High Resolution Human Brain Susceptibility Maps Calculated from 7 Tesla MRI Phase Data

K. Shmueli[1], P. van Gelderen[1], T-Q. Li[1], and J. H. Duyn[1]

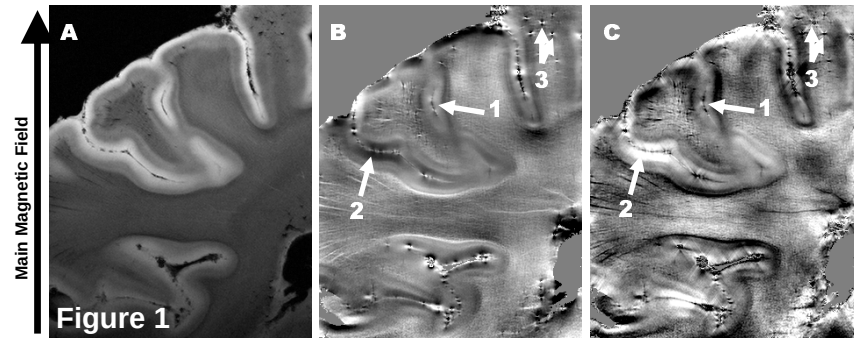
[1]Advanced MRI Section, Laboratory of Functional and Molecular Imaging, National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bethesda, Maryland, United States

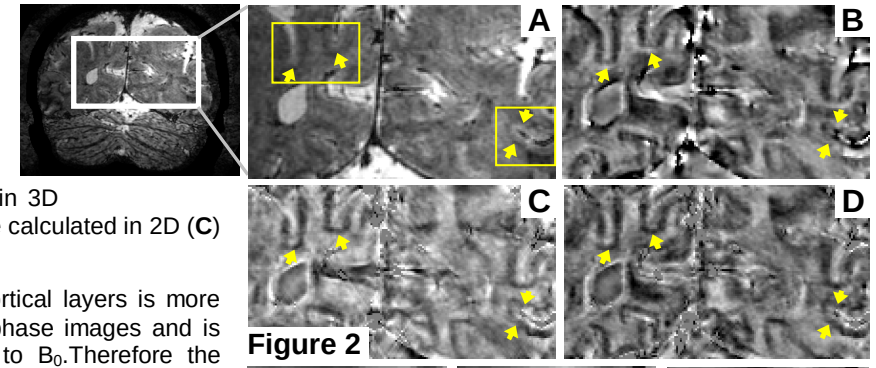
Introduction: Utilizing the phase in susceptibility-weighted MRI has yielded increased image contrast (**1**). However the phase is affected by tissue orientation, geometry and main magnetic field strength and phase changes extend beyond areas of altered susceptibility. Measurement of the underlying tissue magnetic susceptibilities is therefore desirable since the susceptibility is an intrinsic property of tissue that reflects its composition more closely than the MRI phase. Recent theoretical developments (**2-4**) make calculation of tissue susceptibilities from phase images a new prospect. Here we applied these methods to calculate susceptibility images from high-resolution phase images of the human brain (both ex vivo and in vivo).

