High resolution volumetric T1 mapping using a novel MP3RAGE method

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Introduction

The MP2RAGE method, which was modified from the well-known MPRAGE sequence, has recently been proposed to avoid the B_1 inhomogeneity at high fields by properly combining two volumes collected at different inversion times (TIs) [1]. In addition to the unbiased T1-weighted images, a high-resolution 3D T1 map can be simultaneously calculated by using these two samples during T1 recovery process. It was reported that a lookup table for T1 computation can be prepared according to the magnetization evolution once the protocol was determined. Notice that the inversion efficiency (*eff*) of the adiabatic inversion pulse, which is necessary for accurate T1 mapping, was provided by numerical simulation at 0.96 in [1]. Considering the interval between two successive inversion pulses (TR_{mp}), as long as 4 to 8 seconds, was much longer than the duration of each acquisition block of fast gradient echo, a third pulse train at a variant TI can thus be inserted without increase of scan time. With more information gained from the recovery process, *eff* can be taken as a free parameter in the fitting process. In this work, high resolution volumetric T1 mapping of human brain by our proposed method, named MP3RAGE, were presented.

Materials and Methods

Both magnetization-prepared sequences, MP2RAGE and MP3RAGE, begin with an adiabatic inversion pulse, followed by two or three blocks of gradient-echo (GRE) pulse train, respectively. This process is repeated until the second phase encoding is fulfilled. Note that centric encoding was utilized for each GRE block to restore the T1 contrast. Complex data at distinct TIs were saved for offline computation. Phase terms due to off resonance can be firstly removed by simple division [2] as well as proton density, T_2* contrast and receive B_1 field. For MP2RAGE, the relationship between T1 and the ratio of two GRE signals (GRE1/GRE2) can be obtained for T1 mapping once *eff* and all scan parameters, such as TI and flip angle, are determined. With more data acquired at three different TIs in MP3RAGE, it becomes possible to assess T1 and *eff* by solving a nonlinear problem or performing nonlinear fitting in a sense of least squares error.

Human experiments were conducted on a 1.5 T scanner (Signa HDx, GE Healthcare, Milwaukee, WI) with an eight-channel phased array head coil. Four healthy volunteers (22-25 yrs) were all scanned by three T1 mapping sequences. First, a multi-slice inversion-recovery fast spin-echo (IR-FSE) with six TIs (100, 200, 400, 800, 1600, and 2600 ms) was applied with TR/TE = 3600/8.6 ms, ETL = 16, and a voxel size of 1x1x3 mm^3. T1 relaxation time was estimated by the commonly used 3-parameter model for IR-FSE, serving as reference in this study. After that, MP2RAGE was performed at TI1/TI2/TR_{mp} = 700/2800/5000 ms, TR/TE = 8.2/3.1 ms, and a flip angle of 8^0 for both GRE, followed by MP3RAGE with scan parameters almost identical with those of MP2RAGE except TI1/TI2/TI3 = 300/1200/3000 ms. Note that the imaging matrix and voxel size of MP2RAGE and MP3RAGE were kept exactly the same with IR-FSE for direct comparison. In addition, parallel imaging was applied in both MP2RAGE and MP3RAGE to achieve 2-fold acceleration, leading to an equivalent scan time of 8 minutes.

Results

Figure 1 demonstrates the T1 maps obtained by MP2RAGE, MP3RAGE, and IR-FSE from left to right. At first glance, no visual difference was observed except that periodical artifacts (pointed by white arrows) possibly induced by pulsation was found in IR-FSE. Region-of-interest analysis performed on white matter and gray matter was shown in Table 1. Compared with the results of MP2RAGE, T1 measured by MP3RAGE at all regions was obviously closer to that by IR-FSE. However, the standard deviation of MP3RAGE is larger than that of MP2RAGE in general.

Discussion

In MP2RAGE, *eff* plays an important role in the relationship between T1 and the ratio of GRE1/GRE2 (see Fig.2). Through simulation we can find that an over-estimation of *eff* could lead to under-estimation of corresponding T1, especially for long T1 tissues. For example, a GRE1/GRE2 ratio of -0.1 in our MP2RAGE experiment would correspond to a 1262-ms T1 at *eff* = 0.96. As *eff* decreasing to 0.9, 0.8, and 0.7, the estimated T1 value will increase to 1344, 1516, and 1759 respectively (see Fig.2). As a result, MP3RAGE, in which *eff* was found to actually range from 0.6 to 0.9 in our results (not shown), is more insensitive to the variation of inversion efficiency, which means T1 measurement is possible even when the profile of the inversion pulse is not available. Therefore we concluded that MP3RAGE is able to achieve more accurate T1 mapping than MP2RAGE without the cost of longer scan, but it may be more sensitive to the noise because of the nonlinear calculation.

	WM	Caudate nucleus	Putamen	Thalamus	Cortex
IR-FSE	644 ± 45	1133 ± 79	918 ± 59	994 ± 64	1367 ± 136
MP2RAGE	602 ± 25	1003 ± 56	852 ± 57	887 ± 55	1276 ± 85
MP3RAGE	660 ± 42	1073 ± 86	919 ± 69	957 ± 75	1362 ± 132

Table.1 Regional T1 values (mean ± standard deviation) in unit of msec.

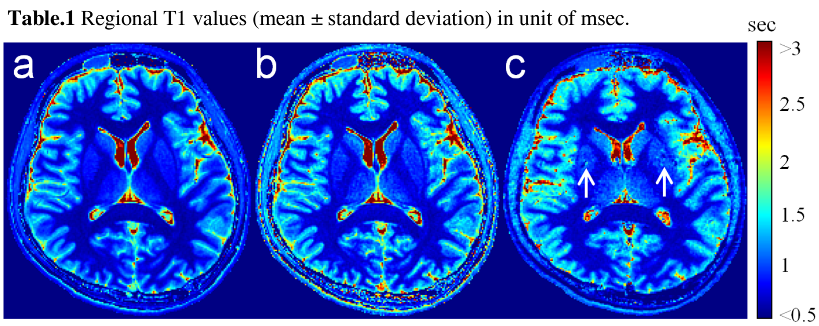

Fig.1 T1 maps at identical position obtained by MP2RAGE (a), MP3RAGE (b), and IR-FSE (c).

References

[1] Marques JP et al. Neuroimage 2010, 49(2):1271-81.

[2] Van de Moortele PF et al. Neuroimage 2009, 46(2):432-46.

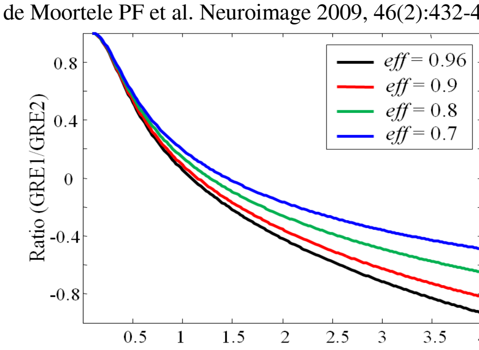

Fig.2 The relationship curves between T1 and the ratio of GRE1/GRE2 in MP2RAGE at different inversion efficiencies (*eff*) from 0.7 to 0.96.