Ultrashort TE Spectroscopic Imaging (UTESI) of the Short T2 Tissues in the Musculoskeletal System

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Background

The human musculoskeletal (MSK) system contains a variety of tissues with short T2 components such as the deep layers of articular cartilage, menisci, ligaments, tendons, entheses and cortical bone (1-5). The 2D UTE sequences allow these previously "MR invisible" tissues to be directly imaged and quantified. The unwanted long T2 water and fat signals are typically suppressed using fat/water suppression pulses, which may significantly reduce short T2 signals through direct saturation or magnetization transfer (2, 6). Furthermore, it is time consuming to evaluate T2* using UTE acquisition at progressively increasing TEs. Spectroscopic imaging (SI) combines acquisition of spectral and spatial information in a single scan, providing robust fat water separation. SI of the short T2 tissues can be achieved through UTE acquisition at variable TEs. Gold et al. employed this approach to image menisci and tendon with four to eight spectral interleaves (3). Here we present a UTE spectroscopic imaging (UTESI) technique for high resolution imaging and quantification, and apply it to six types of short T2 tissues in the MSK on a clinical 3T scanner.

Materials and methods

A 2D UTE sequence with a minimal achievable TE of 8 μs was combined with a multi-echo UTE acquisition at variable TE delays to provide spectroscopic information (6). The radial projections were highly undersampled and interleaved, producing high spatial resolution images with oscillating streak artifacts, which were shifted to high spectral frequencies after Fourier transformation in the time domain, leaving streak artifact free images near the water and fat resonance peaks (6). The spectroscopic images provide information such as T2*, chemical shift, bulk susceptibility, and mobile proton density (6). Here UTESI was performed on six cadaveric specimens and four asymptomatic volunteers. Typical acquisition parameters included: FOV of 10 to 14 cm, TR of 60 to 200 ms, an initial TE of 8 μs and a TE delay step of 120 to 300 μs thereafter, one to four echoes with an echo spacing of 4-6 ms, flip angle of 40° to 60°, bandwidth of ±62.5 kHz, readout of 512, 3 to 8 slices, slice thickness of 2 to 3 mm, 1980 to 2025 projections interleaved into 45 to 72 groups. The total scan time was about 8 to 12 minutes.

Results and Discussion

Figure 1 shows sagittal UTESI imaging of the knee of a 30 year old healthy volunteer with excellent depiction of the deep radial and calcified layers of articular cartilage at around ±200 Hz, where the superficial layers of cartilage has zero signal. Figure 2 shows UTESI imaging of a meniscus sample in the time domain and spectral domain, respectively. Figure 3 shows axial UTESI images of Achilles tendon in a cadaveric ankle sample with a high spatial resolution of 0.2×0.2×2.0 mm^3, providing excellent depiction of the tendon structure. Fat signal was shifted 456 Hz away from the water peak, providing excellent and robust fat suppression in the tendon peak images. Figure 4 shows T2* evaluation using three approaches, including fat suppressed fully sampled UTE acquisition at variable TEs, UTESI images in the time domain and spectral domain. All three approaches show comparable T2* values. Table 1 summarizes the T2* measurements for the deep layers of articular cartilage, menisci, ligaments, tendons, entheses and cortical bone from four healthy volunteers and 6 cadaveric specimens.

Conclusion

UTESI provides high spatial resolution and moderate spectral resolution together with T2* estimation and fat water separation in a single scan of 8 to 12 minutes, therefore is an efficient way for imaging and evaluation of the short T2 tissues in MSK under a clinical setup.

