

High-resolution knee MRI using prospective motion correction for quantification of cartilage compression under in situ mechanical loading

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Introduction: Osteoarthritis of the knee joint can be diagnosed by means of MRI examinations, e.g., based on T₂-weighted contrast [1]. However, early chondromalacia (grade I-II), which is already associated with altered mechanical cartilage properties impairing knee function, may remain undetected. Therefore MRI studies with in situ mechanical loading have been the focus of recent research [2]. However, MRI experiments with in situ loading are strongly hampered by involuntary knee motion. Recently, it has been shown in a proof-of-concept work that imaging of the patellofemoral knee compartment can be performed with prospective motion correction, using a moiré phase tracking (MPT) system with the tracking marker attached to the knee cap [3,4]. In this work, we demonstrate that almost artifact-free high-resolution cartilage imaging can be performed with this method, appropriate for quantitative studies of load-induced cartilage compression. Furthermore, it is shown that this technique can also be applied for imaging of the tibiofemoral joint.

Methods: All experiments were performed on a Magnetom Trio 3T system (Siemens Healthcare, Germany). Knee loading was realized with a home-built MR-compatible loading jig. Prospective motion correction was performed with a tracking system consisting of a single camera mounted inside the scanner bore and a tracking marker with a multilayer structure for accurate orientation measurement (Metria Innovation Inc., Milwaukee, US) [3,5]. The tibiofemoral joint was loaded with a small knee flexion angle of 10-20°, while a birdcage extremity coil was used for signal reception (Fig. 1a). The tracking marker was attached to the shin close to the tuberositas tibiae (Fig. 1b). For imaging of the patellofemoral joint the marker was attached to the knee cap and images were acquired with an 11 cm loop coil (Fig. 1c,d) [4]. Imaging was performed with a spoiled 3D gradient-echo sequence using selective water excitation. In contrast to earlier work, no presaturation of non-rigid structures was used. Instead the readout was switched to the AP direction to prevent artifacts from non-rigid-body motion of dorsal knee structures in the cartilage region. The following sequence parameters were used: TE = 6.9 ms, TR = 16 ms, flip angle = 15°, scan duration: 3 min, resolution of tibiofemoral joint MRI: 0.4 mm (AP), 0.8 mm (RL), 0.5 mm (FH), resolution of patellofemoral joint MRI: 0.4 mm (AP), 0.4 mm (RL), 1.0 mm (FH). Load-induced cartilage compression of the patellofemoral joint was measured in six healthy subjects on the transverse images, using the viewing application of the Syngo software (Siemens Healthcare, Germany).

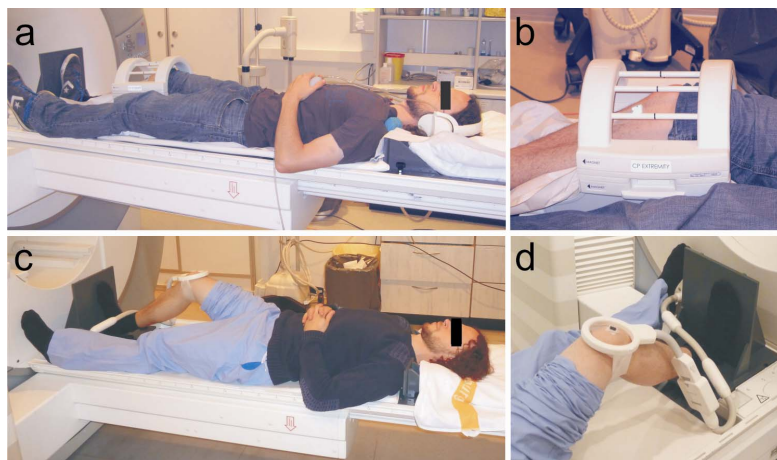


Fig. 1: Experimental setup with a loading jig for imaging of the tibiofemoral joint (a, b, "Setup 1") and the patellofemoral joint (c, d, "Setup 2").

Results: Figure 2 shows sagittal images of the tibiofemoral joint acquired with loading setup 1 without and with prospective motion correction, respectively. Images without major artifacts could be obtained with motion correction (Fig. 2b) while considerable ghosting and blurring of the cartilage contours is visible in the uncorrected image (Fig. 2a). High-resolution motion-corrected transverse images of the patellofemoral joint acquired with setup 2 are shown in Fig. 3. Comparing the images acquired without loading (a) and with loading (b) demonstrates load-induced cartilage compression at the lateral facet. A substantial cartilage thickness decrease was detected in five out of six healthy subjects measured with this technique (Table 1).

Discussion: This work demonstrates that high-resolution knee cartilage imaging with in situ mechanical loading can be realised with prospective motion correction. This works not only for the patellofemoral joint, as previously shown [4], but also for the tibiofemoral joint if the tracking marker is attached to the shin. However, this method may fail for obese subjects with thicker subcutaneous fat tissue at the shin. Furthermore, marker visibility is an issue when a birdcage coil is used for signal reception. It was shown that almost artifact-free motion-corrected high-resolution cartilage imaging is feasible without presaturation if the readout is switched to the AP direction, thus preventing artifacts in the region of interest predominantly arising from non-rigid-body motion of dorsal knee structures. Non-rigid-body motion of the soft tissue on the medial side of the knee (e.g., through muscle twitching of the vastus medialis during loading) might give rise to artifacts in the cartilage region when phase encoding is applied along the RL direction. Such artifacts were not observed in our experiments though. The proposed method may provide new insight into knee biomechanics, paving the way to better diagnosis and treatment of osteoarthritis.

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References:

1. Eckstein et al., NMR Biomed. 2006; 19:822-854.
2. Nag et al., JMRI 2004; 19:317-322.
3. Maclaren et al., ISMRM 2012; #590.
4. Lange et al., ISMRM 2012, #1450.
5. Zaitsev et al., Neuroimage 2006; 31:1038-1050.

Table 1: Cartilage thickness in mm at the lateral facet as measured on the transverse images of the data sets acquired without and with in situ loading. Standard deviations were determined through thickness measurements by several experts.

Subject	1	2	3	4	5	6
w/o loading	3.2 ± 0.1	4.9 ± 0.1	3.7 ± 0.1	4.1 ± 0.1	3.2 ± 0.1	3.7 ± 0.1
with loading	2.8 ± 0.1	4.2 ± 0.1	3.4 ± 0.1	3.8 ± 0.1	3.2 ± 0.1	3.3 ± 0.1

Fig. 2: Sagittal images of the tibiofemoral joint with mechanical loading: a) without motion correction, b) with motion correction.

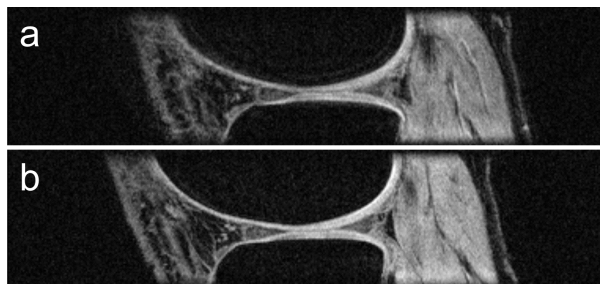


Fig. 3: Transverse images of the patellofemoral joint acquired with motion correction: a) without mechanical loading, b) with mechanical loading. The white arrows indicate the region where cartilage thickness is decreased through load-induced compression.