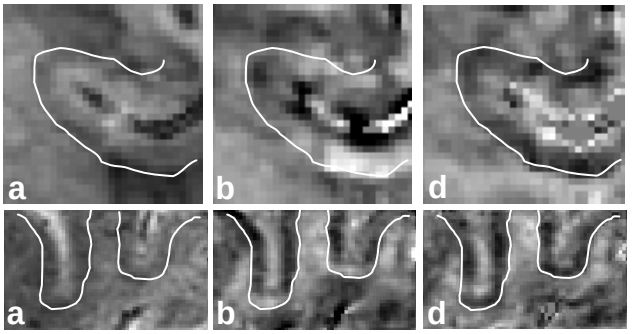
Methods: All images were coronal multislice gradient echo images acquired on a 7 Tesla GE system using 16 channels of a (Nova Medical) head coil. Images of a preserved human brain section in fomblin were acquired with 147 μm in-plane resolution, 0.5 mm slice thickness, 0.5 mm gap, 23.2 ms TE and 1.03 s TR. Here, 25 repeated images from a single coil were added together to increase the SNR. In vivo images of a normal volunteer's brain were acquired with 430 μm in-plane resolution, 0.5 mm slice thickness, 0.1 mm gap, 30 ms TE, 2.1 s TR (and SENSE rate 2). After unwrapping the phase by fitting polynomials up to order 5 (ex vivo) or using FSL prelude (**5**) (in vivo), macroscopic background phase variations were removed by subtracting either the fitted phase (ex vivo) or the phase smoothed with a 10-voxel-wide boxcar average (in vivo). Regions (such as blood vessels) in which |residual phase| > π-2 were masked with zeroes as this had been found to reduce artifacts in the susceptibility maps. The equation below (**2-4**) was applied to sub-sections of the resulting residual phase images, where FT denotes a Fourier Transform, χ is the susceptibility, ϕ is the image phase, γ is the proton gyromagnetic ratio, B_0 is the main magnetic field strength, k_z is the z-component of k-space, and $K^2 = k_x^2 + k_y^2 + k_z^2$. To avoid problems as K^2 tended to zero, the k-space deconvolution filter was truncated at a value of 1. Calculations were performed using 2D and 3D regions of phase data with a 2D and 3D FT respectively.

$$\chi = FT^{-1}\left[FT\left(\frac{\varphi(x,y,z)}{-\gamma * B_0 * TE} \right) * \left(\frac{1}{\frac{1}{3} - \frac{k_z^2}{K^2}} \right) \right]$$

Results: **Figure 1** shows the 2D region from images of the preserved human brain in which the susceptibility was calculated. The magnitude image (**A**) shows standard susceptibility-weighted or T_2* contrast while the phase image (**B**) (scaled between ± 7 Hz) shows variable contrast: the most superficial cortical layer is bright and the deeper layer is darker when they run parallel to B_0 (arrow 1). However this contrast is reversed when the layers are perpendicular to B_0 (arrow 2). The contrast of these layers is more consistent in the susceptibility image (**C**) (scaled between ± 13 x 10^{-9}) in which alternating phase patterns around vessels (or other small regions of altered susceptibility) appear as small homogenous regions (arrows 3). **Figure 2** shows one coronal slice from the 3D region in which the in vivo susceptibility of human brain was calculated. A dark band near the GM-WM border (arrows and tracings in zoomed images **a, b** and **d**) is more clearly visible in the susceptibility image calculated in 3D (**D**) (± 18 x 10^{-9}) than in either the susceptibility image calculated in 2D (**C**) or the magnitude (**A**) or phase (**B**) (± 5 Hz) images.







Images **a, b** and **d** are zoomed regions (yellow boxes) of **A, B** and **D**: magnitude, phase and susceptibility calculated in 3D

Discussion and Conclusions: The contrast of cortical layers is more consistent in the susceptibility images than in the phase images and is independent of the structures' orientation relative to B_0.Therefore the susceptibility images seem to overcome some of the shortcomings of phase images. Figure 2 shows that using 3D data for the susceptibility calculation improves the conspicuity of cortical layers in the images. This new source of contrast shows promise for revealing fine scale brain structure. Further work is necessary to determine the most widely applicable parameters for smoothing the phase data and truncating the deconvolution filter.

References: **1.** J.H. Duyn et al. *PNAS* **2007**, 104(28), 11796-801 **2.** E.M. Haacke et al. *MRI* **2005**, 23, 1-25 **3.** J.P. Marques and R. Bowtell *Conc. in MR* **2005**, 25B(1), 65-78 **4.** R. Salomir et al. *Conc. in MR* **2003**, 19B(1), 26-34 **5.** M. Jenkinson *MRM* **2003**, 49(1), 193-7 and http://www.fmrib.ox.ac.uk/fsl/