References

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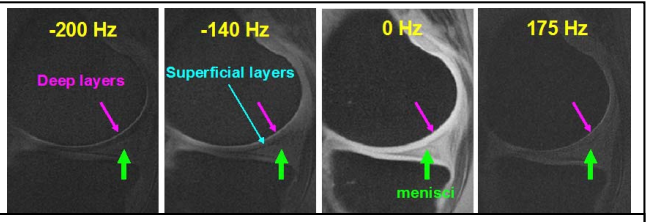

Fig 1 *Selected UTESI images of the knee of a volunteer. High contrast was achieved at around ±200 Hz for the deep layers of cartilage (pink arrows) which have shorter T2 and broader spectra than the superficial layers (cyan arrows). Meniscus (green arrows) was also well depicted.*

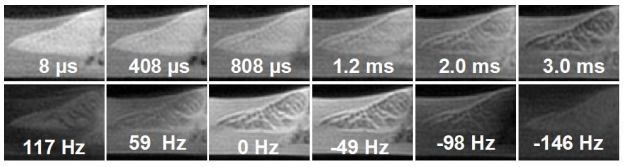

Fig 2 *Selected UTESI images in the time domain (1st row) and spectral domain (2nd row) of a meniscus sample.*

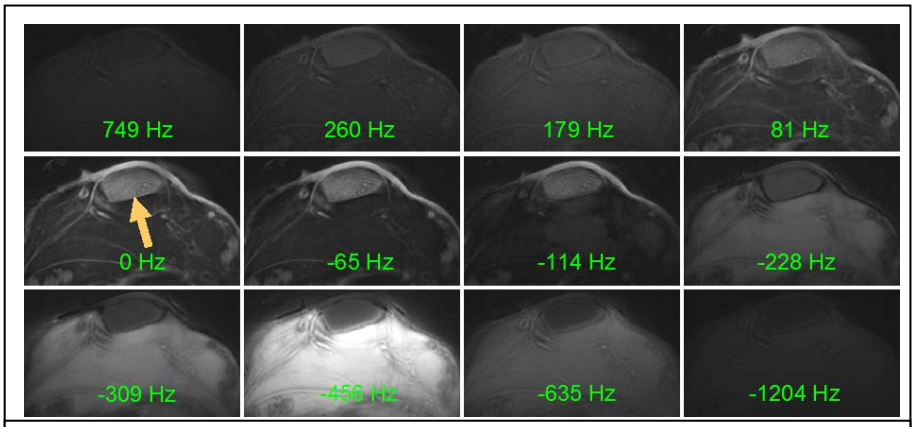

Fig 3 *UTESI of an ankle specimen shows excellent depiction of the Achilles tendon and accurate fat water separation with a high resolution of 0.2×0.2×2.0 mm^3 under a total scan time of 12 minutes.*

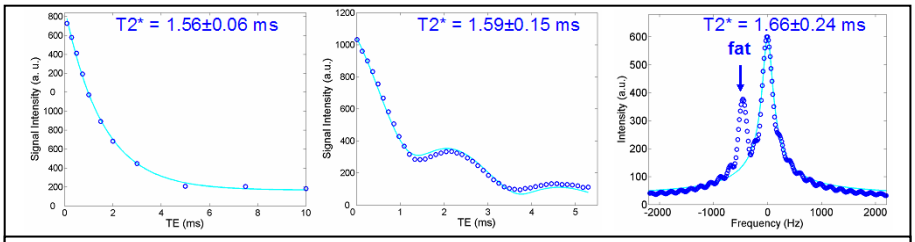

Fig 4 *(a) T2* estimation of tendon using single component exponential decay fitting of fully sampled fat suppressed UTE images at variable TEs; (b) two components exponential signal decay fitting of the UTESI images in the time domain; and (c) line shape fitting of the magnitude UTESI spectrum. Comparable T2* values of 1.56 ±0.06 ms, 1.59 ±0.15 ms, and 1.66 ±0.24 ms were obtained.*

Tissues	Deep Layers of Cartilage	Menisci	Ligaments	Tendons	Entheses	Cortical Bone
T2* (ms)	1.34 ± 0.56	4.19 ± 0.68	3.26 ± 0.34	1.96 ± 0.47	4.21 ± 0.38	0.37 ± 0.08