ROBUST T2 MAPPING OF KNEE CARTILAGE UNDER IN SITU MECHANICAL LOADING USING PROSPECTIVE MOTION CORRECTION

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Introduction: Osteoarthritis of the knee joint is often caused by excessive or inadequate mechanical loading. Therefore knee cartilage response to exercise paradigms involving knee loading such as running or squatting has been the focus of recent MRI research [1]. In particular, the T2 relaxation time of cartilage has been established as a sensitive biomarker, which correlates with collagen microarchitecture and water content and is thus susceptible to loading. However, to date there are only a few studies that have been performed with in situ loading [2-4], mainly because such experiments are strongly hampered by load-induced subject motion. Motion artifacts are particularly severe for loading of the patellofemoral joint, which requires knee flexion. Therefore the three above-mentioned studies focused on the tibiofemoral joint, which can be loaded in a stretched position. Recently, it has been shown in a proof-of-concept work that knee MRI with in situ loading can be strongly improved using prospective motion correction (PMC) that updates the imaging volume during the scan [5,6]. In this work, we demonstrate for the first time robust PMC-augmented T2 mapping of the patellofemoral cartilage under in situ mechanical loading.

Methods: All experiments were performed on a Magnetom Trio 3T system (Siemens Healthcare, Germany), using an 8-channel multipurpose coil (NORAS MRI products, Germany) for signal reception. Knee loading was realized with an MR-compatible pneumatic loading jig enabling accurate load adjustment in the range 0-50 kg. For the loading experiments the subject was positioned on the scanner bed with a knee flexion angle of 40°-50° (Fig. 1). Prospective motion correction was performed with a moiré phase tracking (MPT) system (Metria Innovation Inc., Milwaukee, US) [7] consisting of a single in-bore camera and a tracking marker, which was taped to the knee cap. T2 mapping was conducted in a healthy subject with a 2D multiple spin-echo sequence, using the following parameters: TR = 1 s, TE = [13.8, 27.6, 41.4, 55.2, 69.0, 82.8] ms, 11 slices, slice thickness = 3 mm, in-plane resolution = 0.6 mm, total scan duration = 3:20 min. T2 maps were calculated from the acquired data with the Matlab-based StimFit algorithm, accounting for stimulated echo contributions arising from imperfect refocusing pulse profiles [8]. Initially, three experiments were performed without loading: one scan without motion correction, one scan with a slice position update before every excitation pulse, and one scan with additional slice position updates between refocusing pulses. The three experiments were then repeated with a constant load of 20 kg.

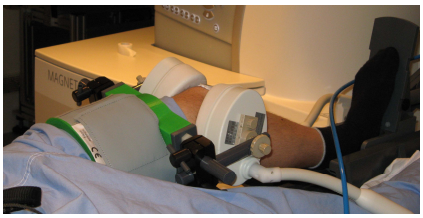

Fig.1: Setup for the MRI experiments with in situ mechanical knee loading.

Results: Figure 2 shows the translational motion logged by the tracking system, spin-echo images with TE = 13.8 ms, and T2 maps (in ms) of the three experiments with in-situ loading, conducted without motion correction (a), with motion correction before every excitation (b), and with additional inter-echo motion correction (c). The logging data show comparable subject motion for the three experiments. While the spin-echo images acquired without correction reveal strong motion artifacts, which translate into partially erroneous T2 mapping results for the cartilage, the motion-corrected images are free of major artifacts and yield cartilage T2 values in the expected range of 30-50 ms. The experiments performed with inter-echo correction did not show a notable improvement of image and T2 map quality compared to the scans performed with a slice update before every excitation only. Scans conducted with and without loading did not yield substantially different cartilage T2 values.

Discussion: This work demonstrates robust T2 mapping of knee cartilage with in situ loading by efficiently correcting for load-induced microscopic knee motion during the scan. Furthermore, the onset of loading typically gives rise to macroscopic motion induced by muscle activation and therefore causes a position change with respect to the unloaded setup, for which the protocol was planned. This can be seen in the images of Fig. 2a where the knee is displaced by more than 1 cm compared to the motion-corrected scans (b and c). Prospective motion correction corrects for motion between scans (position locking) and thus facilitates the comparison of images acquired with and without loading. The finding that additional inter-echo correction did not yield better results than a correction only before the excitation might be due to the latency of about 30 ms between the optical motion capturing and the update in the MR sequence, a delay that is quite large compared to the inter-echo delay of 13.8 ms. However, this issue requires more systematic evaluation and T2 mapping experiments with longer echo trains and subjects less able to lie still might benefit from inter-echo correction. T2 values of cartilage in the tibiofemoral joint have been shown to decrease under loading [2-4]. In contrast, our pilot experiment on the patellofemoral joint did not reveal a significant load-induced T2 change. This raises the question whether the patellofemoral and tibiofemoral cartilage have different mechanical properties accounting for their slightly different function. This question is to be addressed in studies with larger subject cohorts.

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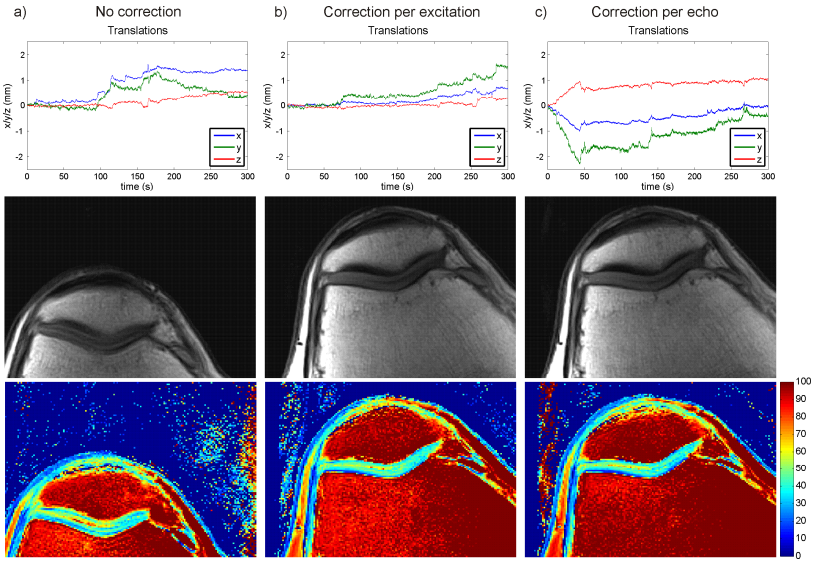

Fig. 2: Translational motion logged by the tracking system (top), spin-echo images with TE = 13.8 ms (middle) and colour-coded T2 maps (in ms) of three experiments with in situ loading conducted without motion correction (a), with motion correction before every excitation (b), and with additional inter-echo correction (c).