In Vitro Correlation of MR Parameters under Loading with Biomechanical Properties of Degenerated Articular Cartilage

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Introduction:

The main function of articular cartilage is to minimize friction of long bones during joint movement and to absorb a pressure loaded on the joint. This can be achieved by the interplay of special ultra-structural components (especially proteoglycans, collagen, or water) of articular cartilage. In the case of articular cartilage tissue degeneration, the functionality of cartilage may be decreased and may cause serious clinical symptoms which decrease patient's life quality, such as pain or low joint mobility. MRI is a powerful tool for successive diagnostic of articular cartilage diseases [1] and can prospectively predict biomechanical properties of cartilage tissue. The purpose of this study was to compare MR parameters under loading with biomechanical properties of cartilage measured by indentation tests to show that the impact of biochemical changes in degenerated cartilage can be predicted by noninvasive imaging approach (MRI).

Materials and Methods:

Cartilage samples were prepared from joints of 10 patients, who underwent a total knee joint replacement. The samples were cuboid-shape, with 10x10x6 mm in dimension. Study was performed on a Bruker 3T Medspec whole-body scanner (Bruker, Ettlingen, Germany) using *BGA-12 micro-gradients* (capable of delivering 200mT/m) with a special designed compression device built for this gradient system. This equipment allows moving the compressive piston with accuracy of 1/100 mm. Cartilage sample was compressed in the way that 15% of thickness decrease was accomplished. T_1 mapping was performed after filling the water-proof chamber of the compression device with a 2 mmol solution of gadopentetate dimeglumine (Gd-DTPA, Schering, Berlin, Germany) and soaking cartilage sample in solution for 24 hours. Then inversion recovery spin echo pulse sequence with TI times were 15, 30, 60, 160, 400 and 2000 ms. For T_2 mapping a multi-echo multi-slice spin echo sequence with TE times 15, 30, 45, 60, 75 and 90 ms was applied. ADCs were calculated from data from pulsed gradient spin echo (PGSE) with 6 different b-values (10.472, 220. 627, 452.8, 724.5 and 957.7). Each of parameters was calculated by fitting to appropriate function. Fitting routines were written in IDL (Interactive Data Language, Research Systems, Inc.) using *mpcurvefit* routine (Craig B. Markwardt, craigm@lheamail.gsfc.nasa.gov). Regarding biomechanical parameters, Eq (equilibrium modulus), I (instantaneous modulus) and τ (time of tissue relaxation) were measured by indentation tests on a Zwick Z050 universal testing device with a 20N-load cell of 1mN resolution. OA status was assessed by histogical evaluation using H&E staining.

Results:

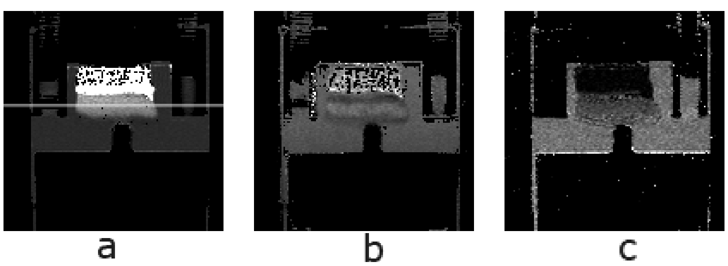

Figure 1. a) T_1 map, calculated from 128 x 128 matrix size, SE, TI = {15, 30, 60, 160, 400 and 2000}, TE = 15ms, FOV 30x30mm. Status: post-compression, b) T_2 map - calculated from 128 x 128 matrix size, MSME sequence used, TE = 15ms. Status: post-compression c) ADC map, calculated from 128 x 128 matrix size, PGSE sequence used with set of 5 different gradient pulses of strength. TR = 4000ms, TE = 15ms, Status: post-compression.

Table 1. Values of T_1, T_2 and ADC, comparison of pre- and during-compression states

	ADC [10^{-3}mm^2/s]	T1 [ms]	T2 [ms]
number of pixels in ROI	166	110	108
without compression	0.96 ± 0.40	180 ± 30	30 ± 9
with compression	0.85 ± 0.39	230 ± 30	27 ± 8
change (%, p value)	11% (p<0.05)	22% (p = 0.238)	10% (p<0.05)

Table 2. Pearson correlation coefficients between MR parameters measured during loading and biomechanical parameters measured by indentation tests

	Eq [MPa]	I [MPa]	I/Eq	τ [s]
T_{1c}/T_{1w}	-0.1884	**0.6324**	**-0.5275**	**0.6092**
T_{2c}/T_{1w}	0.3620	0.1118	-0.0860	0.0257
ADC_c/ADC_w	**-0.4884**	0.1276	-0.2612	**0.5039**

The rows are expressed as a ratio of the MR parameters during compression (c-index) and without compression (w-index).

Discussion/Conclusion: Dedicated equipment for MR evaluation of cartilage in compression was shown to be feasible for studying influence of pressure applied to the cartilage tissue with a high accuracy of the localization and loading control. The pilot data of MR parameters change are in good agreement with already published results, for T_2 [2], ADC [3] and T_1 [4] as well. In some cases, the correlation between MR and selected biomechanical parameters were relatively high, in particular T_1 showed strong relation to the biomechanical parameters (I, I/Eq, which reflect the vitality of cartilage tissue and τ, which reflects the ability of cartilage to relocate water content during loading). τ was also in good correlation with change of ADC. The results of our study suggest that the change of *in situ* measured MR parameters of degenerated articular cartilage exposed to physiological loading can predict the selected biomechanical parameters of cartilage tissue.

References: [1] D. Burstein, Investigative Radiology. 35(10):622-638, October 2000 [2] T.J. Mosher, et al. Radiology 2005; 234:245–249 [3] C.R. Evans, et al. Journal of Biomechanics 2006; 39:1048–1055 [4] J.E. Chiu, et al. Spine 2001; 26:437–444