Ultrashort TE (UTE) Imaging: Application to Magic Angle Study of the Achilles Tendon and Enthesis at 3T

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INTRODUCTION

Collagen fibers in tendons and entheses are highly ordered. 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. These dipolar interactions cause a rapid dephasing of the MR signal, and are dependent on $3\cos^2\theta-1$, where θ is the angle of the fibers relative to B_0 (1-5). When $3\cos^2\theta-1 = 0$, or θ = 55°, 125°, etc, dipolar interactions are minimized resulting in an increase of T2 as well as MR signal. Fullerton et al reported an increase in T2 of Achilles tendon from 0.6 at 0° to B_0 to 22 msec at 55° (1). Henkelman et al. described an increase from 7 to 23 ms when the orientation of the tendon to B_0 was changed from 0° to 55° (2). These studies were performed on a small bore spectrometer using small tendon samples. As far as we are aware, there has been no systematic magic angle study, i.e. investigating signal intensity and T2* vs. angular orientation, performed on clinical scanners using the whole ankle due to the lack of signal at many orientations using conventional MR pulse sequences. The ultrashort TE (UTE) sequence is able to depict signal from short T2 tissues, enabling magic angle imaging and quantification of the whole ankle of cadaveric sample or healthy volunteers/patients on a clinical system.

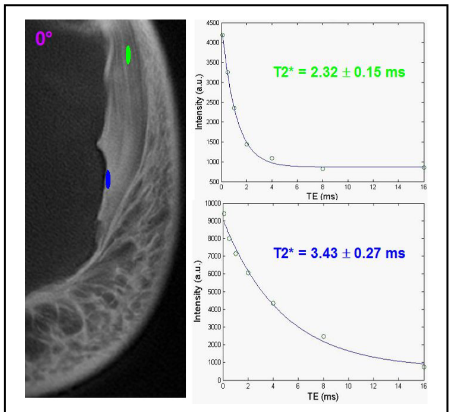

***Fig 1** shows T2* at 0^0 for Achilles tendon (2.32 ± 0.15 ms) and enthesis (3.43 ± 0.27 ms) using UTE acquisition at variable TEs.*

MATERIALS AND METHODS

Five cadaveric ankle specimens were harvested for this study. Four imaging sequences, including T1-weighted FSE, PD-weighted FSE, and UTE sequences with and without fat suppression, were performed at 11 angles (0°, 15°, 30°, 45°, 50°, 55°, 60°, 65°, 75°, and 90°). The position of the ankle and angle to B_0 will be standardized using an ankle brace with an internal goniometer. UTE images at a series of TEs (100 µs, 500 µs, 1 ms, 2ms, 4ms, 8ms, 16 ms, 32 ms) were acquired at each angular orientation for T2* quantification. T1- and PD-weighted FSE sequences were also obtained without fat saturation to investigate the relation between signal intensity and orientation angles. Typical UTE acquisition parameters were: FOV = 10 cm, TR = 250 ms, TE = 0.1 to 32 ms, flip angle = 60°, BW = ±62.5 kHz, readout = 512 (actual sampling points = 284), number of projections = 511, slice thickness = 2 mm, NEX = 2, axial or sagittal imaging planes. Signal intensity, T2* and T1 as a function of orientation angle were investigated.

