Morphological and quantitative ultrashort echo time (UTE) magnetic resonance imaging of the short T2 components in white matter of the brain

Jiang Du[1], Vipul Sheth[1], Shihong Li[1], Michael Carl[2], Scott Vandenberg[3], Jody Corey-Bloom[4], and Graeme Bydder[1]

[1]*Radiology, University of California, San Diego, San Diego, CA, United States,* [2]*General Electric, Global MR Applications & Workflow, San Diego, CA, United States,* [3]*Pathology, University of California, San Diego, La Jolla, CA, United States,* [4]*Neurosciences, University of California, San Diego, La Jolla, CA, United States*

INTRODUCTION

Myelin is a lamellar membranous structure consisting of alternating protein and lipid layers. Imaging of myelin has been of central importance in neuroradiology. Researchers have been working for decades to develop MRI techniques to assess myelin in vivo [1-3]. The non-water protons in myelin and tightly bound water have very short T2s and are "invisible" with conventional clinical sequences [4-7]. We have implemented a 2D adiabatic inversion recovery prepared dual echo ultrashort echo time (2D IR-dUTE) acquisition with a TE of 8 μs. In this study we aimed to morphologically and quantitatively evaluate myelin and tightly bound water in white matter of the brain of normal volunteers at 3T.

MATERIALS AND METHODS

Figure 1 shows the IR-dUTE sequence implemented on a 3T Signa TwinSpeed scanner (GE Healthcare Technologies, Milwaukee, WI) and the contrast mechanism. The ultrashort T2* components represent a small fraction of the total signal from white matter of the brain, with dominant signal from the long T2 components. An adiabatic Silver-Hoult inversion pulse (duration = 8.64 ms) was used to invert and null the long T2 components in white matter. The ultrashort T2 components (T2* < 1 ms) are not inverted due to fast relaxation during the long adiabatic inversion process, and are detected by subsequent UTE data acquisition. Residual signals from other long T2 signals (e.g., gray matter, CSF and fat) are suppressed via subtraction of the 2nd echo from the first one, providing selective depiction of the ultrashort T2* components in white matter. The IR-dUTE sequence was applied to nine healthy volunteers for morphological and quantitative evaluation of the ultrashort T2* components with the following parameters: 24 cm FOV, 5 mm slice, 125 kHz bandwidth, 70°, 1000 ms TR, 330 ms TI, TE = 8 μs and 2.2 ms, 192 sampling points, 131 projections, recon matrix = 256×256, 4.4 min scan time. T2* was quantified with four different TE combinations (TEs = 0.008/4.4, 0.2/4.4, 0.6/4.4 and 1.5/4.4 ms). Relative proton density was quantified by comparing signal from the short T2* components with that of a rubber which has a similar T2* (~0.4 ms) and a similar T1 (~200 ms) [7, 8].

RESULTS AND DISCUSSION

Figure 2 shows comparison between IR-dUTE imaging and clinical T1-FSE, T2-FSE and PD-FSE imaging of white matter of the brain of a normal volunteer. Clinical sequences showed predominantly long T2 signals. The IR-dUTE sequence showed near zero signal for the white matter on the 2nd echo with a TE of 2.2 ms. This directly confirmed that the long T2 components in white matter were efficiently suppressed.

Accuracy of the IR-dUTE sequence in measuring ultrashort T2* species is demonstrated in Figure 3. The rubber phantom has an ultrashort T2* of 0.34 ± 0.02 ms, when measured with both the non-slice selective 2D UTE and IR-UTE sequences. In vivo IR-dUTE imaging shows a T2* of 0.37 ± 0.09 ms for the rubber phantom, indicating relatively accurate assessment of the short T2* species (with 9% overestimation). The ultrashort T2* components in white matter of the brain of the volunteer had a T2* of 0.47 ± 0.04 ms. A RPD of 3.17 ± 0.28% was demonstrated for the ultrashort T2* components by comparing their signal intensities with that of the rubber phantom, which had a RPD of 35.2% as measured by the 3D UTE sequence.

The results demonstrate that the detected ultrashort T2* components in brain white matter have very short T2*s ranging from 0.32 ms to 0.59 ms and low RPDs ranging from 2.97% to 5.25%. On average, a mean SNR of 18.7 ± 3.7 and a mean CNR of 14.6 ± 2.4 were seen between the ultrashort T2* white matter and gray matter in a 4.4 min scan time with a nominal voxel size of 1.25×1.25×5.0 mm^3. A short mean T2* of 0.42 ± 0.08 ms and low mean RPD of 4.05 ± 0.88% were demonstrated for the healthy volunteers at 3T.

CONCLUSIONS

Ultrashort T2* components in white matter of the brain can be selectively imaged and quantified using 2D IR-dUTE sequences at 3T. This may significantly advance the study of normal matter disease.

