

MR T2 Study of Human Knee Cartilage Using In-vivo Compression Device

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Abstract. *Degeneration of cartilage in the knee joint associated with osteoarthritis is a very common disease. Magnetic resonance imaging (MRI) has become the method of choice for the evaluation of cartilage. Series of T2 mapping images under unloading and loading conditions were obtained using multi-slice multi-echo (MSME) technique. In a volunteer study, the mean cartilage T2 relaxation times exhibited a statistically significant decrease in the first loading phase and also statistically significant increase of T2 relaxation times in recovery period. Dynamic of T2 change in cartilage compression phase as well as in cartilage recovery phase were similar. In a patient study, during unloading or loading conditions statistically significant changes were observed in T2 relaxation times in transplant deep zone ($P < 0.0001$), in posterior deep zone ($P = 0,003$), in central deep zone ($P < 0.0001$), in central superficial zone ($P = 0.007$), and in tibia superficial zone ($P < 0.0001$). Results of this study show that the T2 mapping under loading conditions can provide useful information on cartilage transplant in post-surgery period and help to evaluate the efficacy of cartilage-repair surgery.*

Keywords: *MRI at 3 Tesla; Loading of Human Knee Cartilage Transplant In-vivo; T2 Mapping of Cartilage*

1. Introduction

Degeneration of cartilage in the knee joint associated with osteoarthritis is a very common disease. Therefore it is important to discover cartilage damage as early as possible, so that preventive treatment could stop the progression of degeneration. In case the cartilage transplant surgery was the last solution to treat cartilage defects, it is necessary to assess the quality of repair tissue during maturation process, preferably by non-invasive technique.

Magnetic resonance imaging (MRI) has become the method of choice for the evaluation of cartilage, as it allows morphological assessment of the cartilage surface, thickness, volume and status of a subchondral bone, as well as additional properties of repair tissue, such as filling of the defect, integration into adjacent cartilage and bone, surface, structure and signal intensity of transplants [1-3]. Therefore MRI is becoming important tool for non-invasive follow-up of patients after cartilage repair surgery [4].

2. Subject and Methods

Volunteers

Nine healthy volunteers were measured between July 2011 and November 2011, (mean age 31 years \pm 7; six men and three women). These volunteers had no history of knee pain or stiffness, and had never undergone any knee surgery. The study protocol was approved by local Institutional Review Board. All volunteers provided written informed consent after procedures of the study were explained to them.

Patients

Between January 2012 and September 2012 fourteen patients were enrolled to the study. Out of these, four patients were excluded from this study due to too thin transplant tissue, which could not be evaluated. Ten patients (mean age 40 years \pm 8; six males and four females) after matrix-associated autologous chondrocyte transplantation (MACT) were included into this study. Six transplants were located on the medial femoral condyles (MFC) and four on the lateral femoral condyles (LFC). Exclusion criteria were previous cruciate ligament reconstruction, previous meniscectomy, loose or not detectable transplant. The knee surgery at every patient was performed at least two years up to eight years before MRI measurements for this study. Study was performed in compliance with the regulations of the local ethics committee and subjects provided written and informed consent to this study.

MR Imaging

All measurements were performed on a 3 Tesla MR imaging system (Magnetom Trio; Siemens, Erlangen, Germany) using a Tx/Rx 8-channel knee coil (In Vivo Corp, Gainesville, FL, USA) with a multi-slice multi-echo (MSME) Carr-Purcell-Meiboom-Gill (CPMG) technique for T2 mapping. During MR imaging, the volunteers and patients were measured in a supine position, the examined knee was fully extended, and the leg was tightly fixed to a MR-compatible compression device, as well as the pelvis was fixed on MRI bed using a dedicated belt. The foot of the examined leg was secured in a neutral rotational position by fixation on a foot rest of the sliding foot plate. (Fig. 1) The use of dedicated MR-compatible, custom-made, pneumatically controlled compression device allows simulating physiological load of 120 N.



Fig. 1: MR compatible compression device is installed on the MR bed. Patient laying supine was fixed to the bed (fixation not shown on the figure). Knee coil was used for the signal acquisition. Yellow arrow shows the direction of pressure. Piston is located right on the figure. The compression device was controlled by the compressed air through the plastic tube, and the piston provided load to the foot plate.

A series of T2 measurements started with load-free measurement. After this initial load-free measurement, a load of 120 N was applied. Series of loaded T2 measurements were performed. At the end of series, load was released and one more load-free measurement was performed.

