Simultaneous acquisition of T1rho and T2 quantification in cartilage – reproducibility and diurnal variation

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Introduction: Magnetic resonance (MR) T1ρ and T2 relaxation time quantification can detect biochemical changes within cartilage collagen/proteoglycan matrix, and may provide complementary information associated with cartilage degeneration during osteoarthritis (OA) (1,2). These techniques, however, normally need a long acquisition time. Furthermore, although the diurnal variation of intervertebral disc (a tissue with biochemical contents similar to hyaline cartilage) is well known, few studies have explored the potential diurnal variation in cartilage, which like disc, is also expected to undergo loading and compression in joints such as the knee during daily activities (3). The goals of this study were three fold: 1) To develop a sequence that combines T1ρ and T2 quantification; 2) To examine intra-day and inter-day reproducibility of the T1ρ and T2 quantification; 3) To examine the potential diurnal variation of T1ρ and T2 quantification in cartilage in young healthy adults.

Methods: Sequence development The sequence is composed of two parts: magnetization preparation (mag prep) for either T1ρ or T2 weighting, followed by a 3D SPGR acquisition during transient signal evolution immediately after mag prep. The T1ρ preparation pulses contained continuous hard 90_x-spin lock pulses-90_{-x} pulses. T2 preparation pulses contained an MLEV train of nonselective composite $90_x180_y90_x$ refocusing pulses, preceded and followed by a hard $90_x/90_{-x}$ pulse pair. A flag is defined in the pulse sequence to switch between T1ρ and T2 preparation according to numbers of time of spin-lock (TSL) and time of echo (TE) defined by the user. In the case of the first TSL = 0 and first TE = 0, T1ρ and T2-weighted images share the first image during post-processing for reconstructing the maps. Multiple k-space lines (views per segmentation, VPS) are acquired after each mag prep, traversing in segmented radial-centric view ordering (4) to minimize the eddy current effect (as compared to the segmented elliptic-centric order (5)). Ellipsoidal k-space data were acquired (70%) to reduce acquisition time while keeping a comparable spatial resolution. RF cycling was applied to eliminate the adverse impact of longitudinal relaxation on quantitative accuracy, and a variable flip angle train was designed to provide a flat signal response to eliminate the filtering effect in k-space caused by transient signal evolution (5). The combined T1ρ/T2 sequence was validated in phantoms and control subjects by comparing the results to the published MAPSS sequence (5). The difference of quantified T1ρ and T2 between the new sequence and the MAPSS sequence was less than 2%, which is well within reproducibility.
Phantom and In vivo Imaging Six young healthy subjects aged 22-34 years, 2 females, were studied using a GE 3T (Signa HDx) with an 8-channel phased array knee coil (Invivo, Gainsville, Fl). Subjects were scanned in the morning (between 8-10am) and in the afternoon (between 5-7pm), and scanned again on a second day after one week using the same protocol, resulting in four scans per subject (namely AM1, PM1, AM2, PM2). Phantoms with different concentrations (1% to 4%) of agarose were scanned during each imaging set. Each subject filled out modified International Physical Activity Questionnaire (IPAQ) questionnaires for their activity levels for the past year (before AM1 scan), 1 week (before AM1 and AM2), and 1 day (before PM1 and PM2). The imaging protocol included sagittal T2-weighted fat-saturated fast spin-echo (FSE) images (TR/TE = 4300/51 ms, FOV = 14 cm, matrix = 512 x 256 slice thickness = 2.5 mm, gap = 0.5 mm, echo train length [ETL] = 9, bandwidth = 31.25 kHz, NEX = 2) and sagittal 3D fat-saturated high-resolution spoiled gradient-echo (SPGR) images (TR/TE = 15/6.7 ms, flip angle = 18, FOV = 14 cm, matrix = 512 x 512, slice thickness = 1 mm, bandwidth = 31.25 kHz, NEX = 1), and the T1ρ/T2 quantification sequence (TSL = 0/10/40/80 ms, TE = 0/13.7/27.3/54.7 ms, FOV = 14, matrix = 256 x 128, VPS = 64, time of recovery = 1.2s, slice thickness = 4mm, number of slices = 26, total acquisition time = 9 mins 30 sec). Parallel imaging (ASSET) with acceleration factor of 2 was used in all sequences.
Image and Data Analysis Cartilage of the lateral/medial femoral condyles (LFC/MFC), the lateral/medial tibia (LT/MT) and patella (P) were segmented semi-automatically in the SPGR images using an in-house developed software. T1ρ and T2 maps were reconstructed by fitting the T1ρ- and T2-weighted images pixel-by-pixel and were subsequently aligned to the high-resolution SPGR images. T1ρ and T2 values of each compartment were obtained. Reproducibility was estimated using coefficients of variation (CV). Diurnal variation was quantified as percentage change from morning to evening: (PM-AM)/AM x 100%.

