Imaging of Short T2 Species Using a Dual Adiabatic Inversion Recovery Ultrashort TE (DIR UTE) Sequence

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Background

Efficient and uniform suppression of long T2 species is an essential adjunct to imaging of short T2 species such as the deep layers of cartilage and cortical bone (1-3). Long adiabatic inversion pulses which are insensitive to B1 inhomogeneity have been used with UTE imaging to create short T2 contrast (2). Typically a single adiabatic IR pulse is used to selectively invert and null long T2 species using a proper combination of TR and TI (3). Longer IR pulses preserve more short T2 signal but are more sensitive to off-resonance effects. Furthermore, a single IR pulse cannot efficiently null two long T2 species, such as muscle (T1~1300ms at 3T) and fat (T1~360ms) simultaneously. In another approach UTE acquisition with and without IR preparation pulses are summed to suppress signal from long T2 species (2). Improved long T2 suppression can also be achieved by summing UTE signals from sequences with the IR pulse focused on water and on fat. In this technique only a single IR pulse is used to invert (not null) either water or fat with a minimal TI. A scaling factor is needed to compensate for relaxation during the preparation pulses, which together with the doubled scan time may compromise its clinical value. Here we report a novel dual adiabatic inversion recovery ultrashort TE (DIR UTE) sequence which provides very high contrast for short T2 species using a clinical 3T scanner.

Materials and Methods

The DIR UTE sequence shown in Figure 1 is a combination of a regular UTE sequence (minimal TE = 8 μs) with two long adiabatic inversion preparation pulses (~25 ms). The first inversion pulse is centered at 0 Hz to only invert long T2 water signals. The second inversion pulse is centered near -440 Hz to selectively invert fat signals. Figure 2 shows the acquisition scheme, where UTE acquisition started following a time delay of TI_1 for the inverted water protons to reach a null point, and a time delay of TI_2 for the inverted fat protons to reach a null point. To investigate the short T2 contrast enhancement with DIR UTE, a phantom consisting three tubes of distilled water, oil vegetable, and distilled water doped with MnCl2 (T2*~400μs) was imaged with gradient echo (GE) with and without fat saturation, UTE, UTE with single IR and UTE DIR sequences. Ten tissue samples, including patella, spine and bone samples, and five normal volunteers were studied. Typical imaging parameters included a FOV of 5 (for samples) to 10 cm (for volunteers), readout of 512, 511 half projections, 0.7 to 5 mm slice thickness, TR of 300 ms, TI1 of 140 ms, TI2 of 80 ms, bandwidth of ±62.5 kHz and total scan time of 5 to 10 minutes.

Results and Discussion

The phantom study shown in Figure 3 demonstrated the superior short T2 contrast provided by DIR UTE when compared with regular UTE, UTE with echo subtraction, or UTE with a single IR pulse focused on the water or fat peak. Figure 4 shows that the DIR UTE sequence provides exclusive contrast for the deep radial and calcified layers of articular cartilage, which are invisible with clinical PD or T1 FSE sequences, and visible but with very limited image contrast when imaged with UTE or UTE with fat saturation. Excellent image contrast was also generated when imaging cortical bone and the Achilles tendon of healthy volunteers. In DIR UTE the suppression of long T2 water and fat signals depends on a proper combination of TI_1, TI_2 and TR, and is relatively insensitive to RF inhomogeneities because of the use of adiabatic inversion pulses.

Conclusion

DIR UTE can be used to efficiently and robustly suppress signal from long T2 water and fat species, and provide excellent image contrast for short T2 species using a clinical scanner.

