Comparison of Quantitative T<sub>2</sub> Mapping Techniques for Articular Cartilage

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Introduction: T<sub>2</sub> relaxation time mapping of free water content and mobility in articular cartilage provides an indirect assessment of collagen content and orientation [1]. Biochemical changes are characteristic of the early stages of osteoarthritis (OA), and T<sub>2</sub> mapping is increasingly used in both clinical and research settings. New MR pulse sequences, including 3D approaches, provide more advanced and faster methods for T<sub>2</sub> quantitation, but may introduce a bias in T<sub>2</sub> measurements. Previous studies comparing several T<sub>2</sub> quantification methods reported differences up to 42% in agar phantoms [2] and 63% for in vivo knee cartilage [3]. Analysis of current T<sub>2</sub> mapping techniques provides a basis for interpreting absolute and relative relaxation time differences across studies using different MR sequences and allows researchers and clinicians to better interpret their results. To date, relevant studies only compare a couple T<sub>2</sub> mapping techniques and are primarily limited to analysis of patellar cartilage. The present study analyzes quantitative outcomes from six MR sequences for in vivo T<sub>2</sub> mapping of patellar, femoral, and tibial cartilage. Single echo spin echo is used as a reference standard to judge the agreement and utility of all other techniques.

Methods: Acquisition: All imaging experiments were performed on a GE MR 750 3.0T MRI scanner (GE Healthcare, Milwaukee, WI) with a 16-channel coil (NeoCoil, Pewaukee, WI). First, 6 agar phantoms of variable T<sub>2</sub> were imaged with unsuppressed stimulated echo acquisition mode (STEAM) spectroscopy and single echo spin echo (SE) to characterize the baseline error in T<sub>2</sub>. Next, in vivo images were obtained from knees of 8 healthy volunteers (6M, 2F, age 24.4±4.6 years, BMI 23.3±4.2). Sequences tested include: SE, multi-echo spin echo (MESE), 2D-fast spin echo (2D-FSE), 3D spoiled gradient recalled-based acquisition (3D-MAPSS) [4], 3D-fast spin echo with variable flip angle (3D-FSE), and quantitative double-echo steady state (qDESS) [5]. All images were acquired in the sagittal plane with constant imaging parameters: FOV: 16x16cm<sup>2</sup>, matrix: 256x256, BW: ±62.5kHz, and slice thickness 3mm. Additional imaging parameters are outlined in Table 1. Analysis: T<sub>2</sub> relaxation times were calculated using a mono-exponential fit in Osirix and averaged within 26 regions of interest for each knee, corresponding to superficial and deep layers of cartilage in the medial and lateral patella, femur, and tibia as indicated in Figure 1. Error from SE measurements, as measured by root mean square error (RMSE) was calculated for each technique.

Results: Phantoms: The 6 agar phantoms ranged in T<sub>2</sub> from 22–56ms, as calculated from SE measurements. In vivo: Individual measurements from SE are plotted against those from each technique in Figure 2, and corresponding R<sup>2</sup> values are reported. RMSE for each technique was as follows – MESE: 5.0ms, 2D-FSE: 9.3ms, 3D-MAPSS: 3.8ms, 3D-FSE: 4.2ms, qDESS: 4.6ms. Regional analysis of T<sub>2</sub> variation from all sequences reveals that patellar cartilage RMSE (4.9ms) is lower than that of tibial (5.6ms) and femoral (5.7ms) cartilage RMSE.

Discussion: Figure 2 demonstrates that some sequences have a consistent bias from SE T<sub>2</sub> measurements (ie: 2D-FSE, qDESS) while others overestimate in lower T<sub>2</sub> regions and underestimate at higher T<sub>2</sub> regions (ie: MESE, 3D-FSE). The agreement of each technique with SE is not necessarily indicative of its correlation with SE measurements, as evidenced by the minimal error of 3D-MAPSS (RMSE = 3.8) but greater correlation observed with 2D-FSE and qDESS sequences (R<sup>2</sup> = 0.64, 0.60, respectively). Amongst all sequences, greatest agreement was observed in patellar cartilage. Previous studies of T<sub>2</sub> differences between sequences focus primarily on patellar cartilage imaged in the axial plane, and thus likely underestimate the variation occurring in femoral and tibial cartilage. T<sub>2</sub> quantitation of cartilage is meant to track changes in T<sub>2</sub> associated with OA, so some applications of these techniques may benefit from a steeper sloped regression line in Figure 2, rather than more accurate T<sub>2</sub> measurements.

Conclusion: There is an appreciable amount of variation in quantitative results amongst the sequences currently available for in vivo T<sub>2</sub> mapping. The regional analysis above is consistent with much of the literature involving MRI of knee cartilage [6], so the results are likely representative of the discrepancies in absolute and relative relaxation times reported in OA research. An important question this study highlights is whether accurate measurement of T<sub>2</sub> or a general ability to quantitatively distinguish between regions with different biochemistry is more important. Further study of these variations, especially in patient populations, will be necessary to fully understand how best to interpret quantitative MR results and ultimately how best to track OA in its earliest stages.


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