Results: The average intra-day reproducibility for phantoms was 1.0% for both T1ρ and T2 quantification. The inter-day reproducibility for phantoms was 2.2% and 2.0% for T1ρ and T2, respectively. The T1ρ inter-day CV of AM scans ranged from 3.3% to 8.5%, which is slightly higher but within the range of previous published intra-day reproducibility (5). The T2 inter-day CV of AM scans were slightly higher than T1ρ, ranging from 7.2% to 9.0%. The T1ρ inter-day CV of PM scans were higher than those for AM scans especially in the compartment of the MFC and MT, while the T2 inter-day CV of PM scans were comparable to those for AM scans, Fig 1 left. No significant diurnal variation was found in T1ρ or T2 with this cohort. The change percentage ranged from -3.4% to 1.8%, Fig 1 right.

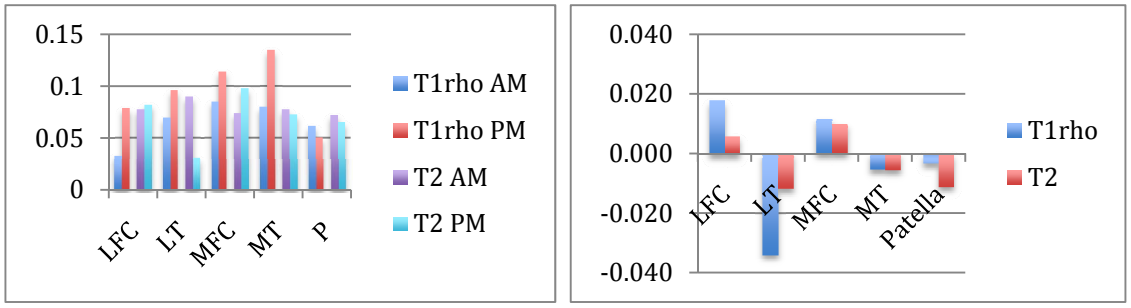

Fig 1. Left: Coefficients of variation of T1ρ and T2 values (%); Right: Percentage changes of T1ρ and T2 values from morning to evening (%).

Conclusions and Discussion: A 3D sequence that can simultaneously quantify T1ρ and T2 relaxation times was developed. Such a sequence will help to reduce the total scan time and facilitate potential clinical applications of these advanced MR techniques. Furthermore, concatetanation of the two measurements in a single scan will allow direct (pixel-by-pixel) comparison between T1ρ and T2 maps by removing potential quantification variations caused by different acquisition sequences (spin-echo vs gradient-echo sequences for example) and minimizing chances of motion between these two quantifications. Our study showed that the sequence provided good in-vivo reproducibility for T1ρ and T2 quantification. No significant diurnal variation of MR relaxation times was found in this cohort, which contained subjects who spent most of their day sitting (the hours for sitting ranged from 6-10 hours on the scan days based on the questionnaires). However, the reproducibility of the PM T1ρ were inferior to the AM scans, especially in the MFC and MT (with CV > 10%), which may potentially be due to different activity levels during the day. Future studies will include subjects who spend more time standing or in other loading-inducing activities, and explore the potential relationship between physical activity levels and diurnal variation. For large cohort and longitudinal studies, it may be optimal to scan subjects early in the morning to minimize potential variation in relaxation times caused by differences in activity levels and loadings during the day.

References: 1. Akella SV, et al, Magn Reson Med 2001;46(3):419-423; 2. Moser TJ, Radiology 2000;214(1):259-266; 3. Waterton et al, Magn Reson Med 2000;43(1):126-32; 4. Busse RF, Magn Reson Med 2008; 60:640–649; 5. Li et al, Magn Reson Med 2008;59(2):298-307.

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