Ultrashort TE Spectroscopic Imaging (UTESI): an Efficient Technique for Free and Bound Water Quantification

J. Du[1], E. Diaz[1], R. Znamirowski[1], S. Statum[1], D. DLima[2], G. Bydder[1], and C. Chung[1]
[1]Radiology, University of California, San Diego, San Diego, California, United States, [2]Scripps Reseach Institution

INTRODUCTION

It is well accepted that biological tissues commonly contain distinct water compartments and display two or more T2 components (1-3). However, conventional T2 relaxometry still focuses on single component analysis using multi-echo spin echo sequences, which typically cannot detect signal from the short T2 components in a variety of musculoskeletal (MSK) tissues. We have previously reported a technique called ultrashort TE spectroscopic imaging (UTESI) which is capable of spectroscopic imaging of short T2 species in a time-efficient way (4, 5). Here we propose a bi-component T2* analysis based on a multi-slice UTESI sequence to quantify T2* and fractions of the free and bound water components in a series of MSK tissues. Phantom studies were performed to evaluate the accuracy of this technique. In vitro evaluation of bovine cortical bone and human menisci, as well as in vivo study of healthy and diseased Achilles tendon was performed in this feasibility study.

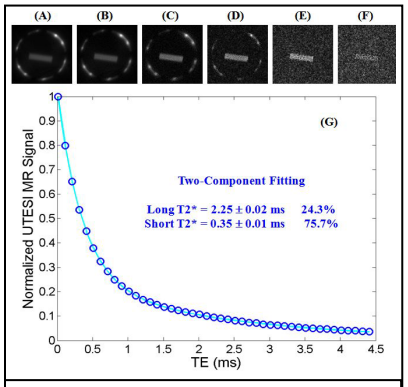

Fig 1 *UTESI images of bovine cortex (A-F) and bi-component fitting(G) demonstrating a short T2* of 0.35 ms and long T2* of 2.25 ms with a fraction of 75.7% and 24.3%.*

MATERIALS AND METHODS

A 2D UTESI sequence with a minimum TE of 8 μs was implemented on a clinical GE 3T scanner. T2* and fractions of the multi-components can be measured through exponential fitting of UTE images. Multi-component fitting analysis is extremely sensitive to SNR, the number of components, minimum TE, the number of echoes, and the separation of T2*. The following procedures were employed to minimize fitting errors: (i) Only two components, namely free water with longer T2* and bound water with much shorter T2* were considered for bi-exponential fitting; (ii) UTESI was employed for data acquisition. UTESI time-domain images provide T2* decay signal started with a near zero TE of 8 μs, therefore allowing the detection of free and bound water components. The UTESI time domain signals can be normalized, thus the sum of the amplitude of the two components should equal 1, eliminating one fitting parameter. Furthermore, UTESI provides a large number of echo images, greatly enhancing the fitting confidence level and reducing fitting errors. (iii) Background noise was estimated through a comprehensive noise estimation algorithm where maximum likelihood (MLE) distribution fitting of background noise histogram provides accurate estimation of the background noise level. As a result, the normalized time-domain UTESI signal intensity (SI*) at echo time TE can be simplified as shown in equation [1]. As a result, there are only three fitting parameters, namely T2* for free water ($T^*_{2,f}$) and bound water (T^*_{2b}), and fraction of the bound water (F_b) or free water ($F_f = 1-F_b$).

$$SI^*(TE) = F_b \times e^{-TE/T^*_{2,b}} + (1-F_b) \times e^{-TE/T^*_{2,f}} + \text{noise} \qquad [1]$$

Phantom, in vitro and in vivo studies were performed. The bi-component model was validated on a phantom with 20% long T2* (~11 ms) and 80% short T2* (~1.3 ms) composition by doping different levels of $MnCl_2$ solution in distilled water. Then the model was applied to bovine cortical bone (n=5) and human menisci specimens (n=5). Finally it was applied to the Achilles tendon of healthy volunteers (n=5) and patients (n=1). Typical imaging parameters included: TR = 200 ms, FOV = 12 cm, slice thickness = 2-5 mm, up to 12 slices, reconstruction matrix = 512×512, 2025 half projections, 1 to 4 echoes, 27 interleaved groups of half projections, Δt = 160-240 μs, resulting in 27 to 108 TEs ranging from 8 μs to 4.5 ms (bone), 45 ms (menisci) or 17 ms (tendon) in a total scan time of ~13 minutes. A 100% slice gap was employed to minimize signal degradation due to imperfect slice profile related to the slice selective half RF pulse excitation.

