Brain morphometry with multiecho MPRAGE

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Introduction and Background

In multispectral brain morphometry it is important that the multiple images with different contrasts be precisely aligned. Moreover, to accurately segment structures requires that the multiple images either not be distorted or all be distorted in the same way so that the edges of structures match. Our multispectral morphometry protocol consists of two or more multiecho FLASH (MEF) scans with different flip angles, a T2-SPACE scan, and a multiecho MPRAGE (MEMPR), all with the same high bandwidth so that the B0 distortion is small, and the same across scans. The MEF scans allow quantitative T1 and PD estimation [1], and an approximate T2* estimate. The MEMPR provides optimal contrast between gray matter (GM) and white matter (WM) and CSF along with reduced B0 distortion that may also be matched precisely to the other scans. The T2* information in the multiple echoes can also be used to segment tissues such as dura that frequently confound cortical thickness estimates in regions where dura and cortex are adjacent.

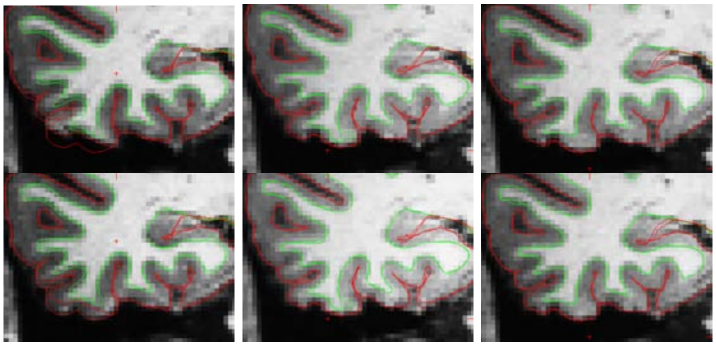

Figure 1: Columns: (left) MPR, (middle) MEMPR with all echo readouts in the same direction (right) MEMPR with echoes alternating in readout direction. Rows: (top) first/only echo readout direction positive, (bottom) first/only echo readout direction negative. Both images in each row show white matter surfaces (green) and pial surfaces (red) calculated from images with opposite readout directions.

Methods and Results

For optimal contrast between GM, WM and CSF at 3T, we selected the following conventional MPRAGE (MPR) [2,3] parameters based approximately on a Bloch equation simulation: TR 2530 ms, TI 1100 ms, TE 3.37 ms, flip angle 7°, 176 sagittal partitions, 256^2 matrix, 1 mm isotropic resolution, bandwidth 195 Hz/px. Similar parameters were used by Han et al. [4] who demonstrated that MPR performed better on cortical segmentation than MEF, while MEF outperformed MPR on subcortical segmentation. MEF bandwidth is typically around 650 Hz/px with 8 echoes, resulting in considerably less distortion due to B0 inhomogeneities than MPR. To achieve the same distortion reduction with MPR we increased the bandwidth, added echoes, and recovered the SNR by combining the echoes to form the final image. With 4 echoes, the TR, TI and time to encode partitions for the MEMPR was close to that of the MPR, resulting in similar GM/WM/CSF contrast.

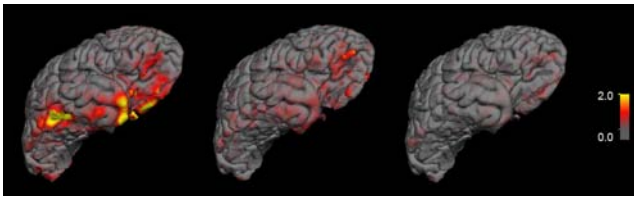

Figure 2: Displacement in mm between pial surfaces calculated from scans with opposite readout directions, displayed on right hemisphere rotated to show cortex where B0 offsets are greatest. MPR (left), single echo MEMPR (middle) and alternating direction MEMPR (right).

