Optimization of Phase Contrast in Susceptibility Weighted Imaging at 7T

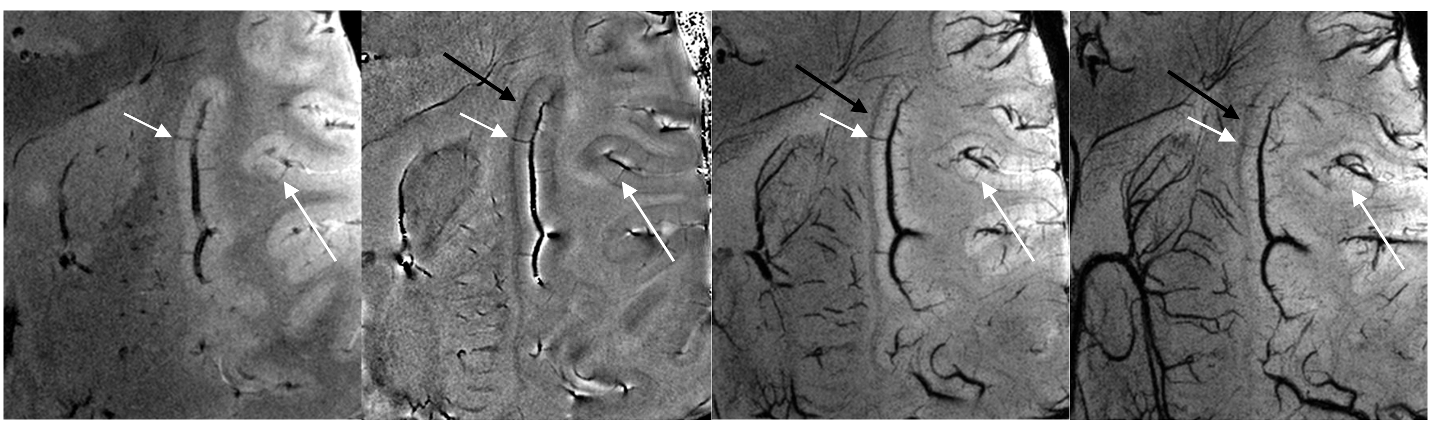
Y. Ge[1], S. Barnes[2], Y. Xu[2], J. Neelavalli[2], R. I. Grossman[1], and E. M. Haacke[2]
[1]Radiology, New York University Medical Center, New York, NY, United States, [2]Biomedical Engineering, Wayne State University, Detroit, MI

Introduction: Ultra-high field MR imaging has been utilized to take advantage of the higher resolution and markedly enhanced susceptibility effect for visualizing small venous structures (1, 2). The identification of venous blood in the cerebral cortex will be useful to improve the spatial specificity in BOLD fMRI. The goal of this work is to image and differentiate the small cortical veins (on the order of 250μ) and venules (on the order of 50μ) in the cerebral cortex regions using a high resolution 3D susceptibility weighted imaging (SWI) sequence at 7T. We describe the best way to collect this data with optimal signal and contrast-to-noise.

Materials and Methods: A series of 4 volunteers were run to evaluate the optimal imaging parameters to best visualize veins and venules as well as structures with small susceptibility differences within the cerebral cortex. A 7T whole-body human MR system (MAGNETOM, Siemens, Erlangen, Germany) was used with maximum gradient strength of 72 mT/m and a slew rate of 200 T/m/s. A head coil (Nova Medical Inc., Massachusetts) designed for 7T with 24-element array was used. A velocity compensated 3D gradient echo sequence was used to generate susceptibility weighted images with a high sensitivity to iron content and deoxyhemoglobin. The SWI filtered phase images were used as a means to both image susceptibility contrast between tissues and as part of the SWI process to enhance contrast in the magnitude images. TR, TE, BW and FA were varied from 30-45ms, 14-26ms, 90-140Hz/pixel and 10-20^o, respectively. Slice thickness was varied from 600μ to 1mm and in-plane resolution from 215μ to 300μ. Using a series of echo times, we measured T2* of venous blood to be 18ms. Theoretically, setting TE = T2* should yield the best contrast in SWI phase filtered images (2, 3). The optimal flip angle for GM and WM at 7T is roughly 12^o and 15^o, respectively. Hence, FA between 10^o and 20^o were used in this study.

Results: We found that the best contrast-to-noise to visualize the principal cortical veins was obtained for TE = T2* of venous blood and a resolution of 215μ to 300μ (Figure 1). The best image quality occurred for TE=15ms, TR=30ms, BW=120Hz/pixel and FA=10°. Alternatively a higher flip angle (15 °) may give slightly better results at the edges of the slab (due to RF fall off) and in the center of the image (due to B_1 inhomogeneities). While longer echo times did increase some contrast in the phase image, the image quality actually decreased due to increased noise, blurring of small vessels, and artificial enlargement of large vessels all caused by increased dephasing. Thicker slices (1mm vs. 600 μ) gave a nice boost to SNR and theory predicts this aspect ratio (1x1x4) to be optimal for 250μ vessels. The boundary separating the gray matter and white matter in the subcortical region surrounding the gyri is also clearly shown and may be due to the myelinated arcuate fibers.

Discussion and conclusions: At 7T, with optimized high resolution and high contrast SWI phase images, small cortical veins that are not visible on conventional lower field MR systems can be directly seen. An early theoretical calculation by Cheng and Haacke (4) shows that structures much smaller than a voxel can often be visualized with a volume fraction of 0.25 or less depending on the local susceptibility difference. In this case, a resolution of 215μ has made it possible to visualize the venules which are 50μ to 100μ in size.



(a) (b) (c) (d)

Figure 1: Original SWI magnitude image (a) showing bright GM and dark veins, SWI filtered phase image (b) showing the deep cortical veins (white arrows) and the arcuate fibers (black arrows) separating the GM/WM, and SWI mIP images over four (c) and eight (d) adjacent slices. Note the elimination of the remnant dipolar effect around the vein in the processed images. The mIP over eight shows enhanced connectedness of veins but smaller vessels are lost. It is always best to look at the original slices despite the unremoved dipolar artifacts. Venules are shown by the white arrows and the arcuate fibers by the black arrows. The venules and arcuate fibers are shown more clearly in the SWI filtered phase and processed mIP images than the original magnitude image.

References: (1) Reichenbach et al, Radiology, 204, 272, (1997). (2) Haacke et al, MRM, 52, 612, (2004). (3) Haacke et al, JMRI, 26, 256, 2007. (4) Cheng et al, NMR in Biomed, 14, 468, 2001.