Magnetic Resonance Imaging of the Knee at 3 and 7 Tesla – comparison using dedicated multi-channels coils and optimized 2D and 3D protocols

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Introduction: At 7T, a substantial increase of the signal-to-noise ratio (SNR) and the contrast-to-noise ratio (CNR) is expected compared to lower field strengths (1). This gain might be used to increase spatial resolution or reduce acquisition time. The actual improvement in SNR however can be altered by different reasons, and thus, for all practical purposes, is not identical to the theoretically expected factor of 2.3 when advancing from 3T to 7T. Besides others, one major limiting factor in the performance of musculoskeletal MRI at 7T is the poor equipment with dedicated coils (2). Hence the development and the availability of dedicated ultra high-field, multi-channel, multi-element coils allow the use of parallel imaging techniques (PAT), thus helping to overcome SAR restrictions. Initial approaches documented the feasibility and the benefits of multi-channel coils combined with PAT at 7T (3). Nevertheless, studies comparing the performance of musculoskeletal imaging in between 3T and 7T are rare.
Aim of this study was to compare the quantitative and the qualitative performance of a routine 8-channel knee coil at 3T and a new 28-channel knee coil (4) at 7T in the evaluation of different anatomical structures within the knee joint. Compared to an optimized 3T protocol, at 7T, i) the resolution was increased whereas keeping the same examination time (7T high res.) and ii) the examination time was reduced whereas keeping the spatial resolution the same (7T quick).

Material and Methods: MRI of the knee was performed in ten knee joints of ten healthy volunteers (mean age, 29.6±7.9years) without known musculoskeletal disease and no history of trauma or pain prospectively. MRI was performed on a 3T whole-body system (Tim-Trio, Siemens Healthcare, Erlangen, Germany) and a side-by-side installed 7T whole-body system (Magnetom 7 Tesla, Siemens Healthcare, Erlangen, Germany). At 3T, a dedicated eight-channel knee coil (In vivo, Gainesville, FL, USA) was used; at 7T, a new dedicated 28-channel knee coil (QED, Quality Electrodynamics, Mayfield Village, OH, USA) was used. The 3T and both 7T sequence protocols consisted of the same five sequences, a coronal fat-saturated (fs) 2D proton-density turbo-spin-echo (PD TSE), a sagittal isotropic 3D T2-weighted steady-state free-precession (TRUFI) sequence with water excitation (we), a sagittal fat saturated isotropic 3D T1-weighted fast low-angle shot (FLASH), a sagittal fat saturated isotropic 3D PD-TSE sequence, called PD SPACE (Sampling Perfection with Application-optimized Contrasts using different flip angle Evolutions), and a sagittal 2D T1-weighted spin-echo (SE) sequence. Optimization of the protocols (3T and 7T) was performed by application specialists and radiologists on basis of clinical routine MRI of musculoskeletal pathologies. Quantitative SNR and CNR measurements were performed, validated as suggested recently (5), to reduce alteration due to multi-channel coils and PAT. CNR was assessed for cartilage–bone, cartilage–fluid, cartilage–menisci, and menisci–fluid. Further qualitative evaluation was done to classify image quality and possible artifacts. Statistical analysis of variance was performed to assess possible differences in between the 3T, the 7T high res. and the 7T quick protocol. Intra- and inter rater agreement was assessed by intra-class correlation.

Results: CNR, in most of the cases, revealed better results for both 7T measurements compared to the 3T measurements. Furthermore, in most of the cases, the CNR values of the 7T quick measurements revealed higher CNR values compared to the 7T high res. measurements. Results and significances ($p<0.05$) are provided in table 1. Exemplary images are provided in Figure 1.
When assessing the subjective quality, although the differences between the 3T measurements, and both 7T measurements were in most of the cases not statistically different, for all sequences the subjective quality was higher for the 7T measurements compared to the 3T measurements. No significant difference was assessed concerning the artifacts and the 3T, respectively both 7T measurements. The highest number of artifacts was visible in the TRUFI sequence.
Inter- and intra rater agreement was very high (0.003 to 0.956).

Discussion: The results of the present study document the possible superiority of 7T MRI in the knee joint compared to 3T in the presence of a dedicated multi-channel knee coil. When comparing to an optimized 3T protocol, comparable or better results could be assessed at 7T, although i) the resolution was increased (whereas keeping the same examination time) or ii) the examination time was reduced (whereas keeping the same resolution). Although there are existing limitations and only volunteers were evaluated, data to compare 3T and 7T is needed and might base the first step in the clinical applicability of ultra-high fields. In conclusion through higher field strength and an optimal coil, resolution can be increased or acquisition time can be reduced, with still superior CNR values at 7T compared to 3T.

References: 1. R. Krug et al. Invest Radiol 2009., 2. R.R. Regatte et al. J Magn Reson Imaging. 2007., 3. G. Chang at al. J Magn Reson Imaging 2010, 4 M. Finnerty et al. Proc. ISMRM 2010, 5 M.C. Steckner. Med. Phys. 2010

Table 1:

	CNR	Cartilage / Bone	Cartilage / Fluid	Cartilage / Menisci	Menisci / Fluid
cor PD TSE fs	3T	24,5	51,2	27,6	78,9
	7T High Res.	56,1§	69,0	52,7	121,7
	7T Quick	50,5§	36,8	53,8	90,3
sag T2 TRUFI we	3T	16,8	33,3	14,0	47,2
	7T High Res.	43,1	54,4	33,6	88,0
	7T Quick	109,3§#	99,3§#	77,3§#	176,4§#
sag T1 FLASH fs	3T	53,6	26,6	34,5#	51,8#
	7T High Res.	36,5	18,2	11,5	8,3
	7T Quick	128,4§#	67,3§#	40,5#	26,8
sag PD SPACE fs	3T	58,7	22,2	27,0	22,5
	7T High Res.	83,3	27,1	71§	97,9§
	7T Quick	137,7§	32,9	105,2§	133,6§
sag T1 SE	3T	13,6	7,3	6,5	3,0
	7T High Res.	41,3§	4,3	4,2	2,8
	7T Quick	56,7§	6,7	6,1	2,5