Comparison of Cortical Surface Reconstructions from MP2RAGE data at 3T and 7T

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Introduction: High field strengths such as 7T enable functional studies with submillimeter voxel sizes, but the analysis of this data over large areas of the folding cerebral cortex requires an accurate, co-registered cortical surface model. Detecting the gray matter boundary automatically and robustly can be challenging at 7T due to spatially varying image contrast between gray matter (GM), white matter (WM), and CSF imposed by flip angle variations across the head. This contrast non-uniformity, together with receive coil detection non-uniformity, can cause errors in the placement of the surface models at the cortical boundaries. Although a separate low-field study can provide the surface models, this requires a separate session and robust alignment procedures. Here we demonstrate that accurate surface models can be generated from 7T anatomical data with the recently introduced MP2RAGE pulse sequence [1] with some additional preprocessing steps prior to using the FreeSurfer software package [2, 3]. We compared the surfaces generated from 7T MP2RAGE data with those generated from 3T MP2RAGE data and 3T MEMPRAGE data [4]. We performed a test-retest analysis with the 3T data to quantify the reproducibility of the surface models and to estimate the precision of the surface reconstruction across the two acquisition methods.

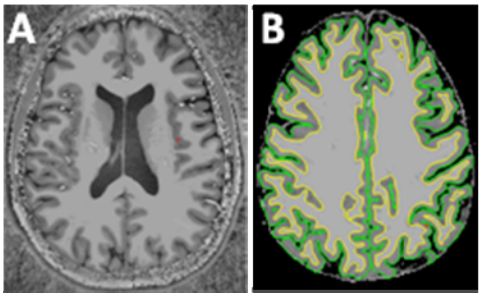

Fig. 1: (A) Flat image of 7T MP2RAGE. (B) Masked flat image with cross-sections of white matter and pial surfaces overlaid.

Methods: Six healthy volunteers were studied after Institutional Review and subject consent using a 7T Siemens scanner equipped with AC84 head gradients (80 mT/m, 400 T/m/s) and a custom-built 32-channel receive array [5]. The MP2RAGE protocol was based on the recommended 7T WIP protocol for 1 mm isotropic voxels [1]: TI1/TI2/TE/TR/flip/voxel/BW = 901ms/3201ms/2.82ms/5000ms/4° /240Hz/pixel. Because of the gradient nonlinearity of the head gradient, we applied the online gradient nonlinearity distortion correction for all 7T acquisitions. Two volunteers returned for a 3T (Siemens Trio) session during which we acquired MP2RAGE data with the recommended 3T WIP protocol for 1 mm isotropic voxels: TI1/TI2/TE/TR/flip/BW = 700ms/2500ms /2.96ms/5000ms/4°/240 Hz/pixel. We compared 3T images before and after the online gradient nonlinearity distortion correction and could not detect any differences. Therefore, this correction was not applied to 3T data. In the 3T session, we acquired two repetitions of MP2RAGE and MEMPRAGE data ("*repeats*"), then removed the subject from the scanner, fluffed the head pillow, and re-acquired both MP2RAGE and MEMPRAGE data ("*rescans*"), for a total of six volumes per session.

The MP2RAGE image reconstruction [1] consists of combining images from two inversion preparations to generate a "Flat Image", which produces spatially uniform tissue contrast but causes noise enhancement outside of the brain (see Fig.1A) that can introduce errors in the automatic segmentation of the brain. To remove this noise, we generated a brain mask by multiplying the Flat Image by the image from the second TI and applied it to the Flat Image data and re-normalized the intensities with a simple global scaling. After this preprocessing, we used FreeSurfer to generate cortical surface reconstructions of the MP2RAGE data. To quantify reproducibility of the surface models, we first aligned the volumes acquired in a given subject and calculated a vertex correspondence [6], then quantified the average distance between corresponding vertices between the WM surfaces or pial surfaces from the two acquisitions.

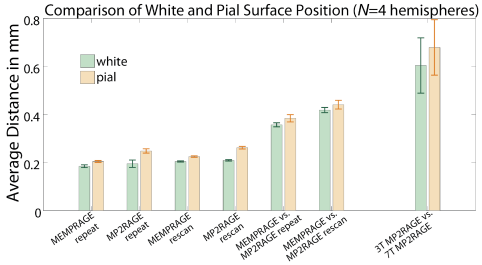

Fig. 2: Comparison of white matter and pial surface position across two subjects (four hemispheres). Error bars show population standard deviation across the hemispheres.

Results: The MP2RAGE acquisition provided anatomical images with high contrast between gray and white matter and between gray matter and surrounding CSF. Our additional preprocessing enabled accurate surface reconstructions with FreeSurfer, verified by manual inspection (see Fig. 1B). No edits or masking were required for the 3T MP2RAGE data. In five of the subjects, minor manual editing of the 7T data was required in the region of the temporal pole where residual intensity biases led to misclassification of white matter.

The average absolute thickness difference between the *rescan* 3T MEMPRAGE data was 0.18 mm, comparable to the value 0.12 mm from a previous study at 1.5T [6]. The average distance between surfaces generated from the "repeat" and "rescan" 3T acquisitions is summarized in Fig. 2. Figure 2 also compares the aligned surfaces of the 3T MP2RAGE to the 7T MP2RAGE. Pial surface position differences are consistently larger than that of the white matter surfaces for all comparisons (p<0.01, one-tailed paired t-test). Average reproducibility within the same pulse sequence was consistently ~0.2 mm. The largest effect on the distance across all comparisons was field strength; the next largest was differences between MEMPRAGE and MP2RAGE.

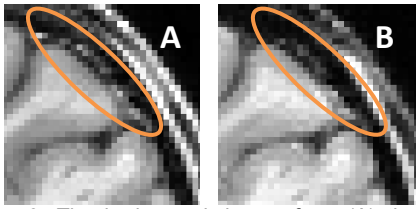

Fig. 3: The brain mask image from (A) the first echo (TE 1.61 ms) and (B) fourth echo (TE 7.17 ms) of a 7T four-echo MP2RAGE acquisition with bandwidth 657 Hz/pixel. Arrows indicate location where dura is less visible in the image with longer TE. Gray-white contrast is comparable in the two images despite the longer echo time.

Discussion: The MP2RAGE method, with some small preprocessing steps, can provide accurate FreeSurfer surface models from 7T data, yet the discrepancy between 3T and 7T surfaces is substantially larger than the intrinsic reproducibility of the surface generation. Therefore we are currently investigating whether 7T surfaces match 7T functional data with higher precision than surfaces acquired from a separate 3T session. Preliminary multi-echo MP2RAGE data (see Fig. 3) suggests that signal intensity from the dura (which can bias position estimates of the pial surface) can be reduced with longer echo times, as previously suggested [4].

References: [1] Marques *et al.* (2010) *NeuroImage* 2:1271-1281. [2] Dale *et al.* (1999) *Neuroimage 9*:179-194. [3] Fischl *et al.* (1999) *Neuroimage* 9:195-207. [4] van der Kouwe *et al.* (2008) *NeuroImage* 40:559-569. [5] Keil *et al.* (2010) *Proc. ISMRM* 18:1493. [6] Han *et al.* (2006) *NeuroImage* 32:180-194. **Acknowledgements:** Supported by NCRR P41 RR14075 and NIBIB R01EB006847.