Quantified T_1, T_2, and PD Mapping in Cartilage with 3D IR-trueFISP

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Introduction: MRI has been shown to be an effective non-invasive method for cartilage imaging. T_1 [1] and T_2 [2] relaxation times have been correlated with cartilage matrix status. Current quantitative mapping schemes usually determine one tissue parameter at a time, and suffer from long scan times. Morphologic cartilage imaging routines involve proton density weighted (PDw) and T_2-weighted (T_2w) fast spin-echo sequences, as well as a T_1-weighted (T_1w) gradient-echo sequence [3]. Recently, an inversion recovery prepped balanced SSFP sequence, known as IR-trueFISP, has been proposed as a fast method to quantify T_1, T_2, and spin density (PD) from a single steady-state recovery curve [4]. In this work, cartilage relaxation parameters have been determined from a single examination, using a 3D version of this IR-trueFISP approach. These parameters may then be used to simulate image contrast in common imaging sequences.

Methods: A novel 3D inversion recovery prepared balanced SSFP sequence was implemented on a 1.5T GE EXCITE clinical MR scanner (GE Medical Systems, Waukesha, WI) and applied to healthy volunteers using an 8-channel phased-array receive only knee coil (MRI Devices, Waukesha, WI). An adiabatic non-slice selective inversion was followed by an $\alpha/2$ steady-state preparation pulse, which was followed by a train of slab-selective profile optimized pulses ($\alpha = 40^o$, $T_R = 3.47$ms, $T_E = 1.73$ms). Magnetization values were sampled at twenty time points ($\Delta t = 100$ms) from each slice in the 3D slab, taken across 2 seconds in the initial curve as magnetization approached a steady-state value. Afterwards, a 3 second dead time was implemented to allow full longitudinal relaxation before repeating the inversion for the next phase encode. Total scan time to acquire a 128x128x32 3D volume (FOV = 16cm, NEX = 1, slice = 3mm) with in-plane resolution of 1.25mm was 8:03s. Tissue relaxation parameters were calculated from these curves via a nonlinear least-squares fitting routine implemented in IDL (Research Systems Inc., Boulder, CO).

Results: Calculated T_1, T_2, and PD maps of a healthy knee are shown in Figures 1, 2, and 3 respectively. A region of interest was taken of the cartilage, which showed a mean T_1 value of 821.354ms (SD: 35.746) and a mean T_2 value of 45.354ms (SD: 6.927). This is in agreement with accepted values for knee cartilage for T_1 [5] and T_2 [6]. From these quantitative maps plus a calculated PD map, T_1w (T_R = 500ms, T_E = 5ms), T_2w (T_R = 10000 ms, T_E = 50 ms), PDw (T_R = 10000 ms,T_E = 5ms), and FLAIR-weighted (T_R = 10000ms, T_E = 5 ms, T_I = 1000ms) sequences were simulated, and are shown in Figure 4. As joint fluid was determined not to be of interest to this particular study, these values have been selectively masked from the maps.

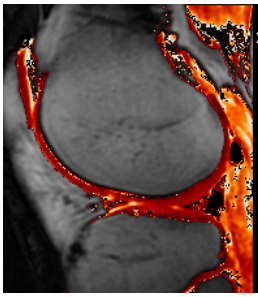

Figure 1. Colorized T1 map overlay, color scale in ms.

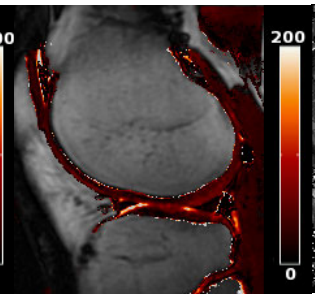

Figure 2. Colorized T2 map overlay, color scale in ms.

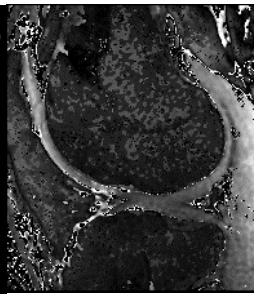

Figure 3. Calculated pseudo-spin density map.

Discussion: IR-trueFISP relaxometry has shown to be a rapid method to quantify T_1, T_2, and PD values. As implemented, slice count affects sampling time resolution rather than acquisition time. Here, 32 slices were acquired in just over 8 minutes. For short T_1 species, the protons fully relax more quickly, and thus the required "dead" time for relaxation can be shortened, accelerating scan time.

Determined tissue parameters have been noted to be sensitive to applied B_1 inhomogeneity. Improved homogeneity using optimized excitation pulses transmitted using the body coil aided the determination of correct tissue values.

Quantitative determination of relaxation values is important for diagnostic decisions and therapeutic monitoring. A fast, precise measurement technique incorporating the advantages of 3D scanning was presented. This sequence can thus be used to map both the structural and functional status of cartilage.

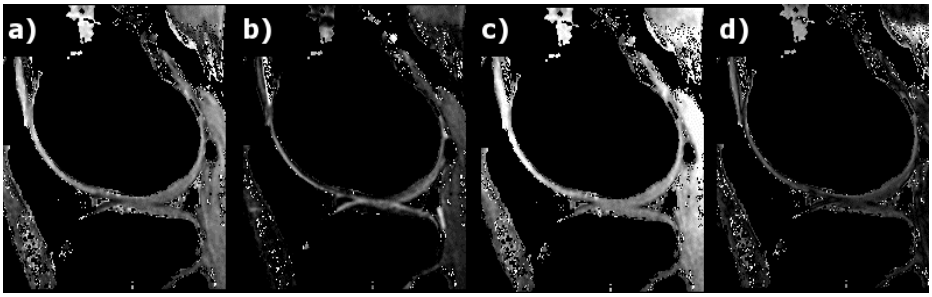

Figure 4. a) T_1w, b) T_2w, c) PDw, and d) FLAIR images as determined by the calculated T_1, T_2, and PD maps. Values were omitted for voxels containing fluids.

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