Quantitative Assessment of the Normal and Abnormal Achilles Tendon in vivo Using a 3D Cones Sequence

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INTRODUCTION

Tendon is a highly ordered collagen-rich fibril tissue links muscle to bone. Rupture is a common event in both sedentary and athletic population. Typical histopathology features include marked inflammation, angiogenesis, collagen degeneration and disordered arrangement of collagen fibers [1]. Multiple water components with distinct MR relaxation times exist in the tendon. Magnetization transfer (MT) sequences have been employed to probe macromolecules in long T2 tissues [2]. However, conventional clinical MT sequences cannot detect MT effects in tendon which has a very short T2. Ultrashort echo time (UTE) sequences with TEs less than 100 µs can potentially detect the multiple water components in tendon, and evaluate the magnetization transfer ratio (MTR) by combining UTE sequences with a MT preparation pulse [3-5]. In this study, we aimed to study the multiple water components in the Achilles tendon, and investigate its MTR as a function of MT pulse frequency offset in healthy volunteers and patients with tendon rupture using a clinical 3T scanner.

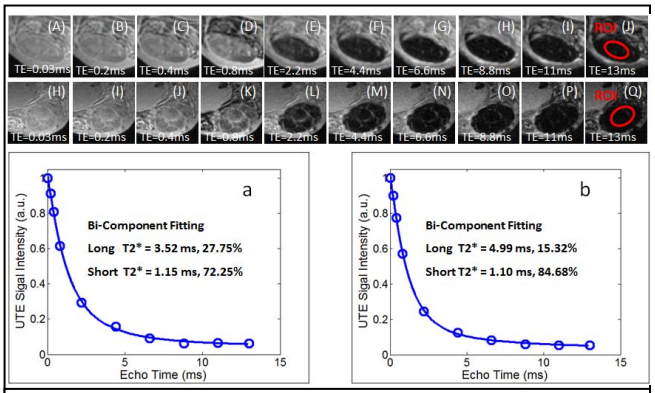

Fig 1 UTE-T2* images of both normal tendon (A-J) and diseased tendon (H-Q) of a 59 year old male volunteer with TEs ranging from 32µs to 13ms, and bi-component fitting of an ROI in the normal tendon (a) and the diseased tendon (b), those shows 28% long T2* component (T2*~3.5ms) and 72% short T2* component (T2*~1.1ms) for normal tendon, and 15% long T2* component (T2*~5ms) and 95% short T2* component (T2*~1.10ms) for the diseased tendon.

MATERIALS AND METHODS

Two patients (male, age = 41 and 59 years) were recruited in this preliminary study, and both previously had a normal Achilles' tendon and an abnormal Achilles' tendon that had been surgically repaired after a rupture (volunteer A got tendon ruptured 10 years previously, and volunteer B got tendon ruptured two and a half months previously). Both of the Achilles' tendon of each volunteers were scanned with a 3D Cones sequence for T2* and T1 measurement, and a 3D Cones-MT imaging for MTR measurement using a 3T GE whole-body scanner. The 3D Cones sequence employed a short rectangular pulse for excitation followed by Cones sampling with a nominal TE of 32 µs. The 3D Cones-MT sequence employed a Fermi pulse (8 ms, maximal saturation flip angle of 670°) for MT preparation. The 3D UTE-MT imaging protocol used the following parameters: TR = 100ms, field of view (FOV) = 10cm, matrix = 256×256, band width = 125kHz, four echoes with TEs of 0.032, 4.3, 8.6, and 12.9 ms, three off-resonance frequencies (Δf = 1.5, 3.0 and 5.0 kHz). Bi-component T2* analysis was performed on five interleaved dual-echo 3D Cones data (TEs = 0.032/4.4; 0.2/6.6; 0.4/8.8; 0.8/11; 2.2/13 ms) with a total scan time of 10 min. The effective T1 of both short and long T2 components was measured with a variable TR 3D Cones approach (TR=5.8, 10, 20, 40, 60, 100 ms) ranging from 10 ms to 100 ms). The T1 of the short T2* components was measured with a 3D IR-Cones approach, using five sets of TR/TI combinations (TR/TI=107/48, 150/64, 200/81, 300/110 and 400ms/131ms) were performed, with each TR/TI combination appropriate to invert and null the long T2 components [6]. A 3-in receive only coil was used for signal reception. The bi-component analysis algorithm was written in MATLAB and executed offline on Dicom images obtained using the protocols described above. MTR corresponding to different Δfs was calculated using ImageJ software.

