2):329-335. [7] Huang, et al. Skeletal Radiol 2008; 37:377 (Abstract 13). [8] Reeder, et al. Magn Reson Med 2005;54(3):748-754.

	IDEAL-SPGR	**FSE-Cube**	**VIPR-bSSFP**	**Overall**
Femoral ICC	0.996	0.994	0.976	0.98
Interobserver COV (%)	0.7	1	2.4	1.9
Intraobserver COV (%)	1	1.4	1.2	1.4

Table 2. FSE-Cube and VIPR-bSSFP allow for similar precision to IDEAL-SPGR in cartilage volume measurement.

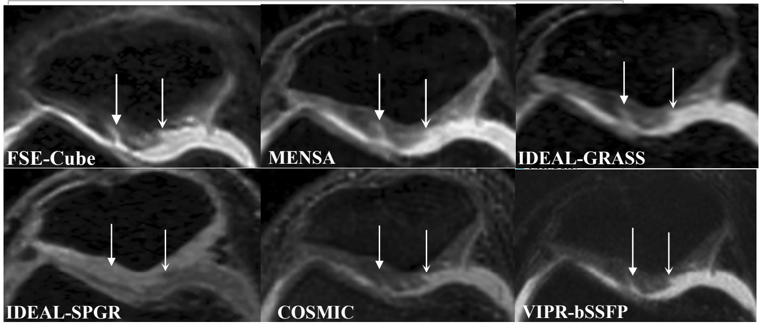

Figure 2. Axial MR image reformations show superficial cartilage fissure on lateral patellar facet (*wedge-shaped arrows*) and partial-thickness cartilage defects on medial patellar facet (*curved arrows*) in OA patient.