High-resolution morphological and biochemical imaging of articular cartilage of the ankle joint at 3.0 T using a new dedicated phased array coil: In-vivo reproducibility study

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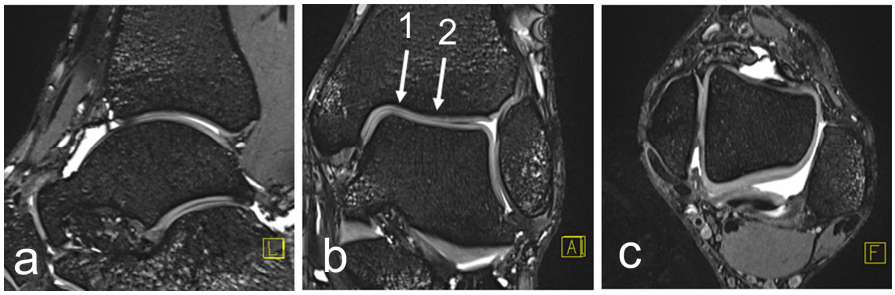
Introduction: The exact analysis of normal cartilage, traumatic or degenerative cartilage lesions in joints with high congruency and thin cartilage layer is technically demanding. The clinical impact of such an assessment is high since modern surgical therapies require preoperative high-resolution magnetic-resonance imaging (MRI) of the ankle joint (1). Studies on cadaver specimen have shown that MRI is capable to exactly visualize cartilage thickness and topography in the ankle at 1.0 and 1.5 Tesla (2). However for high resolution cartilage imaging and precise cartilage segmentation long scan times and the use of anisotropic diffusion noise reduction algorithm was necessary for reproducible results. These efforts detract from clinical application. The importance of sophisticated coil technology in the visualization of joints with thin articular cartilage is unquestionable. With the improved contrast and SNR at 3T, dedicated phased array coils together parallel imaging and sophisticated sequences can base in an optimal diagnosis in relatively short scan time. Recent studies point out that isotropic 3D gradient echo (GE) sequences show promising results (3). At present a 3D-True Fast Imaging with Steady-State Precession (True-FISP) Sequence is of increasing importance, since it provides an isotropic resolution of 0.3mm within the shortest scan time of all 3D GRE sequences (4). Besides morphological imaging hopes have been generated with the introduction of MRI techniques to directly visualize cartilage structure and molecular composition in vivo. One of the most widely implemented MR parameter applied to cartilage molecular imaging is quantitative T2, which is seen to reflect interactions between water molecules and surrounding macromolecules (5). The aim of the present study was to evaluate the feasibility and reproducibility of high-resolution morphological and biochemical MRI of the articular cartilage of the ankle joint using a new ankle dedicated phased array coil. In detail, the first objective was to morphologically compare a standard Proton-Density Fat-Suppressed Turbo-Spin-Echo (PD FS TSE) to an optimized isotropic 3D TrueFISP sequence, second to assess the feasibility and reproducibility of quantitative T2 measurements within thin articular cartilage layers in the ankle joint.

Material and Methods: Ten healthy volunteers without known musculoskeletal disease and no history of trauma or pain (mean age 32.4 years) were included. MRI was performed at a 3.0 T MR scanner (Siemens, Erlangen, Germany). A new 8-channel high resolution, small filed of view foot and ankle imaging coil was used (Invivo, Gainesville, FL, USA). After localizing, a 3D-TrueFISP WE sequence was carried out, covering the ankle with 320 isotropic 0.31x0.31x0.31mm^3 slices using a 160mm FoV and a 512^2 matrix; TR/TE was 9.65/4.18ms, Flip angle 28°, bandwidth 200 Hz/pixel and parallel imaging technique (PAT) with acceleration factor of 3 using a generalized autocalibrating partially parallel acquisition (GRAPPA) technique; scan time was 9:49 min. All consecutive sequences were planned with identical in-plane resolution and slice thickness now set on 3mm sagittal using the 3D reconstruction of the isotropic True-FISP images as localizer (Fig. 1 a,b,c). PD FS TSE sequence was performed with TR/TE 2400/39ms, Flip angle 160°, PAT off, bandwidth of 244 Hz/pixel; 16 slices; scan time 4:02 min. Biochemical quantitative T2 imaging was prepared by a multi-echo spin echo (SE) T2 approach. Using 6 echoes (TE: 16.5, 33.0, 49.5, 66.0, 82.5, 99.0 ms); TR 603 ms; Flip angle 180°, PAT factor 2 (GRAPPA), bandwidth of 130 Hz/pixel; 10 slices in 10:53 min. T2 maps were obtained using a pixel wise, mono-exponential non-negative least squares (NNLS) fit analysis. Analyses were done about 5mm lateral to the medial edge of the talus, were osteochondritis dissecans usually occurs (6) (location 1) and in the middle of the talar dome (location 2) (Fig. 1 b). To evaluate the reproducibility of the measurements, the assessment of cartilage thickness in morphological images and regions of interest (ROI) for quantitative T2 imaging was manually done by three experts in musculoskeletal MRI. Each analysis was repeated three times. Measurements of cartilage thickness and quantitative T2 values were evaluated by analyses of variance using a three way ANOVA with random factor. The reproducibility was determined as coefficient of variation (CV, given in %) for each volunteer, averaged for all volunteers together and was seen as a grade of precision by apportion of standard deviation relating to mean. The average reproducibility was assessed as root mean square average (RMSA, given in %). SPSS version 15.0 (SPSS Institute, Chicago, IL, USA) was used, a P value less than 0.05 considered statistically significant.

