The Magic Angle Effect on Ultrashort Echo Time MRI for analysis of T2* and Magnetization Transfer Ratio

Hongda Shao[1], Michael Carl[2], Eric Chang[1], Christine B Chung[1], Graeme M Bydder[1], and Jiang Du[1]

[1]*Radiology, University of California, San Diego, CA, United States,* [2]*GE Healthcare, San Diego, CA, United States*

INTRODUCTION

The Achilles tendon largely consists of type I collagen fibers embedded in an extracellular matrix [1]. The collagen fibers are orientated in parallel bundles leading to a highly ordered structure. The motion of water molecules bound to collagenous tissue is restricted, resulting in dipole-dipole interactions which are angular dependent (magic angle effect) [2]. NMR studies show that tendons have two or three components with different T2's which can potentially be detected with ultrashort echo time (UTE) sequences [3]. Measurement of the magnetization transfer ratio (MTR) reflecting tightly bound water has been proposed as a sensitive biomarker of tendon degeneration [4-6]. In order to investigate these effects we evaluated the magic angle effect in UTE bi-component analysis of T2* decay and UTE MTR in cadaveric human Achilles tendons using a clinical 3T scanner.

MATERIALS AND METHODS

Recently developed 3D UTE Cones and 3D Cones-MT sequence were employed to quantify T2* and MTR of cadaveric human Achilles tendon specimens at six different orientations to B_0 (0˚-125˚). The 3D Cones sequence employed a short rectangular pulse (32 µs in duration) for signal excitation, followed by 3D Cones sampling trajectories. A Fermi pulse (duration = 8 ms, maximal saturation flip angle = 670°) was used for MT preparation. T2* was quantified using five sets of interleaved three-echo 3D Cones sampling (TE = 0.03/4.3/10; 0.2/6/12; 0.4/7/14; 0.8/8/16; 2.2/9/19 ms). The MTR was measured with three off-resonance frequencies (Δf = 1.5, 3, 5 kHz). Other imaging parameters were shown in **Table 1**. The protocol was applied to four human Achilles tendons, which were sectioned into 2 cm lengths and stored in a 5 ml syringe filled with Fomblin to minimize susceptibility differences. A home-built 1-inch coil was used for signal excitation and reception. A semi-automated Matlab program was developed for bi-component analysis of short and long T2* decays for each angular orientation. The MTR at different Δf was measured using Image J. The angular dependence of short and long T2*s, their relative fractions, and MTR were assessed.

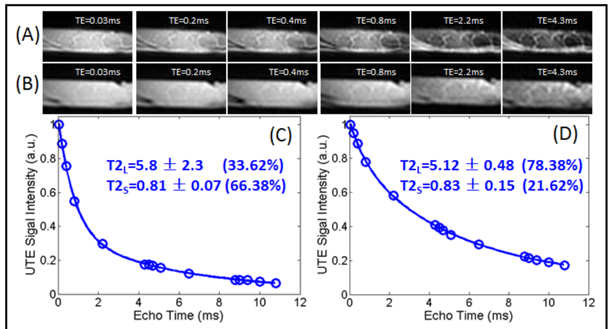

Fig 1 Selective Cones-T2* images are shown in degree of 0˚ (A) and degree of 50˚ (B). Images of tendon at 0˚ and 50° relative to the Bo field shown with TEs of 0-4.3 ms. The signal decayed faster at 0˚ (C) compared to that at 50˚ (D). Bi-component analysis showed the fraction of long T2 component significantly increased, while T2* of the short T2 components remain essentially

	FOV (cm)	TR (ms)	TE (ms)	Recon Matrix	Slice (mm)	BW (kHz)	Angular Orientations relative to B0	Off-rensidence frequency (kMz)	Scan time (mins)
Cones T2*	10	30	0.03, 0.2, 0.4, 0.8, 2.2, 4.3, 6, 7, 8, 9, 10, 12, 14, 16, 18	128×128	2	31	0˚, 25˚, 50˚, 75˚, 100˚, 125˚	/	18
Cones-MT (1.5kMz)	10	50	0.03, 4.3, 8.6, 12.9	128×128	2	31	0˚, 25˚, 50˚, 75˚, 100˚, 125˚	1.5	4
Cones-MT (3.0kMz)	10	50	0.03, 4.3, 8.6, 12.9	128×128	2	31	0˚, 25˚, 50˚, 75˚, 100˚, 125˚	3	4
Cones-MT (5.0kMz)	10	50	0.03, 4.3, 8.6, 12.9	128×128	2	31	0˚, 25˚, 50˚, 75˚, 100˚, 125˚	5	4
Cones-MT off	10	50	0.03, 4.3, 8.6, 12.9	128×128	2	31	0˚, 25˚, 50˚, 75˚, 100˚, 125˚	0	4

Table 1 Imaging protocol for cadaveric human Achilles tendon.

