Dynamic 3D imaging of the free moving knee using a retrospective self-gated sequence with a quasi-random sampling scheme

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Introduction

Knee injuries are among the most common injuries of the musculoskeletal system. To date clinical MRI examinations of such injuries are mostly performed with static MRI. Unfortunately, static MRI often does not lead to satisfying diagnoses, especially in difficult cases. Dynamic MRI may provide valuable additional information and thus increases specificity and accuracy of the diagnosis in those cases. Possible applications are the diagnosis of ruptures of the cruciate ligaments close to the bone, a characterization of the complex motion of the knee or therapy monitoring after cartilage or ligament reconstruction. For this purpose a motion device powered by a pneumatic piston was designed and constructed in our lab [1] to enable a passive reproducible movement of the knee. In this work the device has been used without the pneumatics, allowing an active and thus more physiological movement of the patient's knee. By the loss of the correlation between the motion and the MR acquisition due to the patient-driven motion, a retrospective self-gated 3D MRI [2] together with a U-shaped phased array coil [1] (for a proper DC-signal) was used.

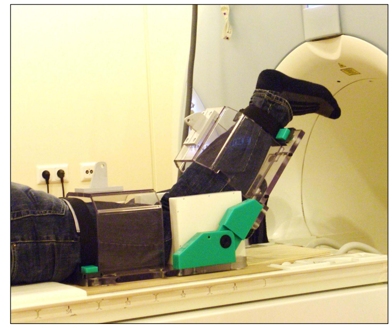

Fig. 1: The motion device guides the patient's knee in ventral position. The U-shaped phased array coil is placed under the knee in the hinge joint.

Materials & Methods

The motion device was designed fully out of MR safe materials. The patient is placed in a ventral position and the device restricts movement and bending of the leg to a single plane while keeping the knee at a stationary position (Fig. 1). The lower leg can be moved by the patient in a well-defined manner (in the spatial domain, not in the time domain). The normal bending duration is approximately 5s per full cycle. The maximum bending angle is limited to the bore diameter of the MR scanner and the size of the patient, with values ranging from 30° to 45°. All experiments were performed on a clinical 1.5 T whole body scanner using an adapted 16 channel phased array coil. A retrospective self-gated 3D FLASH sequence with a quasi-random sampling scheme was used to visualize the moving knee (TR/TE = 5.4/2.0ms, resolution 0.93×0.93×3.00mm³, FOV 178×178×132mm³, 15 repetitions, T_{acq}=11:24min). The central k-space signal (DC-signal) was acquired within each TR for retrospective self-gating. A comparison of the DC-signals resulting from the 16 single coil elements shows some channels with an unambiguous progress due to a well-defined change in spin density. The DC-signal of the most sensitive channel was used for navigation. To distinguish between up and down movement of the knee, the derivation of the DC-signal was additionally used for data selection (Fig. 2). Six full volume datasets, corresponding to various motion states of the knee, were then reconstructed retrospectively. For the final reconstruction of the images, adaptive combining [3] and iterative GRAPPA [4] (for the missing k-space data, due to the gating process) was applied.

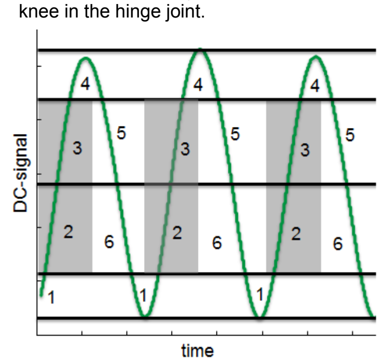

Fig. 2: DC-signal of a certain element of the coil array during the motion of the knee. In this example six frames are reconstructed: The lower turning point (1), two frames upwards (2-3, positive derivation, gray background), the upper turning point (4) and two frames downwards (5-6, negative derivation, white background).

Results

In Fig. 2 as an example the DC-signal of a certain array coil element is shown. Six frames during the motion cycle were reconstructed: One at the lower turning point (1), two upwards (2-3), one at the upper turning point (4) and two frames downwards (5-6). The upward and downward motions were differentiated using the derivative of the obtained DC-signal (shown as gray and white areas in Fig. 2). Fig. 3 shows the results of two partitions of the 3D dataset of one of the two volunteers examined until now. While the femur stays stationary, the tibia is actively moved up and down by the patient.

Discussion & Conclusion

Dynamic imaging of the human knee is feasible with a passively moved knee [1]. Now dynamic imaging was done also in 3D with an actively moved knee by guiding the motion with a motion device and using DC-gating and a 16 channel phased array coil. The quasi-random sampling scheme guaranteed that the missing k-space lines are randomly distributed and can be reconstructed by an iterative GRAPPA algorithm [4]. The method can be further improved by optimizing the sampling scheme (stronger weighting of the center of the k-space) and DC-windows, with respect to number and sharpness of the frames vs. SNR, or distribution of the k-space lines to the frames, overlap of the frames ("view sharing"), filters etc. This technique should enable us to analyze the complex processes during both active and passive motion of the human knee.

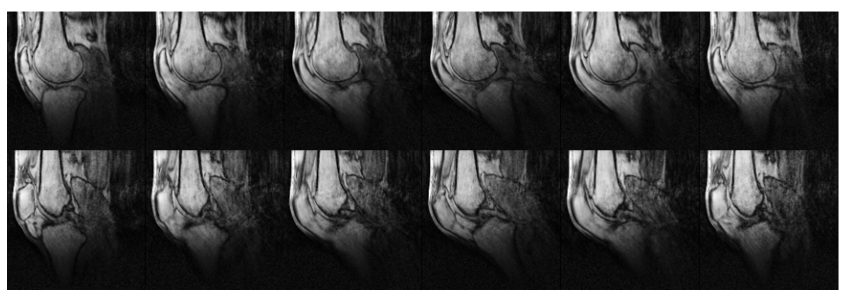

Fig. 3: Six snapshots of two partitions (of 44) of the 3D dataset acquired by the quasi-random DC-gated FLASH sequence during free knee motion guided by the motion device.

Acknowledgement

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References

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