Multiparametric analysis of healthy and diseased articular cartilage at 17.6 T and correlation with histology

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Introduction: In the pathogenesis of osteoarthritis (OA) the articular cartilage is progressively destroyed thus leading to pain and mobility limitation of the articulation. In the early stadium of OA, the proteoglycans (PG) are gradually lost, with a consequent decrease in the swelling pressure. The collagen network then bears an increased load, the fibers fatigue, and finally disruption of the collagen network occurs. First very preliminary results demonstrated the potential of multiparametric analysis of articular cartilage for detecting degeneration in the cartilage matrix [1]. The purpose of this work was to multiparametrically (T2, T1 and ADC, FA and water volume fraction (WVF)) characterize healthy and diseased human articular cartilage at 17.6T in a large collective, and to correlate MR findings with histology of the probes.

Methods: Samples of healthy (n=38, 27±11y), moderate OA (n=11, 63±10y), and severe OA (n=7, 54±16y) 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. 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. Maps of T2, T1, ADC, FA and WVF were calculated for each sample. The profiles of all MR parameters from the BCI to the articular surface (AS) were plotted together after normalization to the water values. After imaging, samples underwent histology. Samples were decalcified, dehydrated and microtomed to a thickness of 9 µm. The PG were stained using 0.5% safranin'O. Histological sections were photographed. Cartilage was automatically segmented on these images and mean image intensity from the BCI to the AS was calculated for comparison with the MR parameters.

Results: Examples of the maps, histology and profiles are shown in Fig. 1. In healthy cartilage theT2 maps allow identifying the radial, transitional and tangential zones. Interestingly, T1 and ADC showed a very similar behavior from the AS to the BCI with constant or slightly decreasing values from AS to the BCI (Table 1). In regions of decreased PG content ADC usually showed increased values (Fig. 1). FA anisotropy rapidly decreased form the BCI to the radial zone (Fig 1). Slightly increased FA at the tangential zone was observed in about 1/3 of the samples. WVF was very constant in the cartilage by 80% and decreased to 30% near to the BCI.

Table 1. Averaged values in all healthy (Heal) and severe OA (sOA) samples

	T2 (ms)		T1 (s)		WVF		ADC (10^{-3}mm²/s)		FA	
	Heal	sOA	Heal	sOA	Heal	sOA	Heal	sOA	Heal	sOA
Phys. sol.	29	29	3.1	3.0	1.01	1.01	1.89	1.93	0.05	0.05
Tangen. z.	16	24	2.1	2.3	0.82	0.95	1.25	1.54	0.12	0.05
Transit. z.	27	23	2.03	2.1	0.83	0.89	1.18	1.36	0.08	0.07
Radial z.	8.6	10	1.8	1.8	0.70	0.72	1.00	1.04	0.39	0.29
BCI	8.4	9.2	1.4	1.6	0.26	0.29	0.70	0.57	0.62	0.32

In diseased cartilage a progressive loss of the tangential zone was observed (Fig. 1) with OA grade. In moderate OA samples, the tangential zone appeared in T2 profiles very narrowed compared to the healthy samples, whereas no sign of the tangential zone could be observed in severe OA samples. Histology sections also showed a progressive loss of PG from the AS to the BCI, which results in increased ADC, T1and WVF (Fig. 1, severe OA). In severe OA samples mean ADC and T1 were 10% higher than healthy samples. Fractional anisotropy showed no characteristic change with OA grade. WVF increased with OA grade by about 10% as expected.

Conclusions: The multiparametric characterization of the cartilage in combination with the analysis of the PG-stained histological sections give a new insight on the dependence of the MR parameters with the integrity of the cartilage matrix and may help clarifying the diagnostic value of the different MR parameters.

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

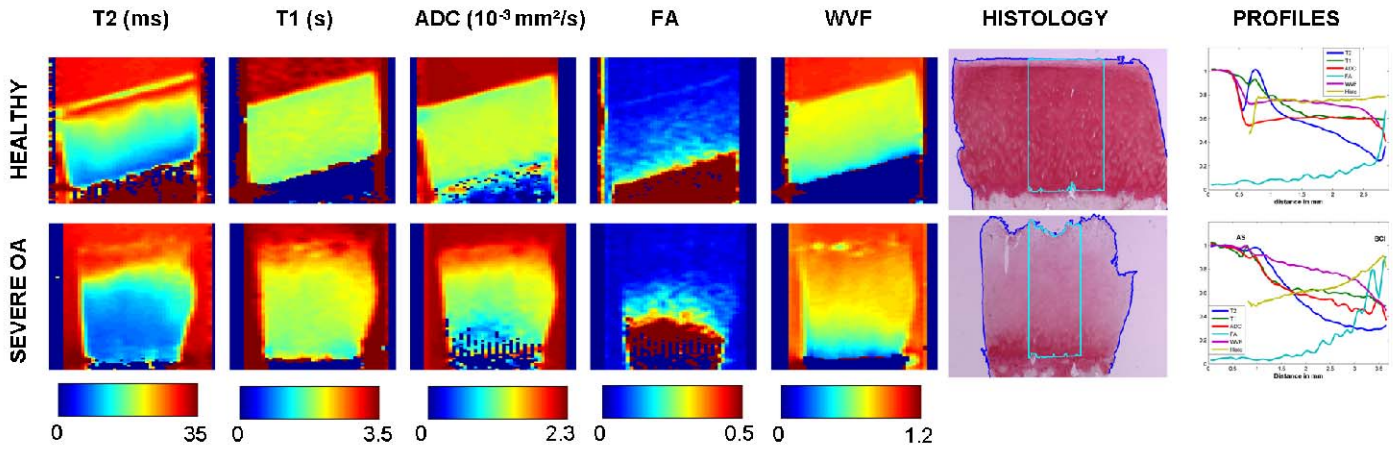

Figure 1: Example of T2, T1, ADC, FA, and WVF maps on healthy and severe OA cartilage. Histology demonstrates different PG content in both samples (blue line is the segmentation and the cyan line the region for intensity analysis). Right. Normalized profiles from the AS to the BCI (T1, T2, ADC, FA, WVF and Histology.