Combined T1- And DTI Weighted Contrast for High Resolution Human Brain Mapping Using 3D MPRAGE

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Introduction

High resolution 3D magnetization-prepared rapid gradient-echo (MPRAGE) with T1 weighting is generally the method of choice for mapping gray and white matter structures in the brain. Previously, MPRAGE has been combined with diffusion encoding [1-2] to achieve diffusion tensor imaging (DTI) without the inherent susceptibility distortions in echo planar imaging (EPI). However, an incorporation of DTI contrast in 3D-MPRAGE has not been shown before on human brain data. Furthermore, a combination of T1 and DTI weighted contrast should benefit assessment of gray/white matter boundaries, which has important implications for accurately imaging brain atrophy. The overall goal of this study was to develop multiple contrast high resolution MRI. Specifically, we show the incorporation of DTI contrast (i.e. fractional anisotropy (FA) and mean diffusivity (MD)) into T1-weighted 3D-MPRAGE using simulations based on equations given in Ref [3] as well as experimental results from human brain at 4T.

Methods

Simulations of MPRAGE were programmed in Matlab 7.0.4. For simulations of the MPRAGE signal, we used tissue parameters (to approximate human model at 4T) including T_1=1724 ms and T_2=70 ms for gray matter, and T_1=1043 ms and T_2=65 ms for white matter. For simulating diffusion contrast, we used values of apparent diffusion coefficients, ADC=0.00079 mm^2/s for gray matter and ADC=0.00056 mm^2/s for white matter based on literature values [4].

For experiments the 3D MPRAGE with DTI weighting was developed and implemented on a 4T MR scanner (Bruker, Siemens). DTI weighting in MPRAGE is achieved by applying radiofrequency (RF) pulses (90^o_{+x}-180^o_{+y}-90^o_{-x}) in presence of diffusion sensitization gradients that encodes diffusion information in the longitudinal magnetization before the magnetization is mapped using the conventional train of shallow flip angle pulses of MPRAGE. The experiment is repeated along multiple directions to obtain DTI information. The following parameters were used; b-value=1000 s/mm^2 for diffusion encoding, derived from a gradient of strength g=15 mT/m with a duration δ=30 ms and diffusion encoding time TE_{diff}= 122 ms. A single housing transmit / 8-channel receiver head coil was used. MPRAGE parameters were; TR/TE =2000/3.1 ms, flip angle=8 degrees and 2mm isotropic resolution. Maps of MD and FA were computed using DTIstudio software.

Results

Simulation of the evolution of longitudinal magnetization in MPRAGE including DTI weighting is shown in Figure 1. Simulations were performed for linear k-space mapping. White matter with high (black) and low (green) diffusion directionality, i.e. FA, is shown in Figure 1, indicating diffusion contrast in MPRAGE. Gray matter is shown in red. The progression of the curves toward equilibrium is governed by a combination of the shallow tips and T1 [3]. The simulation shows that a substantial diffusion contrast between white matter with high and low FA values remains over a reasonable long period (about 400ms) in MPRAGE before the contrast disappears due to progression toward the steady state.

Representative experimental MPRAGE images of T1-w, MD and FA from a healthy subject are displayed in Figure 2. In general, both T1-w and FA maps show high contrast between gray and white matter. However, the FA map provides additional information not available with T1w alone, as shown in Figure 3. In detail, the intensity profiles of T1w and FA maps are superimposed in Figure 3a along a cross-section in the image (red line in Figure 2), showing systematic differences between T1w and FA. This is also depicted in the correlation map between T1w and FA in Figure 3b. In particular, T1w and FA profiles differs substantially in white matter (3c) and gray matter (3d) regions, implying additional contrast information.

Fig. 1. Simulated evolution of longitudinal magnetization in MPRAGE

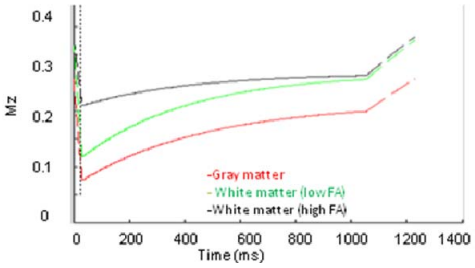


Fig. 2. Representative T1-w, MD and FA maps using DTI 3D MPRAGE from healthy human brain in vivo. The red line is a region along the brain to obtain the intensity profile of the images.

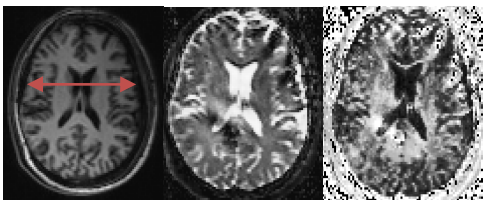
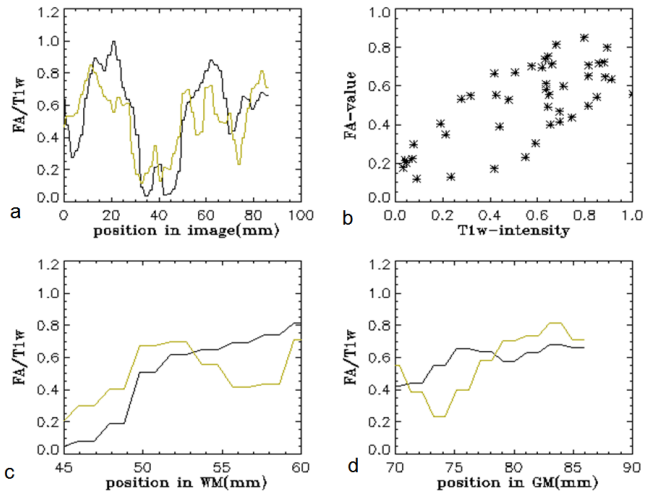


Fig. 3. Intensity profiles of T1-w (black) and FA (green) along a cross-section in the image of healthy human brain (Fig. 2) for the whole brain (a and b), white matter (c) and gray matter (d) regions. The T1-w signal intensities are scaled to 1.0.



Conclusion

This study suggests DTI weighted MPRAGE is feasible for human brain imaging and expected to benefit assessment of gray/white matter boundaries. However, several limitations require improvement. First, residual transverse magnetization from diffusion weighting can interfere with the MPRAGE signal and therefore needs to be minimized either by applying crusher gradients or using RF pulses with more uniform flipping. Second, resolution was currently limited to 2 mm due to limits in SNR. We expect that SNR can be recovered and thus higher resolution afford by shortening the diffusion time (TE_{diff}) in combination with more efficient signal averaging utilizing parallel imaging. Furthermore, DTI contrast can be gained by tailoring dense k-space sampling with regard to diffusion decay of the signal.

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