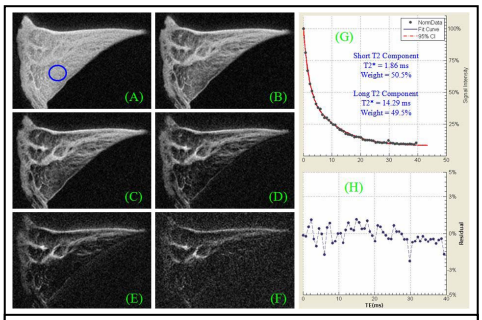

Fig 2 *UTESI images (A-F) of a meniscus sample, and bi-component fitting (G, H) of an ROI shown in (A), showing a short T2* of 1.86 ms and long T2* of 14.2 ms with respective fractions of 50.5% and 49.5%.*

RESULTS and DISCUSSION

Phantom studies show that bi-component fitting of UTESI images provide accurate estimation of the short and long T2* and fractions with an error of less than 4%. Fig 1 shows time-domain UTESI images of a bovine femoral cortex (A-F) and bi-component fitting, which demonstrated short T2* of 0.35 ± 0.01 ms and relative longer T2* of 2.25 ± 0.02 ms with a fraction of 75.7% and 24.3%, respectively. Fig 2 shows selected UTESI images (A-F) of a meniscus sample, and bi-component fitting (G) and residues (H), demonstrating a short T2* of 1.86 ms and long T2* of 14.2 ms with respective fractions of 50.5% and 49.5%. Fig 3 shows in vivo UTESI images of the Achilles tendon from the normal left ankle (1st row) and abnormal right ankle (2nd row) of a 58 year old male patient, and bi-component fitting of a global region of interest (ROI) of the abnormal tendon. A short T2* of 0.65 ± 0.04 ms and long T2* of 4.72 ± 0.77 ms with respective percent composition of 77 ± 5% and 23 ± 5% were demonstrated. Fig 4 shows mapping of the short and long T2* components of the normal and abnormal Achilles tendon, and the corresponding percent composition and linear combination of the short and long T2* components.

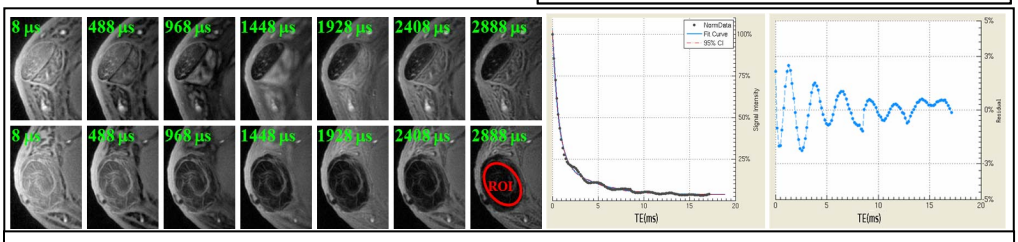

Fig 3 *Selected UTESI images of the normal (1st row) and abnormal (2nd row) Achilles tendon, T2* fitting (middle) of signals from an ROI of the abnormal tendon and the corresponding residual signal (right) which is less than 3%, suggesting good fitting.*

CONCLUSIONS

The multi-slice UTESI bi-component T2* analysis is able to quantify T2* and fractions of the free and bound water components in MR 'invisible' tissues such as the Achilles tendon, meniscus and cortical bone, and has potential for clinical evaluation of osteoporosis (OP) and osteoarthritis (OA) diseases as well as therapeutic monitoring.

Acknowledgement: Grant support from GE Healthcare and VA.

REFERENCES 1. Whittall KP al., MRM 1989. 2. Lattnazio PJ, et. al., MRM 2000. 3. Reiter DA, MRM 2009. 4. Du, et al, MRM 2007. 5. Du, et al., JMRI 2008.

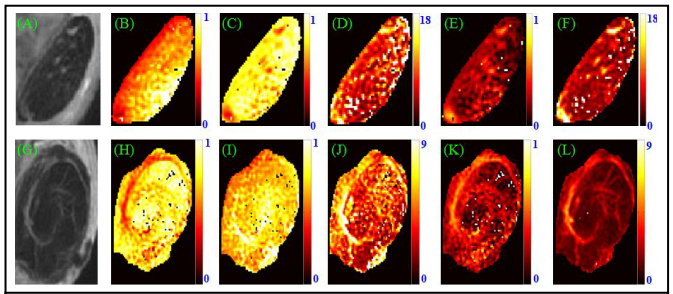

Fig 4 *Normal tendon (A), short T2* map (B), fraction map (C), long T2* map (D), fraction map (E), linear combination (F).Abnormal tendon (G), short T2* map (H), fraction map (I), long T2* map (J), fraction map (K), linear combination (L).*