REFERENCES

1. Whittall KP, et al., MRM 1997.
2. Stanisz GJ, et al. MRM 1999.
3. Lanycaster JL, et al., JMRI 2003.
4. Waldman A, Neuroradiology 2003.
5. Wilhelm MJ, et al, PNAS 2012.
6. Horch RA, et al, MRM 2011.
7. Du J, et al., NeuroImage 2013.
8. Nayak KS, et al., ISMRM 2000.

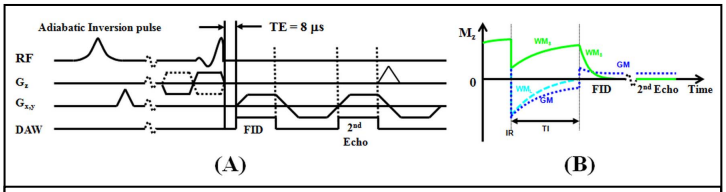

Fig 1 *Pulse sequence for 2D UTE imaging using half pulse excitation and radial ramp sampling with a minimal nominal TE of 8 μs (A). An adiabatic inversion recovery pulse together with dual echo acquisition was used to create short T2* contrast (B). The IR pulse provides robust inversion of the longitudinal magnetizations of gray matter (GM) and the long T2 components in white matter (WM_L). The short T2* components in white matter (WM_S) experience significant transverse relaxation during the long adiabatic inversion process, and are not inverted but partly saturated. The UTE acquisition starts when the inverted longitudinal magnetization of WM_L reaches the null point, leaving signals from WM_S and residual GM to be detected by the FID acquisition. The 2nd echo contains signal from GM, with near zero signal from WM_S due to its short T2*. Subtraction of the 2nd echo from the FID provides selective imaging of WM_S.*

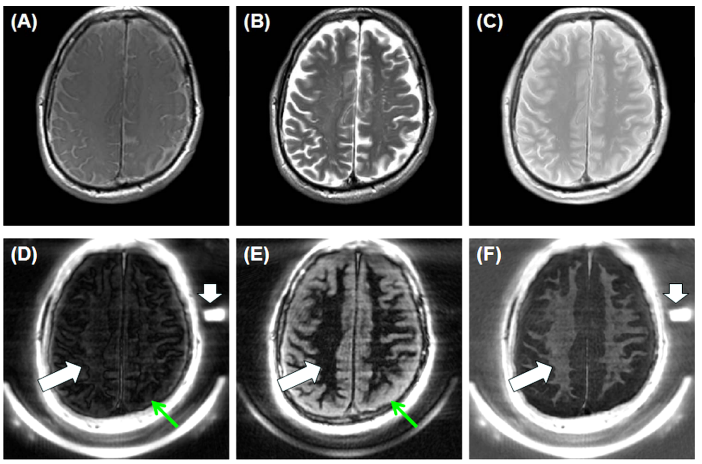

Fig 2 *T1-FSE (A), T2-FSE (B), PD-FSE (C) as well as IR-dUTE imaging with TEs of 8 μs (D), 2.2 ms (E) and a subtraction image (F) of the brain of a volunteer. Signals from the long T2 white matter were nulled by the adiabatic IR pulse (thick arrows). Signals from the long T2 gray matter were suppressed through subtraction (thin arrows), leaving signals from myelin and/or tightly bound myelin water to be selectively depicted (F).*

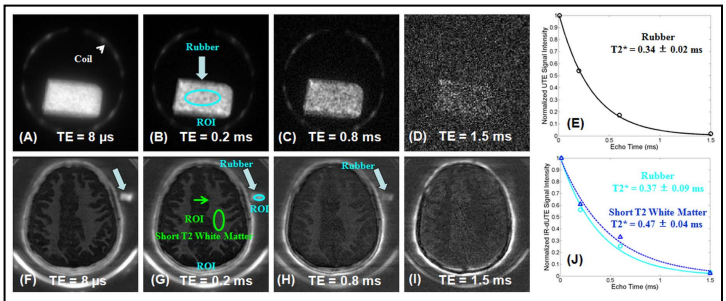

Fig 3 *2D non-slice selective UTE images of the rubber phantom with TEs of 8 μs (A), 0.2 ms (B), 0.6 ms (C) and 1.5 ms (D). Single component fitting shows a T2* of 0.34 ± 0.02 ms for the rubber phantom (E). IR-dUTE subtraction images of a healthy volunteer with a TR of 1000 ms, TI of 330 ms and TEs of 8 μs (F), 0.2 ms (G), 0.6 ms (H) and 1.5 ms (I). Single component fitting shows a T2* of 0.37 ± 0.09 ms for the rubber phantom and a T2* of 0.47 ± 0.04 ms for the ultrashort T2* components in white matter of the brain (J).A low RPD of 4.26 ± 0.49% was demonstrated for the ultrashort T2* components by comparing their signal intensities with that of the rubber phantom (short thick arrows).*