Results: As seen in Table 1, cartilage thickness assessed with the 3D-TrueFISP sequence was significantly higher for all regions than cartilage thickness assessed by the PD FS TSE sequence. Quantitative T2 assessment showed similar results for measurements within the talar and tibial cartilage. Mean T2 values (ms) in articular cartilage of the trochlear surface of the talus were 54.2±6.9; mean T_2 values for articular cartilage of the inferior surface of the tibia were 54.6±7.2 Reproducibility of morphological imaging can be seen in Table 2. Both sequences showed similar results for reproducibility related to volunteers and raters (CV) and averaged reproducibility (RMSA) with slightly, but not significantly, better results for the 3D-TrueFISP. On behalf of quantitative T2 measurements reproducibility CV (%) ranged from 2.2 to 4.1 for talar cartilage measurements with a RMSA (%) of 3.2, CV for tibial cartilage ranged from 2.7 to 5.7 with a RMSA of 4.7.



Discussion: In our study, defined regions within the thin and, in terms of MRI, technically demanding cartilage of the talocrural joint were analyzed and a combined assessment of cartilage thickness and T2 relaxation was performed in a clinically acceptable scan time. The obtained results show good reproducibility of high-resolution isotropic 3D-TrueFISP, PD FS TSE and quantitative T2 cartilage imaging. The results highlight the important role of coil technology together with sophisticated imaging techniques in a clinical background.

Table 1 Cartilage thickness (mean ± StDv) at two anatomic points calculated from the 3D-TrueFISP sequence and the PD FS TSE sequence. P value indicating changes between the two different sequences

Site	3D-TrueFISP	PD FS TSE	P value
Talus (location 1), mm	1.14 ± 0.23	0.99 ± 0.28	p < 0.05
Talus (location 2), mm	1.07 ± 0.22	0.80 ± 0.26	p < 0.05
Tibia (location 1), mm	1.17 ± 0.21	0.99 ± 0.28	p < 0.05
Tibia (location 2), mm	1.08 ± 0.19	0.74 ± 0.15	p < 0.05

Table 2 Reproducibility values of cartilage thickness measurements calculated from the 3D-TrueFISP sequence and the PD FS TSE sequence. P values indicating changes between the two different sequences

Site		3D-TrueFISP	PD FS TSE	P value
Talus (location 1)	CV %	5.3 - 8.6	6.1 - 9.7	p > 0.05
	RMSA %	7.7	8.2	p > 0.05
Talus (location 2)	CV %	4.6 - 8.9	5.3 - 9.1	p > 0.05
	RMSA %	7.4	7.1	p > 0.05
Tibia (location 1)	CV %	4.3 - 10.5	5.9 - 11.1	p > 0.05
	RMSA %	7.6	8.5	p > 0.05
Tibia (location 2)	CV %	3.6 - 11.8	3.6 - 11.6	p > 0.05
	RMSA %	7.9	8.4	p > 0.05

References: 1. Hangody L , JBJS 2003. **2.** Ba-Ssalamah JMRI 2002, **3.** Eckstein F, AnRheuDis 2006. **4.** Weckbach S, InvRad 2006. **5**. Glaser C, RadClinNA 2005. **6.** Steinhagen J, Ortho 2001.