The Dependence of Tissue Phase Contrast on Orientation Can Be Overcome by Quantitative Susceptibility Mapping

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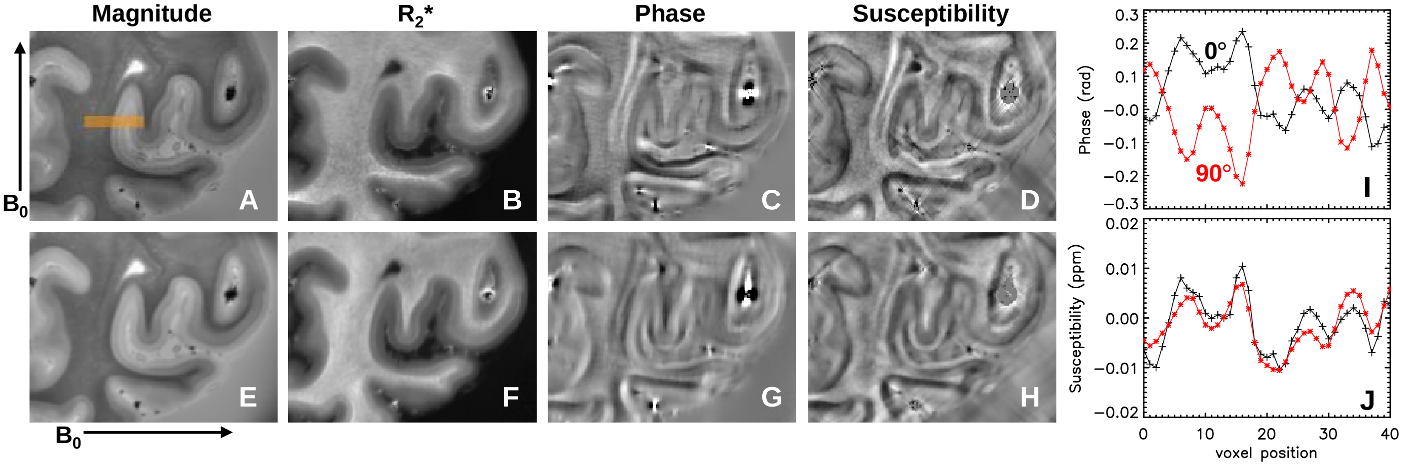
Introduction: The interpretation of gradient-echo phase images is confounded by the dependence of the contrast on the tissue orientation relative to the main magnetic field (B_0). To mitigate this, methods have been proposed to reconstruct the underlying tissue magnetic susceptibility from the phase data (**1-3**). To assess the effectiveness of this approach, we evaluated the similarity of susceptibility maps of brain tissue samples calculated from phase images acquired at varying angles (0° and 90°) relative to B_0.

Methods: Coronal multislice gradient-echo images of preserved human brain tissue sections (from a person with no history of neurological disease) were acquired in a 7 Tesla GE system using a custom-built 8-channel receive-coil array. Images of the occipital lobe sections were acquired with 200 µm in-plane resolution (800 x 800 matrix), 400 µm slice thickness, two echoes at TE = 22.0 and 50.9 ms, 5 s TR for 50 slices, and a readout time of 32 µs per sample. Ten-fold averaging was performed to improve the signal-to-noise ratio. The tissue sample was rotated by 90° about the vertical 'y' axis (that is perpendicular to the B_0 or 'z' axis) and the imaging was repeated with identical parameters. The complex data from the 8 coils were combined using a SENSE algorithm. Small shifts between the ten repetitions were corrected by coregistration of the magnitude images using FSL FLIRT (**4**). The phase of the first echo was used to create phase images. To remove the macroscopic background phase variation and, thereby, phase wraps, spatial high-pass filtering (homodyne filtering) was performed by subtracting from the original data, the complex data smoothed with a Gaussian filter of FWHM = 50 voxels. The filtered phase images from each repetition were coregistered (by applying the transformation matrices calculated from coregistration of the magnitude data) and averaged. A volume of interest (VOI) was selected and the susceptibility in it was calculated from the phase images using the inverse Fourier method (**1-2**) with a k-space deconvolution filter cut-off value of 5 (**3**) and a phase threshold of ± 0.5 rad to reduce streaking artifacts from air bubbles. R_2^* maps were calculated from the averaged coregistered magnitude data. The 90° R_2^* map in the VOI was coregistered to the 0° R_2^* map in the same VOI using FLIRT for linear registration followed by AIR (**5**) for non-linear registration. The resulting coregistration transformations were applied to the 90° phase, magnitude and susceptibility images. For the orange region in Figure A (8x41 voxels), a straight line was fitted to a scatter plot of the voxel values in the 90° image against those in the 0° image and the correlation between the voxel values was calculated.



Results: Figures A to H show a slice from the coregistered VOI in the visual cortex of the preserved brain. At least two cortical layers and white matter structures are visible in this region. The top row (**A-D**) shows images acquired at 0° to B_0 and the bottom row (**E-H**) shows images acquired with the tissues rotated by 90° (in-plane). A strong dependence of the phase pattern on orientation is observed (**C**,**G**), consistent with a susceptibility-dominated contrast mechanism. Phase and susceptibility profiles along a horizontal line within the orange region in **A** are shown in **Figures I and J**. The phase image contrast (**C**,**G**,**I**) often appears reversed by the 90° rotation whereas the contrast in the 0° and 90° susceptibility images (**D**,**H**,**J**) is nearly identical. The results of linear fitting and correlation of voxels in the orange region are shown in the table. All the correlation coefficients (r) are highly significant ($n = 328$, $p<10^{-68}$).

Contrast	gradient	intercept	r
Phase (rad)	-1.04	0.065	-0.84
Susceptibility (ppm)	0.71	-0.0008	0.78
R_2^* (Hz)	1.26	-6.4238	0.99
Magnitude (a.u.)	1.19	-0.2130	0.98

Discussion and Conclusions: The high similarity (large gradient and strong correlation) of the 0° and 90° susceptibility maps demonstrates that the susceptibility calculation overcomes the strong orientation dependence of the phase images. It also supports the hypothesis that tissue susceptibility differences are the main source of the phase contrast between cortical layers, and cortical gray and white matter structures. The 90° images (**E-H**) appear slightly smoother than the 0° images (**A-D**) because of the coregistration applied to the former. This data provides evidence that the susceptibility calculation yields an orientation-invariant tissue property: relative susceptibility. Independent susceptibility measurements are needed to validate the tissue susceptibility values.

References: 1. J.P. Marques and R. Bowtell *Conc. in MR* **2005**, 25B(1), 65-78 **2.** R. Salomir et al. *Conc. in MR* **2003**, 19B(1), 26-34 **3.** K. Shmueli et al. *Proc. ISMRM* **2008**, 642 **4.** M. Jenkinson et al. *NeuroImage* **2002**, 17(2), 825-841 **5.** R.P. Woods et al. *JCAT* **1998**, 22, 139-152