Under each unloading and loading conditions, sagittal T2 maps were obtained using MSME-CPMG, with the following parameters: repetition time (TR): 1110ms; 6 evenly spaced echoes from 11.8 to 70.8 ms; field of view: 160x160mm; matrix: 320 \times 320 interpolated to 640 \times 640; slice thickness: 3mm; signal averaging: 2; total acquisition time: 7min 35s. A frequency-selective fat-suppression technique was used to minimize the chemical shift artefact at the cartilage-bone interface. At each volunteer, one to two sagittal images passing through the center of the lateral and medial femoral condyle were obtained. In this imaging plane the femoral and tibial articular cartilage in the weight-bearing area consisted on cartilage covered by the anterior meniscus, cartilage in contact with the opposing articular cartilage, and cartilage covered by the posterior meniscus. On each slice, up to six regions of interest (ROIs) were drawn manually by a radiology resident E.S. under supervision of an experienced

radiologist S.T. (18 years of experience). In total, three ROIs were drawn. First ROI was drawn in the central tissue in the weight bearing zone of the femoral cartilage (CF). Second ROI was drawn in the posterior area of the femoral cartilage (PF) in the low weight bearing zone. Last, third ROI was drawn in the weight bearing zone of the tibial cartilage (CT). Each ROI was separated into deep and superficial zone. In case of patients, one additional ROI was drawn at the cartilage transplant (Fig. 2, 3 and 4).

3. Results

Volunteers

In the volunteer study a characteristic “U” shape course of T2 values was demonstrated (fig. 5). Mean cartilage T2 relaxation times exhibited a significant decrease in the first loading phase of ten minutes ($60.8\text{ms} \pm 7.5 \rightarrow 54.6\text{ms} \pm 6.2$, $p < 0.05$ in the superficial layer; $47.2\text{ms} \pm 8.6 \rightarrow 44.2\text{ms} \pm 8.6$, $p < 0.05$ in the deep layer), however during another four loading periods of ten minutes stable T2 values were seen. At the last ten minutes without load application a significant increase of T2 values was detected ($54.6\text{ms} \pm 7.4 \rightarrow 61.5\text{ms} \pm 7.5$, $p < 0.05$ in the superficial layer; $43.7\text{ms} \pm 8.3 \rightarrow 46.4\text{ms} \pm 8.1$, $p < 0.05$ in the deep layer).

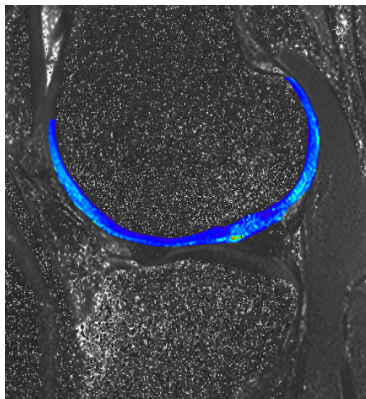


Fig. 2. Sagittal color-coded T2 map of a human knee after MACT.

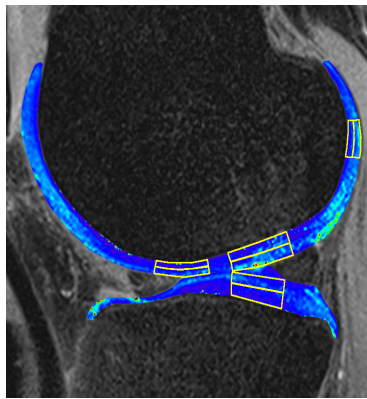


Fig. 3. T2 image of a human knee after MACT in the load-bearing zone.

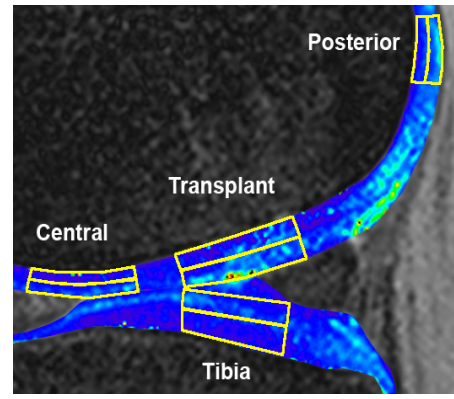


Fig. 4. Definition of regions of interest (ROI) in the femoral and tibial cartilage.