RESULTS AND DISCUSSION

The 3D Cones sequence provided high quality images of the Achilles tendon, including the fascicular pattern. The short and long T2* values did not show significant increase when the tendon sample was re-orientated from 0˚ to ~54° relative to the Bo field. Instead, we observed an obvious increase in long T2* fraction from 33.62% to78.35% (**Figure 1**). This finding suggests that a large proportion of the short T2 component (T2*=0.81±0.07 ms) shifted from a short T2* of 0.81ms to a longer T2* of 5.12ms due to the reduction of dipolar interaction, while the long T2 component (T2*=5.8±2.3ms) was potentially not influenced by the magic angle effect.

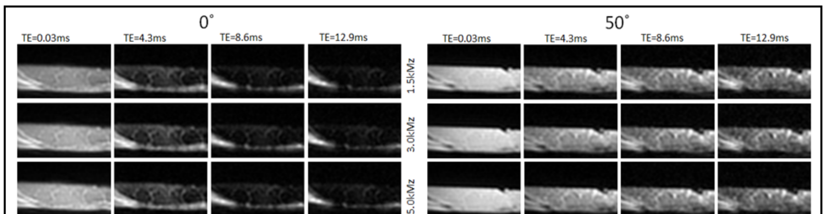

Fig 2 Cone-MT images acquired in four different TEs and three Δf in 0˚ (left) and 50˚ (right) relative to B_0. Higher signal and MTR were observed for all TEs and Δf at 50° over 0°.

Figure 2 shows 3D Cones-MT images at different MT frequency offset. Increased signal intensity was observed on all echo images at higher frequency offsets. There were significant differences of MTR with different values of Δf at all 6 different angles (**Figure 3**). Strong correlation was observed between angular orientation and MTR with TEs of 4.3, 8.6 and 12.9 ms. The strongest correlation was observed with a TE of 8.6 ms. However, nearly no correlation was observed between MTR and angular orientations when a TE of 0.03 ms was used. This finding suggests that the MTR is angular-independent only with UTE imaging. The MTR with conventional gradient echo imaging is subject to a significant magic angle effect.

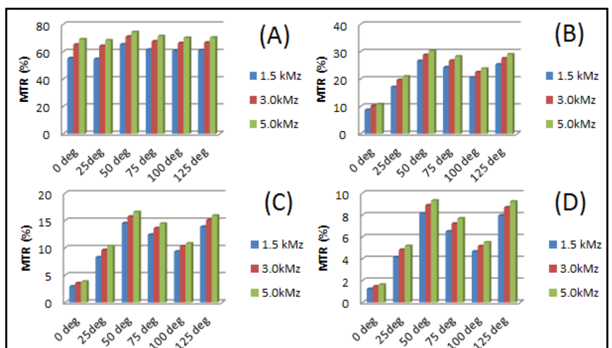

Fig 3 MTR vs. angle for different TEs and Δf. MTR shows strong magic angle effect in B (TE=4.3 ms), C (TE=8.6ms) and D (TE=12.9 ms). Nearly no magic angle effect is observed in A (TE=0.03 ms). **Only UTE-MTR is insensitive to the magic angle effect.**

CONCLUSION

The Achilles tendon shows strong magic angle behavior for the shorter T2* component, and little magic angle behavior for the longer T2* component. MTR shows little magic angle effect with an ultrashort TE of 0.03 ms but marked effects with longer TE's. This preliminary results suggest that UTE-MTR is insensitive to the magic angle effect and may be a robust biomarker for tendon degeneration.

REFERENCES

1. Fukuta, S., et al, Matrix Biology 1998; 17(1): 65–73.
2. Grossman RI, RadioGraphics 1994.
3.Du J, Magn Reson Imaging 2010; 28(2):178-84.
4. Nicola M, etal, Am J Sports Med. 2000; 28(6): 857-63.
5. Eric D, et al, NMR Biomed; 2012; 25: 161-168
6. Grosse U, et al., Magn Reson Med 2013; 70:184-192.