Ultrashort TE (UTE) imaging with off-resonance saturation: creating high contrast for short T2 tissues

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Background

The human body contains a variety of short T2 tissues, including cortical and trabecular bone, tendon, ligaments, macromolecules and membranes in biological tissues (1-8). Magnetization from these tissues can not be spatially encoded between excitation and acquisition before the signal has completely decayed (4-6). These short T2 tissues have a much broader absorption lineshape than the long T2 tissues, making them as much as 10^6 times more sensitive to an appropriately placed off-resonance irradiation (1, 2). This preferential saturation of the short T2 tissues can be transferred to the liquid spins and be detected indirectly with conventional MR sequences (magnetization transfer, or MT effect) (1, 2). However, typical MT imaging still can not directly image the short T2 tissues. Here we present a technique which combines ultrashort TE (UTE) acquisition with magnetization transfer effect to directly image short T2 tissues with high signal and contrast on a clinical 3T scanner.

Materials and methods

A 2D UTE sequence with a minimal TE of 8 μs was developed through the combination of half-pulse excitation, radial ramp sampling and fast transmit/receive switching (5, 6). The UTE MT technique included three steps. First, a regular UTE acquisition was employed to detect signal from both long and short T2 tissues. Second, UTE acquisition was preceded by a high amplitude saturation pulse (hard pulse or Gaussian pulse) applied at +1 to +3 kHz away from the water peak to suppress signal from short T2 species, with long T2 water and fat signals unaffected (Figure 1). Third, the first image was subtracted from the second one to suppress long T2 water and fat tissues, leaving high contrast for the short T2 tissues. Typical imaging parameters included: FOV = 10 cm, 2 to 3 mm thick slice, readout = 512 (284 sampling points), BW = ±62.5 kHz, TR = 50 to 200 ms, TE = 8 μs, 511 projections. This technique has been applied to tibia cortical bone and Achilles tendon of 5 healthy volunteers and one fresh pig bone sample bought from a nearby slaughter house.

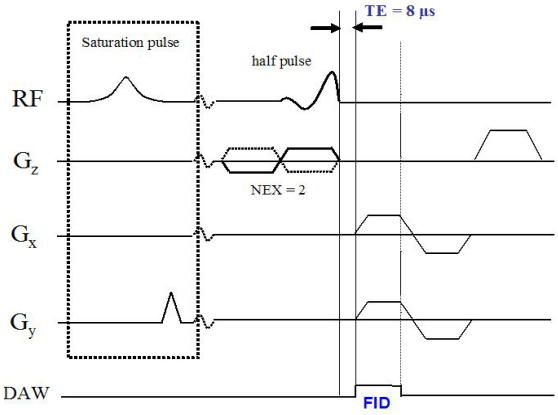

Fig 1 *UTE MT sequence employs UTE acquisition with a minimal TE of 8 μs, preceded by a hard or Gaussian saturation pulse centered at +1.5 to 3 kHz from water peak to selectively saturation short T2 tissues without affect water and fat peaks.*

Results and Discussion

Figure 2 shows UTE imaging of the tibia of a pig bone sample without (left) and with (middle) off-resonance saturation, as well as the subtracted image (right) which shows excellent contrast for cortical bone. Fat signal is well suppressed. Figure 2 shows UTE imaging of the Achilles tendon of a healthy volunteer without (left) and with (middle) off-resonance saturation. The subtracted image (right) shows excellent contrast for tendon.

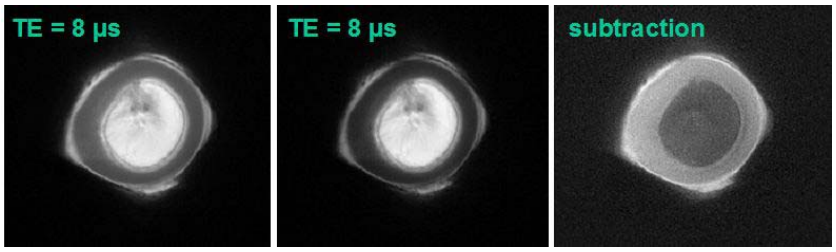

Fig 2 *UTE imaging without saturation pulse (left), with a hard saturation pulse centered +2kHz from the water peak (middle), and the corresponding subtracted image (right), which shows high contrast for cortical bone with excellent fat signal suppression. The total scan time is only 4 minute with a FOV of 10 cm, 512 readout and 3 mm slice thickness.*

Conventional UTE imaging employs either dual echo acquisition or long T2 suppression techniques to improve short T2 contrast. The dual echo approach is susceptible to susceptibility, off-resonance and gradient distortion artifact (4-6). The long T2 suppression pulses are sensitive to off-resonances and may saturate the short T2 signals (6-8). The UTE MT technique employs the same short TE for both acquisitions, therefore less sensitive to susceptibility effect. The saturation pulse was played at far off-resonance, making it less sensitive to off-resonance effect. However, it requires two times the scan time over conventional UTE imaging due to the requirement of repeated UTE acquisitions with and without off-resonance saturation.

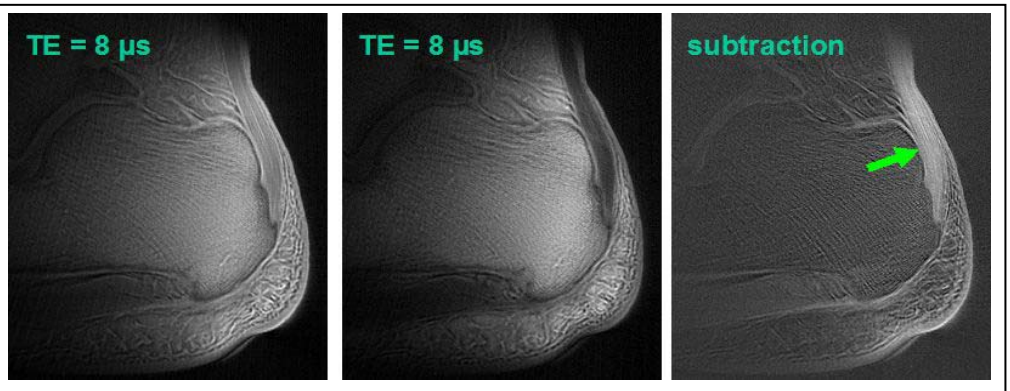

Fig 3 *UTE imaging of the Achilles tendon of a 30 years old male volunteer without saturation pulse (left), with a Gaussian saturation pulse centered at +1.5 kHz away from the water peak (middle), and the corresponding subtracted image (right), which shows high contrast for tendon structure with excellent fat signal suppression. The total scan time is XX minutes with a FOV of 10 cm, 512 readout and 2 mm slice thickness, resulting in a high spatial resolution of 0.2×0.2×2.0 mm^3.*

Conclusion

UTE off-resonance saturation has been shown to be an effective technique in generating high contrast imaging of short T2 tissues. Future work will focus on designing and optimizing the off-resonance saturation pulses and frequencies for maximal short T2 saturation and minimal long T2 suppression.

References

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