Contrast between grey and white matter in 7 T phase images and its potential for segmentation

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Introduction

Small differences in the resonant frequency within different tissue compartments can be translated into measurable phase differences in gradient echo data [1], which may be used as a new source of tissue contrast. In this abstract, we explore grey/white matter contrast based on the phase of gradient echo MR images acquired at 7T. The phase shift between grey matter (GM) and white matter (WM) has been measured as a function of echo time and it is shown that this difference can be used to generate high contrast images at 7T. Furthermore we present an approach to segmentation of images into GM and WM compartments based on phase data and compare the results with those of a standard segmentation of T_1-weighted, MPRAGE image data using FSL (2). The phase images are generally phase wrapped and although unwrapping can be performed to preserve local phase shifts between regions of interest, the unwrapped images also show long-range variations in phase resulting from non-local field perturbations. To remove this effect a smoothed version of the unwrapped image can be subtracted from the phase data. Fourier based smoothing has the problem that the edges of the brain become blurred. For this reason we investigated as an alternative, smoothing using a two-dimensional, first order polynomial fit carried out over different sized regions.

Methods

Imaging was performed on a 7 T Philips Achieva system using a 3D spoiled-FLASH sequence with the following parameters: flip angle= 11°, *TR* = 45 ms, *TE*= 20, 25, 30 ms, which were found to generate a high contrast to noise ratio in the phase data. The image matrix size was 240 x 240 x 70 with 1 x 1 x 1 mm^3 voxel size. The phase images were unwrapped using PRELUDE within the FSL package (2). To remove large length-scale phase effects, the unwrapped images were smoothed using a first order 2D polynomial fit to nearest neighbours with different kernel sizes (squares with sides of length 3, 6, 10, 15 and 20 pixels). To evaluate the effect of kernel size on the GM to WM phase difference images were generated by subtracting the smoothed phase images from the unwrapped phase data and then plotting the difference in phase of grey and white matter regions found in relatively close proximity to one another as a function of the kernel size. The feasibility of segmenting GM and WM based on phase data was tested using the difference image produced from smoothing with a kernel of 3 pixels extent with *TE*=30 ms.

Results and Discussion

The averaged phase values in small regions of interest (ROI) in GM and WM, which lay in close proximity to each other were subtracted in the phase images. The ROI were selected in a region where the phase was not wrapped in the raw phase image, to allow confirmation that after unwrapping, the phase difference between GM and WM was unaltered. Figure 1 shows the effect of smoothing on the phase difference. It can be seen that smoothing with kernels of 10 pixels (i.e. 10 mm) or greater in size leaves the phase difference unaltered. The phase varies linearly with echo time, *TE,* following the simple equation $\Delta\varphi = -\gamma\Delta B \cdot TE$. Fitting the data points in Figure 1 to a linear variation with *TE* the difference in frequency between GM and WM regions is found to be 3.1 ± 0.5 Hz. Figure 2 shows the phase image used in the sementation test. A histogram of the values of the phase in a ROI (Figure 3), which contains both GM and WM, shows a tail running from 0.08 radians to higher phase values corresponding to GM pixels. In the "difference image" the voxels, which are in the range from 0.08 to 1 were therefore classified as GM (Figure 4 left). The quality of segmentation achieved with difference images formed using larger kernel sizes was poorer, because of the effect of residual long range phase variation. Figure 4 also shows the result of segmentation of the same slice based on MPRAGE data. Comparison of the two images shows that the phase-based segmentation produces a similar map of GM, but with clearer definition of the sulci.

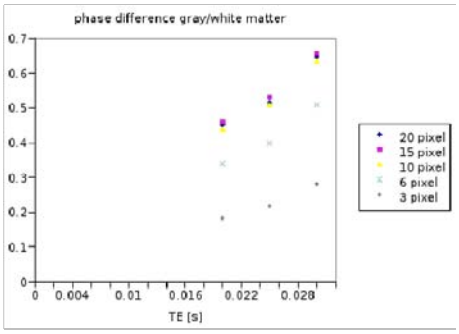

Figure 1: Phase difference of GM and WM as a function of *TE* and the extent of the smoothing kernel. The data points are based on the "difference image" = "unwrapped image" - "smoothed image". The GM and WM ROI's are localised very closed to each other (as shown in Fig. 2).

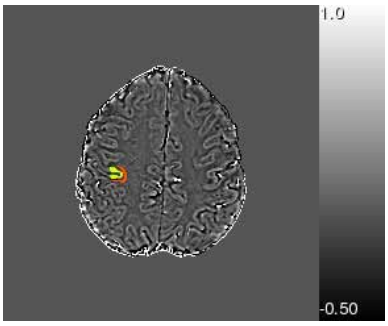

Figure 2: The "difference image" (*TE*=30 ms; smoothing with 3 pixel sized kernel) shows excellent contrast between GM and WM. The ROI's for GM (yellow) and WM (red), which are used for the calculation in Fig. 1 are indicated.

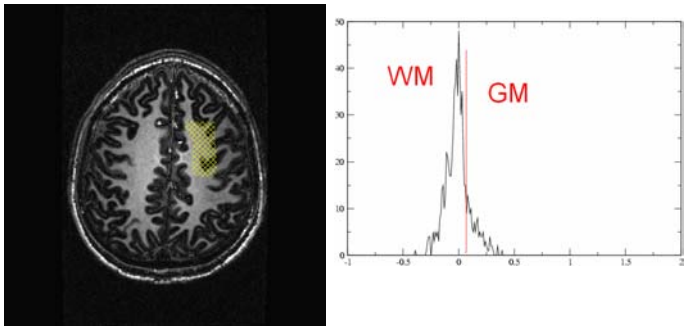

Figure 3: T_1-weighted MPRAGE image (left) and the ROI containing GM and WM, which is used for the histogram (right) discribed in the text.

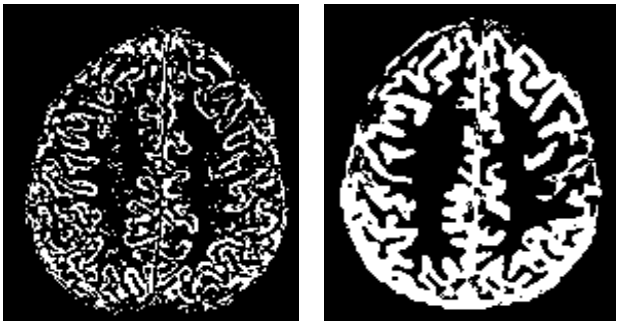

Figure 4: Improved segmention of GM based on the phase data (left) as compared to T_1 weighted images (right).

References

(1) Haacke EM *et al.* Magn. Reson. Med. **52**, 612-618 (2004) ; (2) Smith SM *et al.* Neuroimage **23** (S1), 208-219 (2004)