In-Vitro Evaluation of Pre- and Post-Compression States of Human Articular Cartilage Using MRI at 3 Tesla

[1,2]V. Juráš, [1]M. Bittšanský, [1,2]Z. Majdišová, [1]S. Trattnig

[1]MR Centre of Excellence, Medical University of Vienna, Lazarettgasse 14, A-1090, Vienna, Austria
[2]Institute of Measurement Science, Department of Imaging Methods, SAS, Dúbravská cesta 9, 841 04 Bratislava, Slovakia, email: vladimir.juras@savba.sk

Abstract: *The purpose of this study was to evaluate changes of several MR parameters (T1, T2 and ADC) before and after compression in human cartilage samples using unique micro-imaging compression system. Cartilage samples were prepared from joints of 10 patients, who underwent a total knee joint replacement. Study was performed on a Bruker 3T Medspec whole-body scanner (Bruker, Ettlingen, Germany) using BGA-12 micro-gradients with a special designed compression device built for this gradient system. Employing this equipment there is a possibility to reach accuracy of moving the compressive piston of 1/100 mm. T1 mapping was performed by the inversion recovery spin echo pulse sequence, for T2 mapping a multi-echo multi-slice spin echo sequence was used and ADCs were calculated from data collected from pulsed gradient spin echo (PGSE), all before and after compression. Fitting routines were written in IDL using mpcurvefit routine. Equipment for cartilage compression evaluation seems to be feasible for studying influence of static compression on cartilage tissue. Significant changes of T1, T2 and ADC parameters during compression were found. Biochemical imaging provided by multi-parametric MR improves biomechanical studies of articular cartilage.*

Keywords: MRI, cartilage, biochemical testing

1. Introduction

Cartilage tissue behavior and mechanical changes under compression were mainly reported on bovine samples [1] [2]. The effects on human cartilage were investigated for the influence of exercise on cartilage, e.g. [3].
The purpose of this study was to use special designed compression device adapted to a micro-gradient system to study the effects of mechanical compression of human cartilage explants on T1, T2 and apparent diffusion coefficient (ADC) by application of a highly accurate and localized compression of articular cartilage.

2. Subjects and Methods

Cartilage samples were prepared from joints of 10 patients who underwent a total knee joint replacement. The samples were cuboids-shape, with 10x10x3 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. T1 mapping was performed after filling the water-proof chamber of the compression device with a 2mmol solution of gadopentetate dimeglumine (Gd-DTPA, Schering, Berlin, Germany) and leaving 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 T2 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, NASA/GSFC Code 662, Greenbelt, MD 20770; craigm@lheamail.gsfc.nasa.gov). Comparison of T1, T2 and ADC was performed within selected region of interest. In the case of T1 and ADC ROI was placed in the radial zone of the cartilage (ROI_2 depicted on fig. 1). T2 was evaluated within all three regions of interest (superficial, radial and deep zones - ROI_1, ROI_2 resp. ROI_3).

3. Results

Values of T1, T2 and ADC were obtained. Maps of these parameters were constructed for pre- and post-compression states. Experiments showed feasibility of compression device for investigating compression-induced changes in human cartilage. Accuracy of piston moving was confirmed as well. Crucial point of this study was to find out how reliable the exchange of liquid in the waterproof chamber is. During all experiments the exchange of phosphate buffer solution (PBS) and PBS with contrast agent was very comfortable and quick; moreover, only few air bubbles appeared in the chamber without degrading image quality. The appearance of cartilage sample with piston in the micro-imaging device is depicted and labeled on figure 1. Calculated T1, T2 and ADC maps of one sample are depicted on figure 2. We have observed a mean decrease in T2 of 12.2% (radial zone), 3.68% (superficial zone), 15.03% (deep zone), ADC decreased as well, with 11.5%, and T1 increased with 28.3%. Mean values are summarized in table 1 and 2.