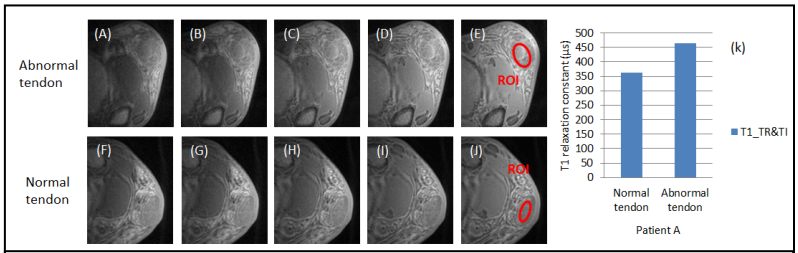

Fig 2 3D Cones T1 mapping of abnormal tendon with a TR of 10 ms (A), 20 ms (B) , 40 ms (C), 60 ms (D), 100 ms (E), and normal tendon with a TR of 10 ms (F), 20 ms (G), 40 ms (H), 60 ms (I), 100 ms (J). Abnormal tendon shows ~30% higher T1 (K).

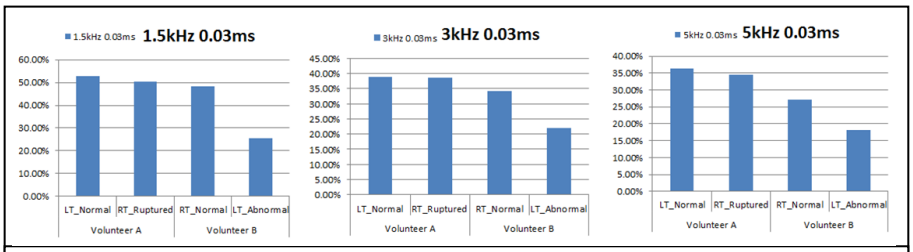

Fig 3 UTE-MT images with different TEs and different off-resonance frequencies of the normal tendon in volunteer A shows excellent detail of its fiber structure (not displayed). The MTR was decreased in the diseased tendon compared with the normal tendon at different Δf (1.5, 3, 5 kHz) with a TE of 32 µs.

RESULTS AND DISCUSSION

Figure 1 shows bi-component T2* analysis of the interleaved dual-echo 3D Cones images. The long T2* component increased from T2*~3.52 for the normal tendon to ~4.99ms for the abnormal tendon. T2* of the short T2* component remained essentially unchanged (1.15 vs 1.10 ms). The fraction of the long T2 component decreased from 28% for the normal tendon to 15% for the abnormal tendon.

Figure 2 shows the T1 increased from 362.72 ms for the normal tendon to 464.41 ms for the abnormal tendon.

Figure 3 shows 3D Cones-MT imaging of the normal tendon of volunteer acquired at different frequency offsets and TEs (images not displayed). The 3D Cones-MT sequence provided high quality morphological images with high signal and resolution, as well as MTR values of the tendon. The MTR chart shows the ruptured tendon has a lower MTR value which especially in the fresh ruptured tendon (volunteer B) at all the different frequency offsets and TEs.

The bi-component T2* results are a little different from our previous study of volunteer A using a 2D UTE bi-component analysis [3]. This might be caused by multiple factors: tendon changes during the interval of ~2 years, and differences between the 2D UTE and the 3D Cones sequences (e.g., 2D UTE sequence is more sensitive to eddy currents had a longer half-pulse and a shorter rectangular pulse was used in 3D Cones). The histopathologic change in diseased tendon is a complex process[4]. Tendon is known to have multi-components. A bi-component T2* model is a simplification [5]. Our T1 values are also lower than published values [4], potentially related to errors in flip angle, which plays a key role in T1 quantification using variable TR approach. Further research is needed to resolve this discrepancy.

CONCLUSIONS

The study shows differences in long T2*s and fractions, T1 and MTR between normal and diseased tendons. MTR differences were especially obvious with ultrashort TEs, suggesting that UTE-MTR may be a robust method in evaluating the process of tendon degeneration and recovery.

REFERENCES

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