Patients

In the weight bearing zone, repair tissue showed statistically significant increase of T2 relaxation times in comparison to the reference native cartilage in the central region ($P < 0.0001$). Characteristic “U” shape of T2 values was not as obvious as in volunteers (Fig. 6). During unloading or loading conditions statistically significant changes were observed in T2 relaxation times in transplant deep zone ($P < 0.0001$), in posterior deep zone ($P = 0.003$), in central deep zone ($P < 0.0001$), in central superficial zone ($P = 0.007$), and in tibia superficial zone ($P < 0.0001$) (Table 1).

Table 1: T2 Values of each ROI (Mean \pm SD) in each zone under Unloading and Loading conditions.

Zone	1. No Load (ms)	1. Load (ms)	2. Load (ms)	2. No Load (ms)	P-value
1. Transplant superficial	55.09 \pm 10.30	53.96 \pm 9.69	53.98 \pm 10.06	56.38 \pm 9.91	= 0.133
2. Transplant deep	47.65 \pm 7.99	44.84 \pm 8.01	44.50 \pm 7.29	47.10 \pm 7.70	< 0.0001
3. Posterior superficial	57.82 \pm 14.84	57.48 \pm 13.55	54.91 \pm 11.95	58.42 \pm 13.37	= 0.075
4. Posterior deep	48.43 \pm 8.92	46.23 \pm 9.89	46.10 \pm 8.84	48.58 \pm 8.53	= 0.003
5. Central superficial	51.39 \pm 8.00	50.84 \pm 9.95	49.95 \pm 9.00	53.28 \pm 10.19	= 0.007
6. Central deep	39.44 \pm 8.29	36.89 \pm 9.26	36.65 \pm 9.34	40.34 \pm 10.18	< 0.0001
7. Tibia superficial	44.55 \pm 12.09	42.21 \pm 11.25	42.81 \pm 12.03	45.76 \pm 12.04	< 0.0001
8. Tibia deep	33.13 \pm 6.77	32.76 \pm 7.76	32.87 \pm 7.33	34.74 \pm 8.76	= 0.237

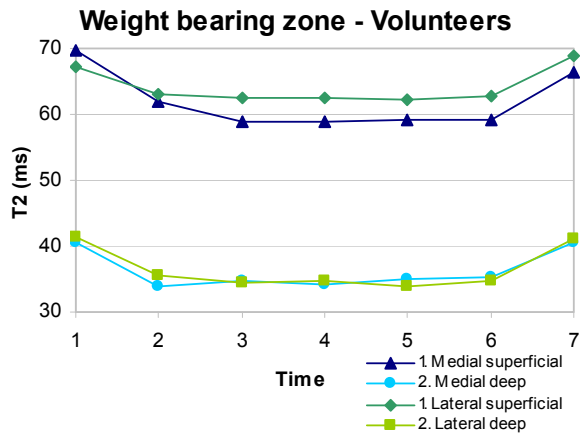


Fig. 5. T2 load dependence of the medial and lateral femoral condyle in the weight bearing zone cartilage of volunteers.

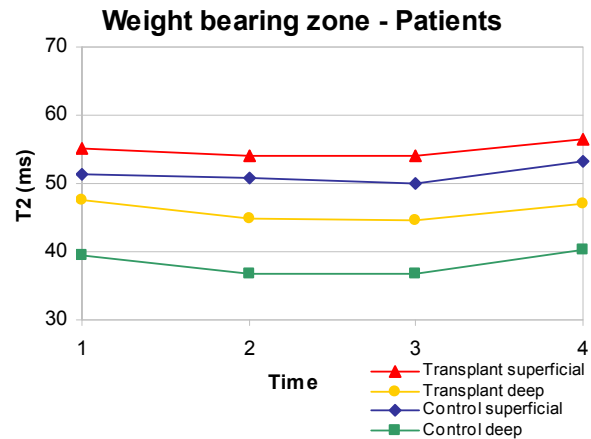


Fig. 6. T2 load dependence of superficial and deep cartilage in the weight bearing zone of patients.

4. Discussion

Unlike in healthy volunteers, where both superficial and deep zone showed significant drop of T2 values, in cartilage transplant of patients, the significant decrease in T2 was observed only in deep zone. This may imply that the collagen fiber organization within the repair tissue had not yet developed after MACT cell-based cartilage transplantation technique, and therefore, the matrix within the repair tissue had reacted differently to the static load applied during these experiments. This suggests that the proposed method could be used for the further evaluation of cartilage transplant maturation over time, in the post-surgery period, and may give insight into the biomechanical properties of repair tissue after surgery.

5. Conclusions

T2 mapping may provide new parameter useful in early cartilage degeneration diagnosis, and help to evaluate the efficacy of cartilage-repair surgery.

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