First Protocol for High Field MRI of the Knee at 7.0 Tesla

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Introduction:

Measurement protocols which have been optimized for MRI at field strengths of 1.5 T or 3.0 T can not be directly transferred to 7.0 T. Specific absorption rate (SAR) limitations, different relaxation times of the tissues, as well as new image artifacts, e.g. due to enhanced susceptibility effects, require adjustments of the sequence parameters. Previous investigations of the change of relaxation times with increasing field strength showed increases in T_1 relaxation times of around 20% between 1.5 T and 3 .0 T [1] and of 35-45% from 3.0 T to 7.0 T [2], while T_2 decreased by 10-35% from 1.5 T to 3.0 T [1] and does not show significant changes when compared between 3.0 T and 7.0 T [2]. Our study aimed to develop a protocol of the knee at 7.0 T which allows visualization of all relevant anatomical structures and the most common pathologies.

Methods:

All measurements were performed on a Magnetom 7T whole-body scanner (Siemens Medical Solutions, Erlangen, Germany) with a quadrature transmit/receive extremity coil (Invivo Corp., Gainesville, FL). Starting with sequence parameters used at 1.5 T, the parameters were modified in order to obtain optimal image contrast, full coverage of the knee, and the highest resolution within a reasonable acquisition time. The protocol was first optimized on two healthy volunteers and subsequently tested on two patients with pathologies that were previously diagnosed at 1.5 T. We acquired high-resolution images with different T_1 and T_2 weighted 2D and 3D spin- and gradient echo sequences and compared them with 1.5 T images. Three radiologists were asked to perform a visual evaluation in order to reach a consensus on image contrast between cartilage and bone, water, and pathologies, as well as on overall quality. Furthermore, signal difference-to-noise ratios (SDNR = (signal of tissue A – signal of tissue B) / noise) were calculated between cartilage and adjacent bone.

Results and Discussion:

Short TI inversion recovery (STIR) sequences allowed the visualization of the medial or lateral knee joint with an in plane resolution of 0.7 mm and a slice thickness of 3 mm within 3:22 minutes (6 slices, 100% distance factor). An inversion time of TI = 250 ms is needed for optimal fat suppression at 7.0 T; the echo time was set to TE = 33 ms, as higher TE creates more prominent susceptibility artifacts, whereas lower TE results in proton density weighted images and a more intense background signal (bone, muscle). A T_1 weighted 3D-FLASH (fast low angle shot) dataset with a resolution of 0.4 x 0.4 x 1.0 mm^3 and 128 slices covering the whole knee can be obtained within 4:45 minutes yielding the highest spatial resolution of all sequences for good anatomic overview (bones, intra-articular fluid). For a double echo turbo-spin echo (TSE) sequence, a repetition time of TR = 3530 ms and echo times of TE = 9.6 ms for proton density (PD) and TE = 96 ms for T_2 weighting is needed in order to achieve good contrast and tolerable SAR values. However, due to the large flip angle of 150°, SAR becomes a major issue for this sequence, resulting in a limitation to only 3 slices. This mandates several measurements to obtain whole-knee coverage. Gradient echo sequences, 2D multi-echo data-image combination (MEDIC) in particular, appear to be very suitable for the assessment of cartilage pathologies, since due to the low flip angle (30 degrees), there are no relevant SAR and thus coverage limitations. For the MEDIC we used TR/TE = 1000ms/13ms, matrix = 384x384, 17 slices, BW = 395Hz/Px, voxel size = 0.5x0.5x1.5mm^3. Additionally, a double echo steady state (DESS) sequence with TR/TE = 18ms/3.35ms, flip angle = 25°, matrix = 288x320, 128 slices BW = 543Hz/Px was also tested to display cartilage lesions. The MEDIC sequence yielded highest contrast between cartilage and bone (SDNR = 29), followed by DESS (SDNR = 21) and PD (SDNR = 11). These values perfectly mirror the qualitative impression of the image quality.

Figure 1 shows a comparison between 1.5 T and 7.0 T images of the knee joint. Especially in the 7.0 T MEDIC and STIR images, pathologies of the meniscus appear in greater detail due to the higher resolution compared to 1.5 T, and the 7.0 T DESS image shows the cartilage with high quality. However, despite optimization of the sequence parameters, bone marrow edema is better visualized on the 1.5 T compared to the 7.0 T STIR images.

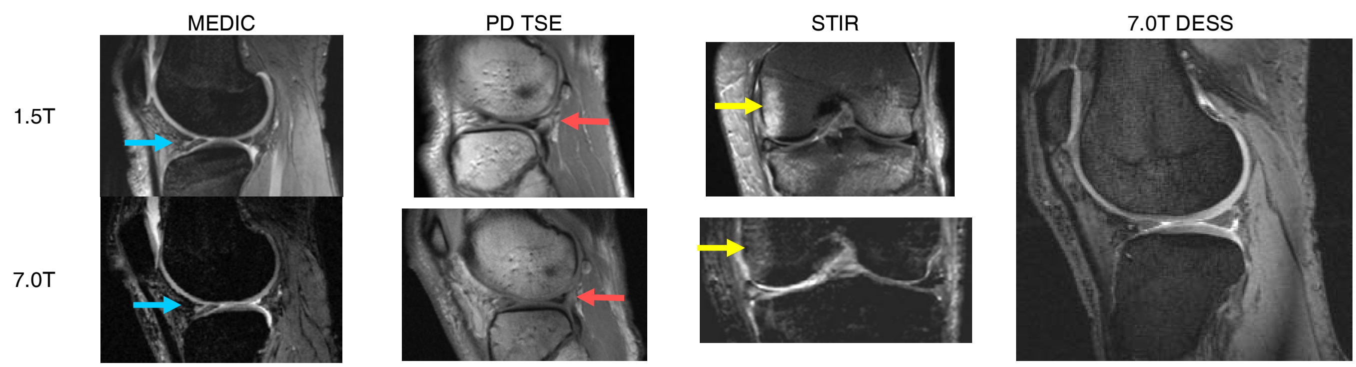

Figure 1: *Pathologies of the knee at 1.5T and 7.0T in different sequences. MEDIC at 7.0 T shows better delineation of linear meniscal tear (blue arrow); PD TSE renders comparable images at both field strengths (meniscal tear; red arrow). The bone bruise in the medial femur is visible at 7.0T (yellow arrow). The high spatial resolution of the DESS sequence at 7.0 T allowed reliable exclusion of cartilage lesions.*

Conclusion:

In order to take full advantage of the higher signal-to-noise (SNR) ratio at 7.0 T, extensive modifications of the sequences and parameters are necessary. The proposed measurement protocol provides a complete examination of the human knee with a total acquisition time of approximately 40 minutes. Only double echo TSE is significantly restricted in spatial coverage, but – due to good performance of the other tested sequences – might in the future be omitted. A comparison of pathologies as seen at 1.5 T and 7.0 T clearly shows the advantage of MRI at higher field strengths, especially the higher SNR, which we translated into a higher matrix than at 1.5T. With completely new sequences and dedicated multi-channel coils which allow for parallel acquisition techniques, the image quality will certainly be further improved within the very near future.

References:

[1] Gold GE et al., AJR 2004; 183:343-351. [2] Pakin SK et al., Proc. ISMRM 2006, page 1252.