Relaxometry of tendons, ligaments and menisci in the knee joint at 3 T

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Purpose

Over the last years, a number of MRI techniques have been introduced to study tissues with short T_2 values [1, 2]. Musculoskeletal tissues such as menisci, tendons, or ligaments have short T_2 values in the range from one to several milliseconds. For the optimization of sequence parameters (TR, TE, acquisition bandwidth, flip angle) as well as for numerical simulations based on Bloch's equations, the knowledge of tissue relaxation times is essential. However, the major problem in quantifying short tissue relaxation times is to get a reasonable signal intensity of the examined tissues. So far, there has been no comprehensive MRI regarding the systematic measurement of relaxation properties of ligaments, tendons and menisci. Therefore, the purpose of this study was to quantify the $T_{1\rho}$, T_1, T_2, and T_2^* relaxation times of these tissues in the human knee joint at 3T in an acceptable examination time.

Materials and Methods

Nine healthy volunteers were examined on a 3T MR scanner using an 8-channel RX/TX knee coil. The measurements of T_1, $T_{1\rho}$, T_2, and T_2^* relaxation times were performed with 3D spoiled gradient echo (GRE) sequences in a total measurement time of only 1 hour. The parameters of 3D GRE sequence preceded by different preparation schemes were identical in all measurements unless otherwise noted: TR/TE=100/1.82 ms, flip angle=25°, FOV=154×154×144 mm^3, matrix 192×256×48, voxel size 0.8×0.6×3 mm^3, BW=260 Hz/pixel, echo asymmetry of 75%. Acquisition time (TA) of 3:30 min for each sequence was possible due to parallel acquisition technique in both phase and slice direction with acceleration factor 2×2. The $T_{1\rho}$ and T_2 measurements were performed using adequate magnetization preparation methods [5, 6]. A B_1-compensated spin-lock (SL) technique with a pulse series of $90°_y$-(SL_x-SL_{-x})-$90°_{-y}$ and a SL-pulse of 5.9 µT was used for $T_{1\rho}$ magnetization preparation. For T_2 magnetization preparation a pulse series of $90°_y$-(T_{2prep}/2)-$180°_x$-(T_{2prep}/2)-$90°_{-y}$ was applied with variable length of T_{2prep}. In order to calculate $T_{1\rho}$ and T_2 maps pixel-by-pixel, measurements were performed with various spin-lock times (*TSL*) and T_{2prep} of 2, 4, 8, 16, and 32 ms, respectively. For T_1 mapping the variable flip angle method based on three optimal flip angles (7°, 34° and 42°) was used with TR=40 ms, thus TA was 2:50 min [3, 4]. A multi-echo (n=12) approach using a GRE sequence with TE_1=1.5 ms and increment ΔTE=3.7 ms was used for T_2^*-mapping; parameters were slightly adjusted: BW=450 Hz/pixel, NA=2, TA=6:40 min. For accurate quantification additional B_1 maps were measured by the actual flip angle imaging (AFI) technique [7] with following parameters: TR_1/TR_2/TE = 20/100/5 ms, flip angle = 60°, matrix = 96×128×48. All images were co-registered using Statistical Parametric Mapping (SPM, Version 5.0) software. T_1, $T_{1\rho}$, T_2, and T_2^* parameter maps were calculated using in-house software developed with Matlab (Mathworks, Natick, MA). The regions of interest (ROI) were evaluated by an experienced MR physicist.

Results

Table 1 shows the T_1, $T_{1\rho}$, T_2, and T_2^* values (mean ± standard deviation (SD)) of the anterior and posterior cruciate (AC, PC) ligaments, lateral and medial menisci, quadriceps and patellar tendons. Mean T_1 values ranged from 915 ms for lateral meniscus to 1207 ms for AC ligament. Mean $T_{1\rho}$ values were 17 ms for menisci increasing to 29 ms for AC ligament. T_2 measurements revealed relatively low mean values for menisci (10 ms) in contrast to ligaments (22 ms) and tendons (17 ms). The T_2^* values ranged from 3.6 for patellar tendon to 15.2 ms for AC ligament. Figure 1 shows representatively T2-w. fat-suppressed sagittal MR image of the knee joint (A) and the corresponding calculated T_2 (B), $T_{1\rho}$ (C), T_2^* (D), and T_1 (E) maps with a segmented medial meniscus.

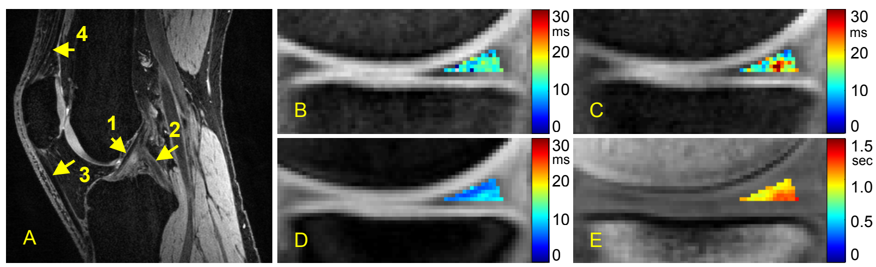

Fig. 1: *T2-weighted fat-suppressed sagittal MR image of the knee of a 28-year old subject (A) and corresponding calculated T_2 (B), $T_{1\rho}$ (C), T_2^* (D) and T_1 (E) maps with a segmented medial meniscus. The arrows in (A) show the musculoskeletal tissues of interest: AC (1) and PC (2) ligaments, quadriceps (1) and patellar (2) tendons.*

Discussion

The relaxometry of musculoskeletal tissues such as tendons, ligaments and menisci is usually hampered because of their rapid signal decay as well as the small and complex anatomical structures involved. In the presented work, T_1, $T_{1\rho}$, T_2, and T_2^* relaxation times of these tissues have been quantified by 3D GRE sequences. The application of short non-selective RF pulses (0.1 ms) and the use of a strong echo asymmetry (75 %) allowed a short TE of 1.5-1.8 ms. Furthermore, the utilization of parallel acquisition technique with a total acceleration factor of 4, made an acceptable examination time of about 1 hour possible. The measurements were performed using a slice thickness of 3 mm which was chosen in consideration of measurement time and SNR. Thinner slices would reduce partial volume effects and thus increase the accuracy of the measurement. In conclusion, the results of this work might be useful to analyze degenerative and traumatic diseases of the knee joint.

Tab. 1: *T_1, $T_{1\rho}$, T_2, and T_2^* relaxation time values (mean ± SD) for anterior (AC) and posterior (PC) cruciate ligaments, lateral and medial menisci, and patellar and quadriceps tendons obtained in nine healthy volunteers.*

	T_1 (ms)	T_2 (ms)	T_2^* (ms)	$T_{1\rho}$ (ms)
AC ligament	1207 ±178	24.5 ± 8.0	15.2 ± 7.6	28.8 ± 17.4
PC ligament	1068 ± 206	18.6 ±6.8	8.9 ± 1.5	25.2 ± 5.1
Lat. meniscus	915 ± 185	9.1 ± 2.2	6.6 ± 1.1	17.9 ± 8.4
Med. meniscus	1105 ± 110	10.2 ± 3.7	8.0 ± 0.7	16.1 ± 8.1
Pat. tendon	1025 ± 118	16.5 ± 5.6	3.6 ± 0.6	23.6 ± 7.1
Quadr. tendon	1139 ± 164	16.6 ± 9.1	6.7 ± 1.3	17.7 ± 15.2

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