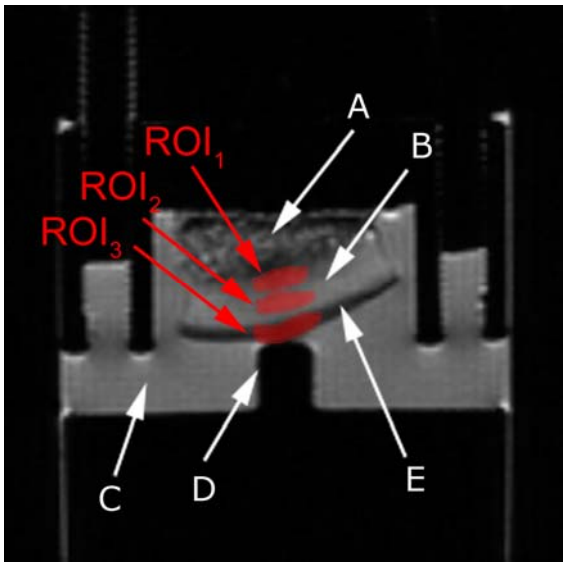

Fig. 1. Cartilage specimen in micro-imaging system (SE sequence used, TR = 4s, TE = 15ms): A – bone tissue, B – deep zone of cartilage (radial zone), C – PBS + GdDTPA2- solution, D – compressive part of piston, E – superficial zone of cartilage (transitional zone), ROIs defined for different cartilage zones (1 - deep, 2 - radial, 3 - superficial).

Table 1. Values of T1, T2 and ADC, comparison of pre- and post-compression states (radial zone).

	ADC [mm^2/s]	T1 [ms]	T2 [ms]
number of pixels	166	110	108
pre-compression	$0.96\ 10^{-3} \pm 0.40\ 10^{-3}$	182.49 ± 30.34	31.32 ± 8.56
post-compression	$0.85\ 10^{-3} \pm 0.39\ 10^{-3}$	234.07 ± 29.63	27.48 ± 8.05

