Ultrashort TE (UTE) T1ρ Magic Angle Imaging of the Achilles Tendon

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INTRODUCTION

T1rho relaxation has been proposed to detect proteoglycans (PG) depletion in the early stages of cartilage degeneration (1). Recently it has been employed to detect degeneration in short T2 tissues such as meniscus (2). However, there are contradictory views on the T1rho relaxation mechanisms in the literature. Duvvuri et al. (1) suggested that proton exchange between chemically shifted NH and OH groups of PG and tissue water may be an important relaxation mechanism in normal and pathological cartilage. Mlynarik et al reported that the dominant T1rho and T2 relaxation mechanism at B0 ≤ 3T is a dipolar interaction due to slow anisotropic motion of water molecules in the collagen matrix (3). Collagen fibers in tendons are highly ordered and the protons within the bound water are subject to dipolar interactions whose strength depends on the orientation of the fibers to the static magnetic field B_0 (4). In this study we used a spin-lock prepared ultrashort TE (UTE-T1rho) sequence to measure T1rho of the Achilles tendon at a series of angular orientations and a series of spin locking field strengths to investigate the contribution of dipolar interaction in T1rho relaxation mechanism using a 3T scanner.

MATERIALS AND METHODS

Five cadaveric ankle specimens were harvested for this study. Four imaging sequences, including UTE T1rho, UTE T1, UTE T2* and spiral T1rho sequences were performed with the Achilles tendon at six angles (0°, 25°, 40°, 55°, 70°, and 90°) to B_0. The position of the ankle and angle to B_0 were standardized using an ankle brace with an internal goniometer. Typical UTE acquisition parameters were: FOV = 12 cm, slice thickness = 2 mm, TR = 500 ms, TE = 8 μs, flip angle (α) = 45°, BW = ±62.5 kHz, readout = 512, number of projections = 511, NEX = 2, oblique axial imaging plane. Fat saturated UTE-T1rho images at a series of spin locking times (TSL = 8 μs, 1 ms, 4 ms, 12 ms) and a series of spin locking field strength (100 Hz, 200 Hz, 300 Hz, 400 Hz and 500 Hz) were acquired at each angular orientation for T1rho quantification. A 3-inch coil was used for signal reception and body coil was used for signal excitation, which limited the maximal TSL to 12 ms and spin locking field strength to 500 Hz with a TR of 500 ms due to SAR limitations. At 0° a quadrature knee coil, which allows spin locking field strength up to 1 kHz, was used for study of T1rho dispersion. For comparison, fat saturated UTE images at a series of TEs (8 μs, 1 ms, 4 ms, 12 ms, 25 ms) were acquired at each angular orientation for T2* quantification. A saturation recovery UTE technique was used for T1 quantification. This was needed for T1-compensated T1rho fitting using the following equation (5):

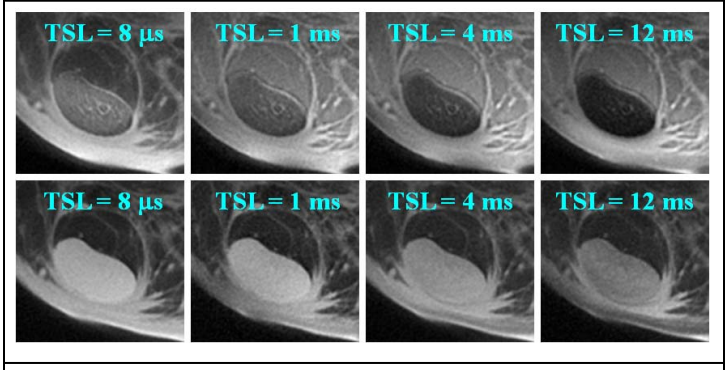

Fig 1 *UTE T1rho imaging of the Achilles tendon of an ankle specimen at 0° (1st row) and 55° (2nd row) relative to the B0 field at a series of TSLs of 8 μs, 1 ms, 4 ms and 12 ms. Signal from the Achilles tendon decays much slower at 55°.*

$$S(TSL) \propto \frac{e^{-TSL/T1rho}\,(1\text{-}e^{-(TR\text{-}TSL)/T1})}{1\text{-}e^{-TSL/T1rho}\,e^{-(TR-TSL)/T1}\cos\alpha}\sin\alpha \qquad [1]$$

RESULTS AND DISCUSSION

Figure 1 shows fat suppressed oblique axial UTE-T1rho imaging of a cadaveric ankle specimen at a series of TSLs under two different angles of 0° and 55°, respectively. The UTE T1rho images show much higher signal intensity at a TSL of 12 ms at 55°, suggesting a longer T1rho relaxation time. Both T1rho and T2* show a significant magic angle effect, as shown in Figure 2. Figure 3 shows there is a significant T1rho increase as the spin locking field strength is increased from 100 Hz to 1 kHz at 0°, but T1rho remains constant at 55°, suggesting that dipolar interaction is the dominant contribution to T1rho relaxation in the Achilles tendon.

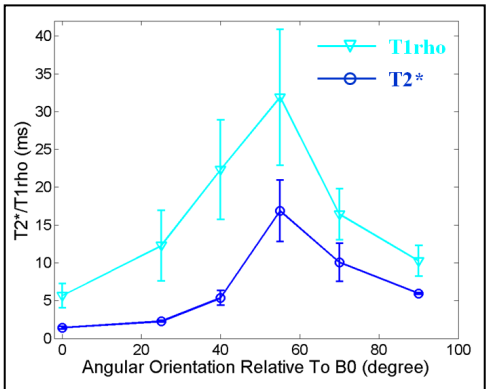

Fig 2 *UTE T1rho and T2* as a function of angular orientation from 0° to 90° relative to the B0 field. These curves show similar significant magic angle effects for both relaxation parameters.*

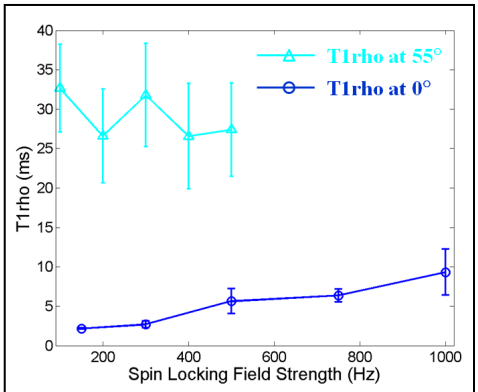

Fig 3 *There is a significant T1rho dispersion at 0° where T1rho increased from 2.17 ± 0.07 ms for B1rho of 100 Hz to 9.33 ± 2.91 ms for B1rho of 1 kHz, while T1rho remains largely constant at 55° relative to the B_0 field.*

CONCLUSIONS

This UTE T1rho magic angle study on five cadaveric ankle specimens demonstrates that the dipolar interaction makes a dominant contribution to T1rho and T2* relaxation in the Achilles tendon. The dipolar interaction may play a similar role in other short T2 tissues, such as the meniscus and ligament. The dipolar interaction may also play an important role in T1rho relaxation in cartilage, where the collagen fibers are more randomly oriented and subject to weaker dipolar interaction and so may display less T1rho dispersion.

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