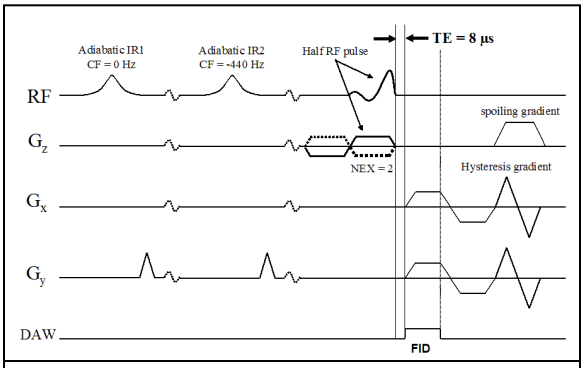

Fig 1 *The dual inversion recovery UTE (DIR UTE) sequence combines a regular UTE (TE = 8 μs) sequence with two long adiabatic IR pulses to suppress long T2 water and fat signals.*

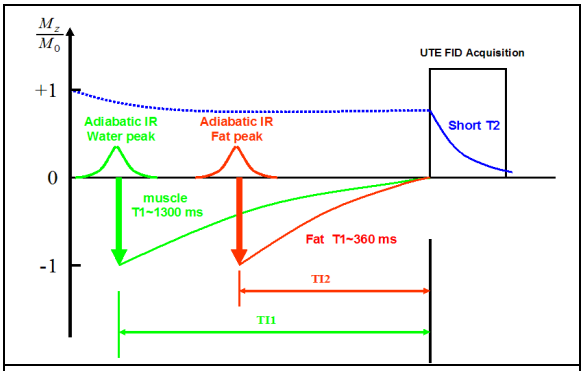

Fig 2 *DIR UTE data acquisition scheme: the first adiabatic IR pulse inverts long T2 water magnetization (blue), while the second adiabatic IR pulse inverts fat magnetization (red). Short T2 magnetization is largely uninverted. The UTE acquisition starts when both water and fat magnetization reach the null point.*

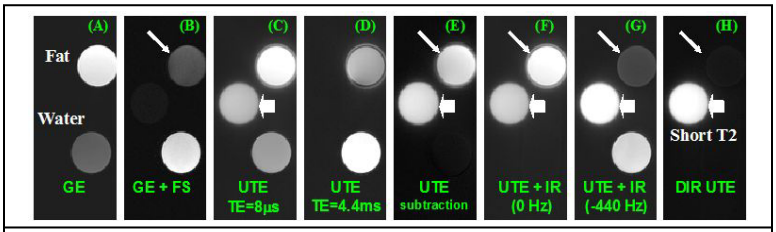

Fig 3 *Conventional and UTE imaging of a phantom consisting of three tubes: distilled water, fat (thin arrows) and short T2 water with T2*~0.4 ms (thick arrows). From left to right the images correspond to: gradient echo (A), gradient echo with conventional fat saturation (B), UTE with a TE of 8 μs (C) and a minimal 2nd TE of 4.4 ms with fat and water in-phase (D), UTE with echo subtraction (E), UTE with a single IR to invert and null water (F) or fat (G), and DIR UTE (H). The residual fat signal in (B) and (G) is due to the -CH=CH- peak which is close to the water peak. DIR UTE effectively suppresses this fat peak and creates excellent short T2 contrast.*

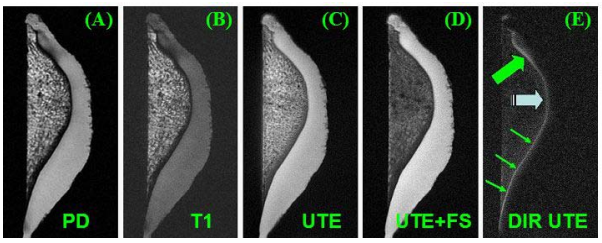

Fig 4 *Axial imaging of a patellar slice using PD-FSE (A), T1-FSE (B), regular UTE without (C) and with (D) fat saturation, and DIR UTE (E) sequences, respectively. The DIR UTE sequence selectively suppresses signals from the superficial layers of cartilage and bone marrow fat, creating excellent image contrast for the deep radial and calcified layers of cartilage. The normal deep layers in this patella are represented by a linear, well-defined area of bright signal adjacent to the low signal intensity subchondral bone (thin arrows). Effacement and thickening of the linear MR signature of the calcified layer of the medial facet suggests a deep layer lesion (thick arrows). Histological study is being performed to assess the significance of this finding.*

References

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