Susceptibility Weighted Imaging: Why is the negative phase mask so successful in highlighting veins independent of their orientation?

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Introduction: Practically Susceptibility Weighted Imaging (SWI) is a powerful new method for highlighting veins and micro-hemorrhages in MRI. It is usually run only in the transverse orientation and a negative phase mask is applied to enhance the CNR in magnitude images. However, the mechanism behind the practice remains unclear. We simulate the phase behavior of vessels as a function of resolution, vessel size and acquisition orientation. By simulating the phase behavior, we examine the optimal resolution and acquisition orientation to maximize the contrast in the phase image and in turn to better enhance the contrast in the magnitude image.

Materials and methods: We model a vessel with a diameter less than the in-plane resolution as an infinitely long cylinder perpendicular to the main magnetic field. The net phase of a voxel containing the vessel is obtained from the phase of the complex sum of the signal from the vein and the phase from the tissue surrounding it. For the intra-vascular field, the field difference, ΔB_{in} can be written as

$$\Delta B_{in} = -4\pi\chi_{do}B_0(1-Y)Hct/6 \qquad (1)$$

where $\chi_{do} = 0.18x10^{-6}$ is the susceptibility change between de-oxygenated and oxygenated blood, B_0 is the main static field strength, Y is the fractional oxygen saturation of the blood in the vessel, and Hct is the fractional haematocrit. For the extra-vascular field, the field difference ΔB_{out} can be written as

$$\Delta B_{out} = 4\pi\chi_{do}\cos 2\phi B_0(1-Y)Hct/2 \qquad (2)$$

where ϕ is the polar angle between the position P in the voxel to the the main static magnetic field B_0 with the center of the vessel serving as the origin. The area surrounding the vessel is then divided into sub-pixels to sample the complex signal from the analytic solution. Phase and magnitude of the voxel are calculated by complex average of all the sub-pixels within the voxel. The in-plane signal is predicted by summing over the complex signals adjacent to the vessel. In these simulations we take B_0=1.5T, TE = 40ms, Hct = 0.45 and Y = 0.55 for veins in the brain.

Results and discussions: The complex signal summations make it possible to predict the in-plane signal response as shown in Fig. 1. The radius is taken to be 25 units and the in-plane resolution w 50, 100 and 200 units with the through plane thickness h of 200 or 400 units. When h=200 units, this corresponds to a vessel of diameter ¼ that of the slice thickness. For this case the in-plane resolution is then either the same as or twice that of the diameter of the vessel. These conditions scale to the usual transverse SWI acquisition of 0.5mm x 1.0 mm x 2.0mm and a vessel of 0.5mm similar to pial veins in the brain. When the in-plane resolution is the same size as the vessel the phase is dominated by the phase along the slice thickness (i.e. along the main field B_0) which is negative (despite the fact that the phase in the vessel is itself positive). The partial volume of these two components then leads to a negative phase as shown in Figure 1 for the voxel centered on the vessel. Using the special phase processing of SWI which uses only negative phases, the contrast of these vessels is enhanced as shown in Figure 2. Note that the case of w=100 and h=200 corresponds to a lower resolution image of the vessel and that the phase is much less negative than the case when w=50 and h=200. The former is shown in Figure 2a (horizontal arrow) and the latter in 2b (vertical arrow) where the vessel perpendicular to the read direction is now beautifully shown thanks to the dramatic phase effect.

Conclusions: In gradient echo imaging, the phase in the image is a function of vessel size, imaging resolution and acquisition orientation.

References: 1. J. R. Reichenbach et al, Small Vessels in the Human Brain: MR Venography with Deoxyhemoglobin as an Intrinsic Contrast Agent. Radiology 1997; 204:272-277. 2) J. R. Reichenbach et al, High-Resolution Venography of the Brain Using Magnetic Resonance Imaging. MAGMA 1998;6(1):62-69. 3) J.R. Reichenbach et al, High-Resolution MR Venography at 3 Tesla" JCAT 24; 949-957, 2000. 4) K.A. Tong et al, Improved detection of hemorrhagic shearing lesions in children with post-traumatic diffuse axonal injury: Initial results. Radiology 227: 332-339; 2003.

Figure 1

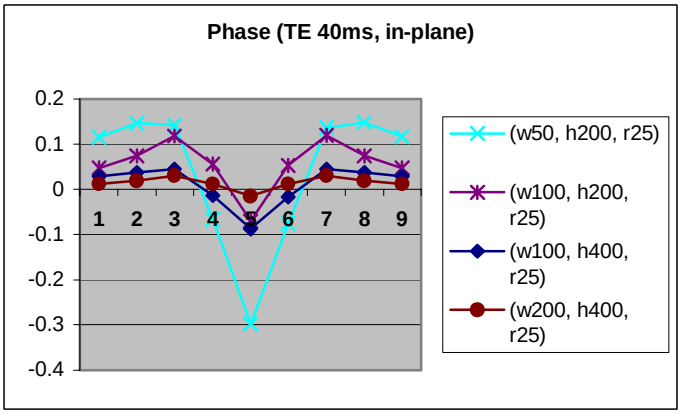

Figure 2a

Figure 2b

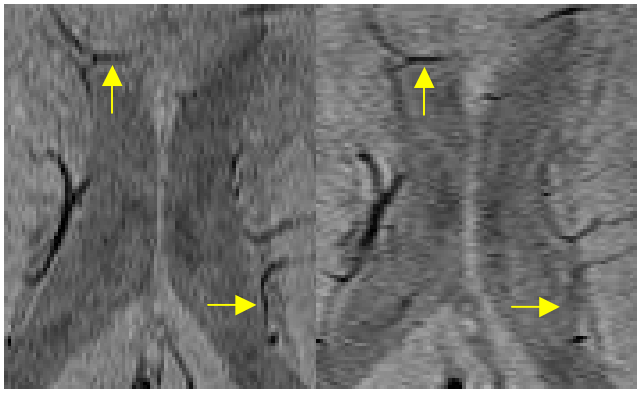

Figure 1 A plot of the phase as a function of in-plane voxel location relative to the center of the vessel (pixel 5) for different resolutions and slice thicknesses.
Figure 2 a) an SWI image with the in-plane resolution 0.5mm x 1.0mm (horizontal versus vertical) and b) an in-plane resolution of 1.0mm x 0.5mm.