T_2 and T_2* Relaxometry in the Meniscus using a Novel, Rapid Multi-Echo Steady State Sequence

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Introduction: Imaging the meniscus is challenging due to its short T_2 relaxation time and highly organized collagen architecture. The meniscus plays an important role in osteoarthritis and it is becoming increasingly clear that detecting early degeneration, before gross morphological changes occur, is essential for evaluating disease progression and treatments. T_2 and T_2* relaxation time can be used to detect early meniscal degeneration[1,2]; however, lengthy scans are required (10 to 20 minutes per measure). In this work we show that a novel multiecho steady-state sequence can be used to estimate T_2 and T_2* relaxation times in the meniscus *simultaneously in under 5 minutes*.

Methods: A quantitative DESS sequence[3,4] was modified to include multiple gradient echo readouts ("MEDESS", Figure 1). In this sequence, the S^+ signal has the usual T_2* decay; however, the S^- signal has T_2 decay with rephasing, similar to gradient-and-spin echo methods[5,6]. In TR_1, we have included two S^+ and two S^- signals. This sequence is then repeated with an offset of ΔTE in TR_2. Interleaving TR_1 and TR_2, we have four S^+ and four S^- signals within one acquisition. T_2* relaxation time can be estimated by fitting a monoexponential decay curve to the four S^+ signals. T_2 relaxation time can be estimated using S^+ and S^- signal pairs (ie:1 & 8, 2 & 7) and a signal model ($T_2 = (TE_{S+,1} - (TR + TE_{S-,8}))/ \log (S_{-,8} / S_{+,1}))^4$. This signal model does not consider the mixed T_1/T_2 contrast present in the S^+ signal which causes an underestimation of T_2. Extended phase graph (EPG) simulations can be used to correct the estimate (assuming $T_1 \approx 800$ ms, based on previous laboratory measurements).

We compared estimates of T_2, corrected T_2 and T_2* relaxation times obtained using the MEDESS sequence to standard measures in four cadaver knee specimens. All scans were acquired in the sagittal plane (matrix: 256 x 256, field of view: 20 cm, slice thickness: 3 mm). 2D spin echo (SE) was used as the standard measure of T_2 (eight scans, TE: 10 to 24 ms, TR: 1 s, total time: 35 minutes). A 3D multi-echo GRE (MEGRE) was the standard measure of T_2* (eight echoes, TE: 2 to 20 ms, TR: 100 ms, FA: 30°, time: 19 minutes). Monoexponential curve fits were used for both standard measures. Differences between MEDESS and standard measures were described as the root mean square (RMS) absolute difference for a single slice.

Results: T_2 and T_2* relaxation times estimated using MEDESS were similar to standard measures (Figures 2 and 3); the RMS absolute difference was 3.5, 2.9 and 2.0 ms, for T_2, corrected T_2 and T_2*, respectively. MEDESS consistently underestimated the T_2 and T_2* relaxation times (Figure 2); this was true for mean differences and pixel-wise differences (Figure 3).

Discussion: The EPG-based correction provided a modest improvement to the T_2 estimate. However, since the variation within the maps was consistent between the methods, the observed bias is not of great concern; it will still be possible to detect changes over time and between patient groups. This novel sequence, can be used for estimation of meniscal T_2 and T_2* relaxation times in under 5 minutes, about a 75% time reduction compared to acquiring both of these measures with other techniques.

References: 1. Rauscher et al, Radiology, 2008; 2) Williams et al, Osteoarthritis Cartilage, 2012; 3) Staroswiecki et al, MRM, 2012; 4) Welsch et al, MRM, 2009; 5) Ma et al. JMR, 1996; 6) Yablonskiy et al. MRM, 1997.
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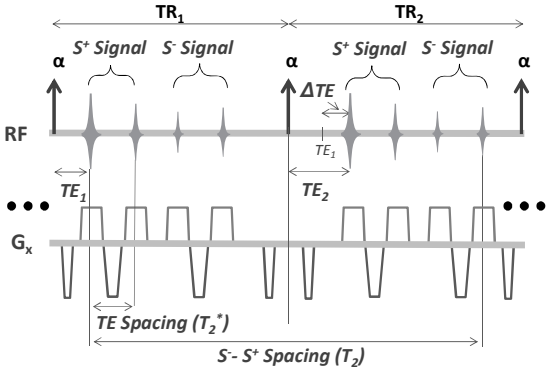

*Figure 1: Multi-echo Steady State Sequence. Parameters include: TR = 12 ms, S^+ TE = 2.0, 3.2, 4.3, 5.4 ms, S^- TE = 6.5, 7.7, 8.8 and 9.9 ms, FA = 30°, time = 4.5 minutes. (TE relative to α pulse, echo spacing = 2*ΔTE)*

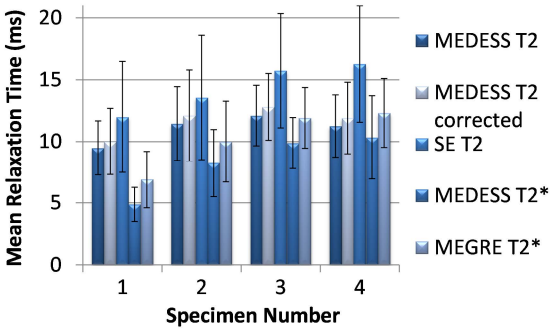

Figure 2: Multi-echo steady state (MEDESS) vs. standard measures of T_2 and T_2 relaxation times.*

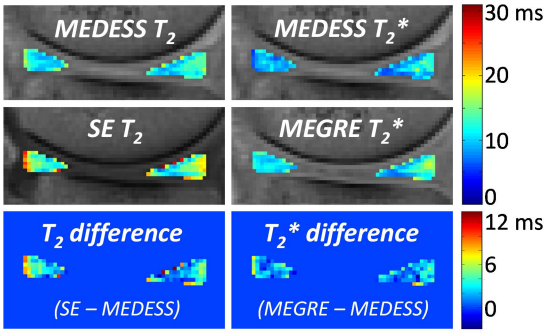

Figure 3: MEDESS consistently agreed with standard measures. Using specimen 3 as an example, the pixel-wise differences were 3.5±2.9, 2.7±2.7 and 2.1±2.0 ms, for T_2, corrected T_2 and T_2 relaxation times, respectively, similar to the RMS absolute difference. *note different scales*