To demonstrate potential improvement in morphometry with MEMPR we collected 6 scans on each of two healthy volunteers viz. two single echo MPRs with + and - readout directions and four MEMPRs with readouts all in the same direction (++ and --), and alternating (+- and -+). Parameters were as follows: (MPR) above; (MEMPR) TI 1200 ms, TE 1.64 + n.ΔTE ms (n=0,..,3), where ΔTE=1.86/2.95 ms (+-/++), other parameters same as MPR (Siemens 3T TIM Trio). We analyzed each scan (the RMS average in the case of the MEMPR) with SIENA [5] and FreeSurfer [6]. SIENA calculates the percentage brain volume change (PBVC) from two scans, with an accuracy of around 0.2% (see Table 1). For both subjects, the PBVC between the scans with opposite readout directions was smaller for the MEMPR than for the MPR. We used FreeSurfer to calculate WM and pial surfaces. Figure 1 shows the 3 pairs of scans, with the calculated pial and WM surfaces for the scans with opposite readout directions superimposed on both images. The edges of structures in the MPR image move by up to 3 mm, whereas in the MEMPR they move by less than 1 mm. The displacement of the surfaces is mapped to the cortical surface and shown in Figure 2. The areas most affected are the areas of greatest susceptibility change, and the effect is more pronounced with the MPR scan than with the MEMPR scan. The displacements were smallest for the alternating direction MEMPR. Cortical thickness estimates are less affected than absolute position of the surfaces, since the inner and outer surfaces of the cortex tend to shift in the same direction.

Table 1: Brain volume differences.

Sequence	PBVC Subj. 1	PBVC Subj. 2
MPR + vs -	1.7	-4.3
MEMPR ++ vs --	-0.60	-0.04
MEMPR +- vs -+	-0.07	-0.05

Table 2: SNR and CNR averaged across subjects/directions for different sequences.

	Sequence MPR	Sequence MEMPR
SNR (GM)	47.5	58.3
SNR (WM)	91.1	102.1
CNR (WM/GM)	43.6	43.8

The T2* information encoded in the echoes can be exploited for segmentation properties. For example, a linear combination of echoes can be calculated to optimize contrast between certain structures. A particular problem with conventional MPR is that there is little contrast between cortex and dura, and automatic cortical segmentation algorithms may include dura with cortex in certain regions. Dura has substantially shorter T2* than cortex. A simple way to segment dura from cortex using MEMPR is to divide the image intensities of the first and fourth echoes and compare to a threshold. Dura labeled in this way, with the cortical surface nudged accordingly is shown in Figure 3, and may result in more reliable thickness estimates in the affected regions.

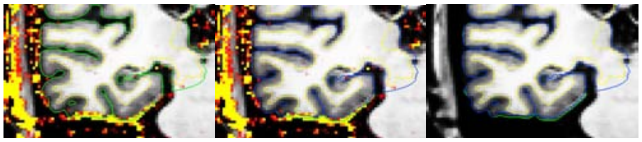

Figure 3: MEMPR with T2* estimate overlay and (left) cortical outer surface without correction for included dura, (middle) corrected cortical outer surface and (right) uncorrected and corrected cortical surfaces.

Conclusion

The acquisition times for MEMPR and MPR are equal. The same "optimal" contrast can be achieved with reduced distortion and comparable SNR and CNR (see Table 2). The MEMPR also provides T2* information, that may be used to segment dura from cortex. The MEMPR bandwidth can be matched to other scans in multispectral morphometry protocols so that they register precisely. MEMPR therefore provides considerable benefits over MPR with no apparent drawbacks.

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References

[1] Deoni SC et al, Magn Reson Med. 2003 Mar;49(3):515-26. [2] Mugler JP 3rd, Brookeman JR, Magn Reson Med. 1990 Jul; 15(1):152-7. [3] Mugler JP 3rd, Brookeman JR, J Magn Reson Imaging. 1991 Sep-Oct; 1(5):561-7. [4] Han X et al, NeuroImage. 2006 Aug 1;32(1):180-194. [5] Smith SM et al, NeuroImage. 2002 17(1):479-489. [6] Fischl et al, NeuroTechnique. 2002 Jan 33:341-355.