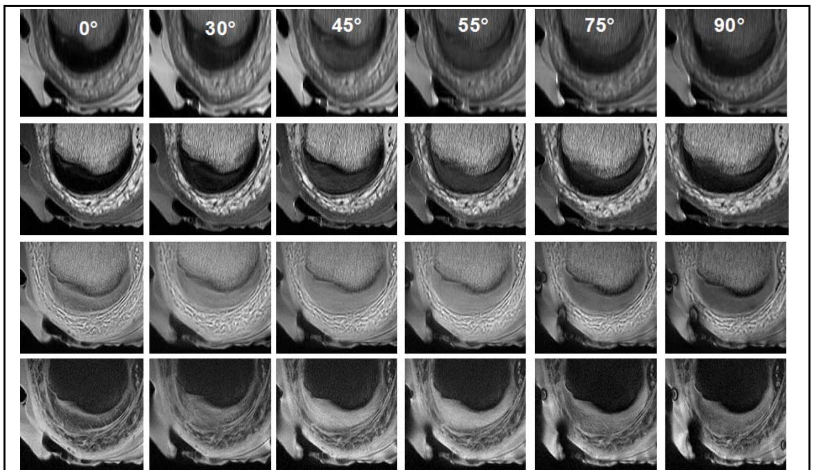

***Fig 2** Magic angle imaging of an ankle specimen using PD FSE (1st row), T1 FSE (2nd row), UTE (3rd row) and UTE fat sat sequences(4th row) shows a gradual signal increase of the tendon and enthesis from 0^0 to 55^0, then a gradual decrease in signal as the orientation angle is increased further to 90^0.*

RESULTS AND DISCUSSION

Figure 1 shows a typical sagittal UTE image at 0^0, as well as T2* quantification for Achilles tendon and enthesis using single component exponential signal decay fitting. Figure 2 shows the axial images of PD FSE and T1 FSE, UTE without and with fat saturation, respectively, at selected orientation angles. A significant signal increase was observed near 55^0 for all four sequences, with UTE sequences showing less signal increase, as is demonstrated in Figure 3. Fat signal is angularly independent. Figure 3 also shows the fitted T2* from UTE acquisitions as a function of orientation angle for one sample. T2* is relatively constant at around 2 ms for Achilles tendon and 4 ms for enthesis up to 30°, reaches a peak near 55°, and gradually drops as the angle increases to 90°. T1 shows little angular dependence at around 650 ms for tendon and 700 ms for enthesis.

CONCLUSIONS

Tendons and entheses show an obvious magic angle effect, with a significant signal intensity and T2* increase near 55^0. UTE sequence allows quantitative evaluation of magic angle effect of whole ankle specimens or volunteer/patients on a clinical 3T scanner.

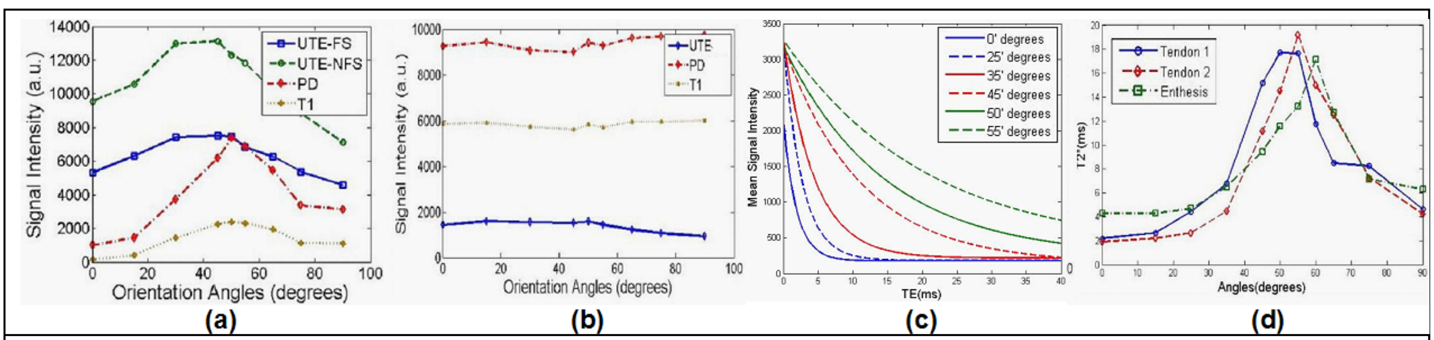

***Fig 3** Signal vs. orientation angle for tendon (a) and fat (b) from T1-weighted FSE, PD-weighted FSE, and UTE sequences without fat saturation (NFS) and with fat saturation (FS). Fat signal is angular independent, confirming that the signal variation in tendon is due to magic angle effect. The fitted signal decay vs. angle for tendon (c) and T2* as a function of angle for tendon from two ROIs and enthesis from one ROI (d) show a significant T2* increase near 55^0.*

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