Development of in vivo multi-slice spiral T1rho mapping in cartilage at 3T and its application to osteoarthritis

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INTRODUCTION

The T1ρ parameter describes spin-lattice relaxation in the rotating frame. It probes the slow motion interactions between motionally restricted water molecules and their local macromolecular environment. The extracellular matrix (ECM) in articular cartilage provides a motionally restricted environment to water molecules. Changes to the ECM, such as proteoglycan (PG) loss, therefore, may be reflected in measurements of T1ρ (1). Since the loss of PG has been shown to be an initiating event in early stages of OA, T1ρ mapping has been proposed as a promising diagnostic tool for the early detection of OA (2). However, the relationship between Tρ and the PG/collagen matrix, and whether Tρ can provide additional information to T1 quantification remains controversial in the literature (3,4). We have previously developed a single-slice T1ρ weighted imaging method based on a spiral sequence (5). In this study, a multi-slice T1ρ imaging technique was developed and patients with osteoarthritis were examined at 3T.

MATERIALS AND METHODS

The spin-lock sequence consists of a hard 90 degree pulse followed by a spin-lock pulse and a hard ~90 degree pulse (Fig. 1). The phase of the second half of the spin-lock pulse was shifted 180° from the first half to reduce artifacts caused by B1 inhomogeneity (6). Magnetization stored along the z-axis is read out by a multi-slice spiral sequence. The spiral acquisition was placed as close together in time as possible followed by time for T1 recovery. A RF cycling technique was used in order to eliminate T1 recovery from slice to slice (7). The magnetization is inverted immediately after alternate Tρ preparation. The longitudinal magnetization at the time of acquisition (ta) can be described as: M1(ta) = Mprep e-γSp(ta) - M0. (1 – e-γSp(ta)) without inversion and M1(ta) = - Mprep e-γSp(ta) - M0 (1 – e-γSp(ta)) with inversion. Thus, the difference of these signals is proportional to M1(ta) = 2Mprep e-γSp(ta) where Mprep is proportional to exp(-TSL/T1). Data with varying TSLs were acquired, and a Levenberg-Marquardt non-exponential fitting algorithm developed in C was used to reconstruct a pixel-by-pixel T1ρ map. Cylindrical homogeneous agarose gel phantoms were used for sequence development and reproducibility studies. Nine volunteers (4 female and 5 male, ages 22-61, median=30) without OA symptoms and five patients (1 female and 4 male, ages 18-62, median=52) with OA symptoms and/or radiologic findings of cartilage degeneration were examined on a 3T GE Excite Signa MR scanner using a quadrature knee coil. Among them, four volunteers were scanned twice to study reproducibility. The acquisition parameters were: 14 interleaves/slice, 4,096 points/interleaf, FOV=15 or 16cm, effective in-plane resolution = 0.6 + 0.6 mm, slice thickness = 3mm, skip = 1 mm, number of slice = 14-16, TR/TE = 2s/5.8ms, TSL=20/40/60/80 ms, spin lock frequency = 500 Hz, total acquisition time approximately 13 minutes. T1ρ-weighted images with the shortest TSL were registered to high-resolution T1-weighted SPGR images acquired in the same exam. The transformation matrix was applied to the reconstructed T1ρ map. Cartilage was segmented semi-automatically based on high-resolution VSPGR images using a software package based on IDL (Interactive Data Language) developed in-house. 3D cartilage contours were generated and overlaid to the registered T1ρ map. Mean, standard deviation, and median T1ρ values were calculated. A non-parametric rank test was used to compare T1ρ values between controls and patients.

RESULTS

Fig. 2 shows T1ρ values through the 18 slices of an agar phantom (concentration approximately 4%, g/ml) collected in a single multi-slice acquisition with a median of 54 ms. The T1ρ values were consistent with those obtained with the single slice method and the variation from first slice to last was within 3.7%. The reproducibility (average coefficient of variation for median T1ρ) was 1.46% for phantoms and 4.80% for volunteers. Table 1 shows the mean and standard deviation of median T1ρ values within femoral (trochlea) and patellar cartilage respectively for healthy volunteers and patients with OA. A significant difference was found in T1ρ of femoral cartilage between controls and patients. Fig. 3 shows the T1ρ-weighted images of a healthy volunteer. Fig. 4 shows T1ρ maps for a healthy volunteer (a) and a patient with OA (b).

CONCLUSIONS AND DISCUSSION

A robust in vivo multi-slice T1ρ imaging method has been developed. Increased T1ρ relaxation time in femoral cartilage indicated that T1ρ may be a promising marker for OA detection. The non-significant differences between OA patients and controls in the patella are not unexpected since the patella is non-weight-bearing, and the most pronounced changes in OA are found at the femoro-tibial joint. Spatial heterogeneity of T1ρ within the cartilage has been observed and will be addressed in the future by generating z-score maps and line profiles of T1ρ. A larger cohort of healthy volunteers and patients with different stages of OA will be studied in the future and changes of T1ρ relaxation time in the longitudinal follow-up in patients with OA and volunteers will be analyzed.

REFERENCES


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