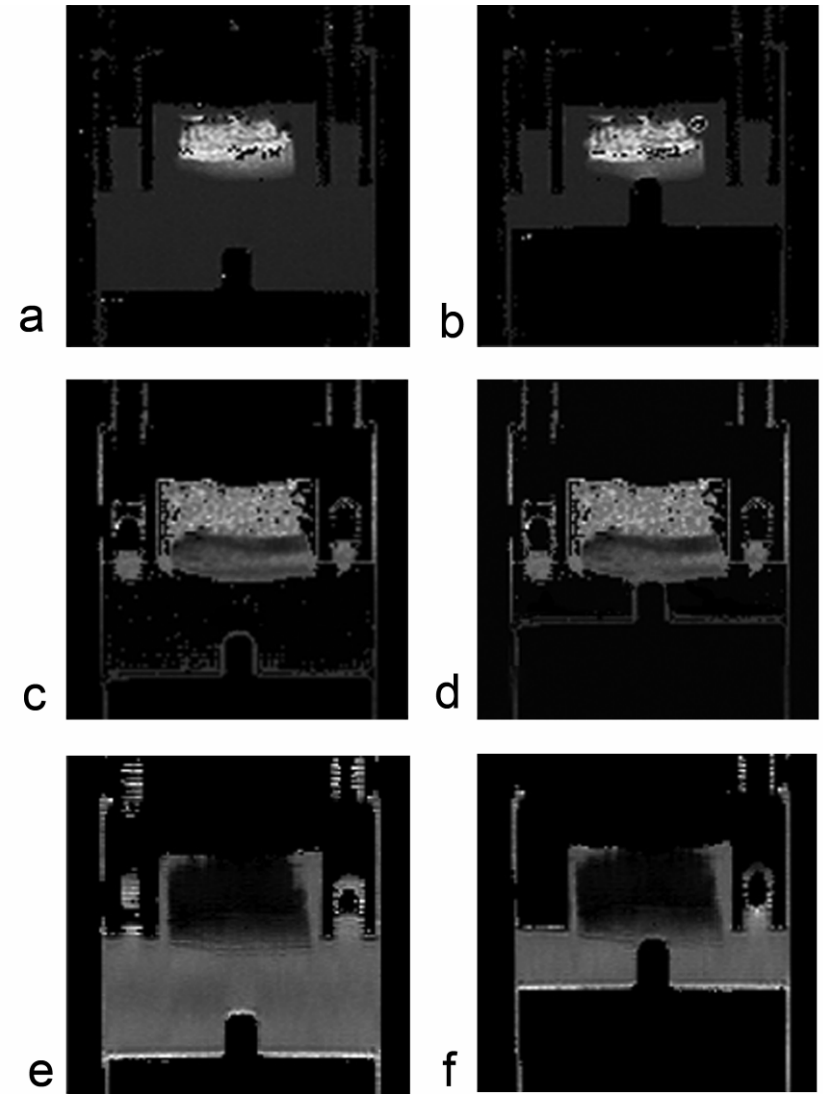

Fig. 2 a) T1 map, calculated from 128 x 128 matrix size, SE, TI = {15, 30, 60, 160, 400 and 2000}, TE = 15ms. Status: pre-compression, b) T1 map, calculated from 128 x 128 matrix size, SE, TI = {15, 30, 60, 160, 400 and 2000}, TE = 15ms. Status: post-compression, c) T2 map - calculated from 128 x 128 matrix size, MSME sequence used, TE = {15, 30, 45, 60, 75, 90}, TE = 15ms. Status: pre-compression d) T2 map - calculated from 128 x 128 matrix size, MSME sequence used, TE = {15, 30, 45, 60, 75, 90}, TE = 15ms. Status: post-compression e) ADC map, calculated from 128 x 128 matrix size, PGSE sequence used with set of 5 different gradient pulses of strength {5, 80, 120, 155, 180}. TR = 4000ms, TE = 15ms, Status: pre-compression, f) ADC map – calculated with same parameters as in previous figure, measured in post-compression status.

Table 2. Values of T1, T2 and ADC, comparison of pre- and post-compression states (radial zone).

	T2 [mm^2/s] (superficial)	T2 [ms] (radial)	T2 [ms] (deep)
number of pixels	115	108	86
pre-compression	32.00 ± 7.55	31.32 ± 8.56	24.74 ± 4.11
post-compression	30.82 ± 11.15	27.48 ± 8.05	21.02 ± 7.63

4. Discussion

T2 values decreased after compression in 12.2%. These observations agree well with previously published results and support the hypothesis that cartilage compression results in greater anisotropy of superficial collagen fibers, because region of interest was defined very close to piston head, i.e. mostly in superficial part of cartilage. Eckstein et al [3] demonstrated a 5%–6% decrease in patellar cartilage volume after compressive loading induced by performing 50 deep knee bends. Besides tissue consolidation and the resulting decrease in water content due to efflux of water as a possible factor responsible for the observed change

in cartilage T2 prior ex vivo studies designed for the evaluation of changes in collagen fiber orientation with loaded conditions suggest that changes in fiber orientation is the dominant factor for T2 shortening [4],[5]
T1 values of cartilage after penetration of $Gd(DTPA)^{2-}$ allow assessment of the proteoglycan (GAG) component of articular cartilage [6]. Applying compression to cartilage sample invokes changes in water content in cartilage tissue. Amount of proteoglycans stays unaltered, but amount of liquid part decreases. Due to squeezing liquid content from cartilage, concentration of $Gd(DTPA)^{2-}$ decreases as well. Thus, T1 values increase. This is in agreement with the results – T1 changed in 28.3%.
In contrast to $Gd(DTPA)^{2-}$ enhanced T1, which reflects changes in chemical composition diffusion constants may reflect micro-structural degradation of the cartilage matrix. ADC correlates with structural changes rather than with changes in chemical composition [7]. Compression may induce cartilage matrix impairment which leads to decreasing of ADC.
In conclusion, compression device used in this study provides convenient way to quantitatively evaluate load-induced changes in human cartilage with extremely high accuracy.

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