Multiparametric assessment of healthy and OA articular cartilage under loading at 17.6 T

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Introduction: The articular cartilage contributes to reduce friction between the articulating bones in a joint and participates in the distribution of load between bones. Degradation of articular cartilage in OA leads to loss of its mechanical properties, which subsequently results in functional impairment, pain, and ultimately in disability. Assessing the functionality of cartilage is of great importance for the diagnosis of its integrity. Therefore, the purpose of this work was to use a multiparametric approach (T2, T1 and ADC, FA and water volume fraction (WVF)) to characterize the change in articular cartilage under loading in healthy and OA diseased human articular cartilage at 17.6T.

Methods: Samples of healthy (n=11, 26.7±8.9 y), and OA (n=3, 70.3±5.5 y) patellar cartilage were drilled from excised human patellar cartilage harvested within 24 hours after death. Samples were examined at a 17.6-T MRI scanner (Bruker Advance, Bruker Biospin GmbH, Rheinstetten, Germany) using a 5-mm birdcage coil. Throughout the MRI examination samples were kept immersed in physiologic saline to prevent drying. The MRI protocol included a multiecho SE sequence (TR/TE=938/7 ms, echo spacing=7 ms, 20 echoes, bandwidth (BW)=138.9 kHz, 16 averages (avg), acquisition time(TA)=20:00 min), a saturation-recovery FLASH sequence (TE=2.56 ms, flip angle=10°,TI=0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 7.5 and 10 s, BW=138.0 kHz, 20 avg, TA=17:12 min), a FLASH sequence with a preparation hard pulse of varying duration for B1 calculation (TR=6.05 ms, flip angle=10°, BW=138.0 kHz, duration of the pulse changed from 2 µs to 101 µs in 1 µs increment, TA=15:00 min) and a diffusion-weighted SE sequence (TR/TE=938/15.0 ms, b-values=0, 500 s/mm², 6 directions, BW=130.0 kHz, 10 avg, TA=2:20 h). All four sequences used the same FOV of 12.8×12.8 mm², in plane resolution of 50×100 µm², and slice thickness of 800 µm. After the first MRI measurement (native) samples were taken out of the scanner, indented using a strain of (26±5)% and imaged again in the same plane. A subset of samples (n = 5 healthy, n = 1 severe OA) were imaged a third time, after 4 h relaxation. After imaging samples underwent histology with safranin-O staining to assess the integrity of the sample. Maps of T2, T1, ADC, FA, the diffusion angle, θ, and WVF were calculated for each measurement. The diffusion angle is defined as the angle of the first eigenvector with the direction of the magnetic field. WVF were calculated from the signal intensity at zero echo time corrected from the T1 and B1 maps. In each image three cartilage regions were manually segmented: a central region positioned under the indenter and two lateral regions on the right and left sides of the indenter. Regions covered the same position in all measurements of the same sample. From each of these regions averaged profiles of all MR parameters were calculated and their height normalized between 0 at the bone-cartilage interface (BCI) to 1 at the articular surface (AS). The difference in MRI parameter profiles between the native and the indented measurements were characterized by the largest difference across the profile and the percentage of the cartilage height, where such high differences in MRI parameters occurred.

Results: Fig. 1 shows the maps of a sample of a 24 y-old donor acquired native, under indentation and 4 h after relaxation. Indentation causes changes of variable extent in the different MRI parameters, thus indicating the diverse information contained in the parameters. For the central region the largest change of the MRI parameters was found directly underneath the indenter (Table 1). Relative to the values in the native measurements the healthy samples showed an average decrease in T2 (-41%), T1 (-28%), WVF (-37%), θ (-11%), ADC (-43%) and a huge increase in FA (910%, due to the low values in the native measurements 0.09). Lateral to the indenter the profiles did not show any systematic variations in ADC, FA, T2, T1 and θ. However, in some of the samples, like in Fig. 1, a tendency to broadening was observed in the most superficial cartilage, which corresponds to the location of the tangential zone. Characteristic changes in WVF distribution were observed consistent with redistribution of water under indentation loading.

Table 1. Largest change and range of change between native and indented measurements

		T2 (ms)	WVF	T1 (ms)	θ (°)	ADC (10^{-3}mm²/s)	FA
Healthy	Change	-7.6±2.1	-0.29±0.07	-550±170	-10±8	-0.52±0.18	0.66±0.11
	Range(%)	54±6	33±14	15±4	19±10	23±2	15±11
OA	Change	-11.2±2.0	-0.50±0.03	-998±255	-27±8	-0.97±0.25	0.54±0.03
	Range (%)	43±6	31±7	23±5	24±12	42±7	38±15

OA samples showed more intense changes in all parameter maps and also larger portions of the cartilage were involved presenting changes of the MRI parameters (Table 1). Relative to the native values a decrease in T2 (-49%), T1 (-42%), WVF (-54%), θ (-11%), ADC (-63%) and increase in FA (510%) was observed. The higher changes in all MRI parameters with the only exception of FA are partially explained by their increased values at the AS as compared with the healthy samples. Interestingly, after 4 h relaxation the OA sample presented signs of reduced T2, T1, ADC, WVF and increased FA in the superficial cartilage at the former position of the indenter.

Conclusions: Multiparametric analysis of articular cartilage under loading can characterize the functionality of the articular cartilage and provide evidence of loss of its mechanical properties during OA.

References: [1] Raya JG et al., Proc ISMRM.2008; 18:330

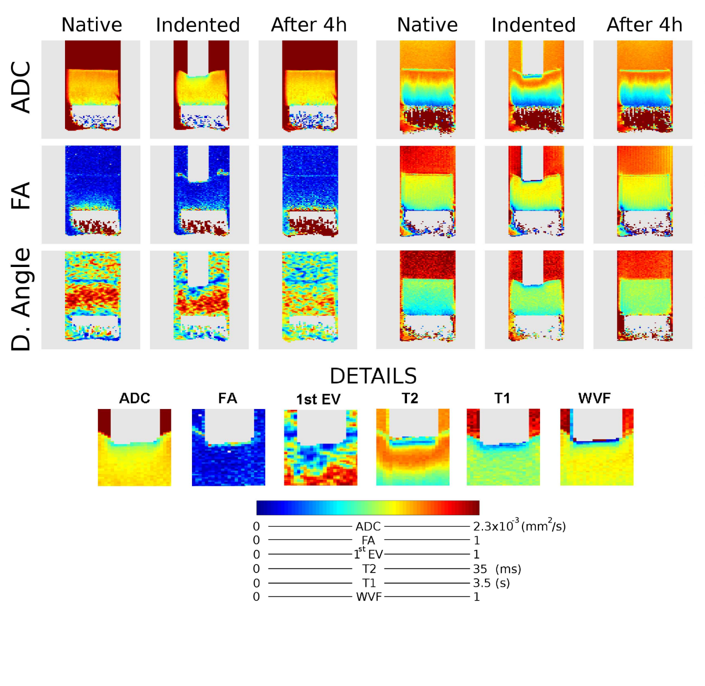

Figure 1: T2, T1, ADC, FA, and WVF maps in a sample of a healthy 24 y-old donor measured native, under indentation and 4 h after relaxation. Indentation led to changes in all MRI parameters to a different extent. Observe the increased FA at the tangential zone under loading, which is consistent with a broadening of the tangential zone in the diffusion angle. Also interesting is to observe the redistribution of water under indentation with decreased WVF under the indenter and increased WVF at both sides of the indenter. The lower row shows details of the indentation in all parameter.