Achieving Heightened Contrast in Magnitude, Phase, and Susceptibility-Weighted Brain Images at 7T

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Introduction: The utility of Susceptibility-Weighted Imaging (SWI) and phase imaging for evaluating pathology and the effects of treatment has been shown throughout the literature at various field strengths[1-3]. Both are valuable techniques for high-resolution imaging of brain tissue that have greatly benefitted from the emergence higher field strength MR scanners. Since both methodologies take advantage of the same underlying mechanism for detecting susceptibility shifts in the B0 field caused by paramagnetic iron in residual blood products, they can be generated from the same T2*-weighted gradient echo sequence. However, at 7T, the imaging parameters for each technique have been developed separately, often at various institutions and utilizing either 2D or 3D acquisitions, and it has not been established when it is most appropriate to use magnitude, phase, or SWI. Having a single scan is important in patient studies to minimize costs, patient discomfort, and motion. The goal of this study is to optimize a single high-resolution gradient-echo acquisition for the reconstruction of conventional magnitude, phase, and susceptibility-weighted images in order to determine which image acquisition protocol yields the best contrast both between gray and white matter and for microvasculature detection in normal-appearing brain tissue. Heightened gray-white matter contrast is important for the accurate segmentation required for volumetric estimates while elevated microvascular contrast is necessary for early detection of neovascularization and microbleed formation.

Methods: High-resolution, phase-sensitive GRE imaging was performed on 6 volunteers using a GE whole body 7 Tesla scanner (GE Healthcare) with volume excitation and 8-channel phased-array reception (Nova Medical). All scans were acquired twice, at three different TEs, 9,12, and 15ms, with a 20° flip angle, 512 x 256 image matrix, 22cm FOV, 2mm slice thickness, and reconstructed to a 0.43×0.43 mm in-plane resolution. For three volunteers, a 2D sequence was utilized with 250ms TR, while the other 3 volunteers were scanned using a 3D GRE sequence with 50ms TR. Three excitations and 22 slices were acquired for the 2D acquisitions to match the 6.5-minute scan time and coverage of the 3D sequence. Magnitude, phase, and SWI images were reconstructed using methods described in previous studies[1,2]. Minimum intensity projected (mIP) images with 10mm thickness were also created for each image. ROIs of white matter, gray matter, and veins (Fig 1) were defined on phase images using a combination of FSL routines[4] and in-house software. Noise in the ROIs was calculated using the root-mean-square of the difference in calculated voxel values between two successive identical acquisitions[5] for each of the magnitude, phase, and SWI images. Contrast-to-noise ratio (CNR) between two ROIs was calculated as the difference in mean values between ROIs divided by the larger noise. CNR was evaluated between gray and white matter using the original images, and between veins and surrounding brain parenchyma using the mIP images.

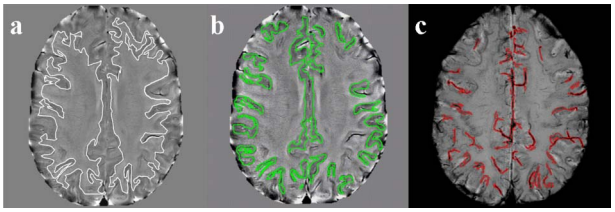

Figure 1. ROI contours of (a) white matter, (b) grey matter, and (c) veins on phase images.

Results and Discussion: The average CNRs of gray to white matter and veins to surrounding brain parenchyma at different TEs from both 2D and 3D scans are shown in Figure 2 (a) and (b), respectively.

2D vs. 3D: CNRs from the 2D scans were generally higher than those from 3D scans regardless of TE. The only exception was CNR between white and gray matter on SWI, which gave similar CNR for both 2D and 3D scans. After averaging over all TEs, the CNR increased by 30.3% from 3D to 2D scan between gray and white matter on phase image; and by 35.3% between veins and surrounding parenchyma on SWI. Figure 3 shows an example of the improved contrast attained with the 2D scan. This result suggests that CNR does not necessarily scale similarly to SNR.

Magnitude vs. Phase vs. SWI: Phase images generated the highest contrast between gray and white matter (CNRs were 3.3 and 2.3 times higher than that of SWI for 2D and 3D, respectively), which was consistent between both 2D and 3D scans, as well as among all TEs. The CNR from magnitude and SWI images were similar in the 2D scans across all TEs, while for the 3D scans the CNR was higher for the SWI than the magnitude images at all TEs. The highest CNR between veins and surrounding brain tissue was achieved when using SWI, with CNR values 1.6 and 1.7 times as much as that of phase image for 2D and 3D, respectively. This result was observed for both 2D and 3D scans and among all TEs.

TE of 9ms vs. 12ms vs. 15ms: CNR values for both 12 ms and 15 ms TEs were approximately twice as large as values obtained from images acquired with a TE of 9 ms for both 2D and 3D acquisitions. In the 2D scans, TEs of 12ms and 15ms gave comparable CNR for gray-white matter, while a 15ms TE gave a slightly higher CNR for veins. For the 3D SWI acquisitions, a 12ms TE was found to have slightly elevated CNR values for both grey-white matter and vessel contrast.

Conclusions: For optimal high-resolution, T2*-weighted brain imaging at 7T, a 2D GRE sequence with an echo time between 12-15 ms should be utilized. Phase imaging had the best contrast between gray and white matter and therefore should be used for automatic segmentation routines and volumetric measures. SWI images were best for visualizing vasculature and should be generated for early detection of microbleeds or angiogenesis. Future studies will focus on assessing the performance of phase unwrapping algorithms and confirm these parameters in patients with varying tumors and treatment strategies.

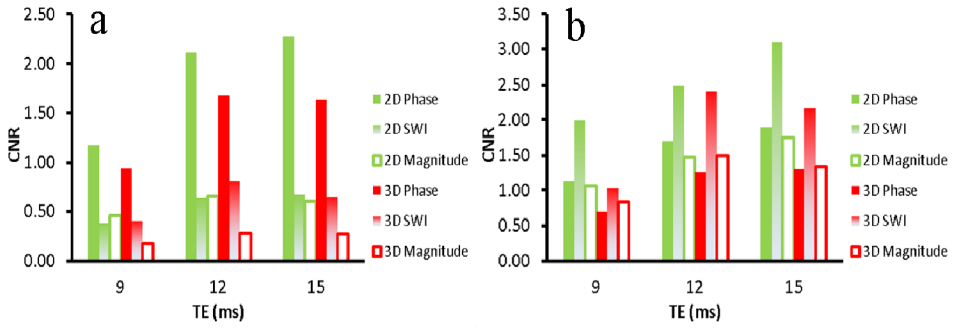

Figure 2. CNR values for (a): gray vs. white matter; (b) veins vs. surrounding parenchyma at 3 different TEs

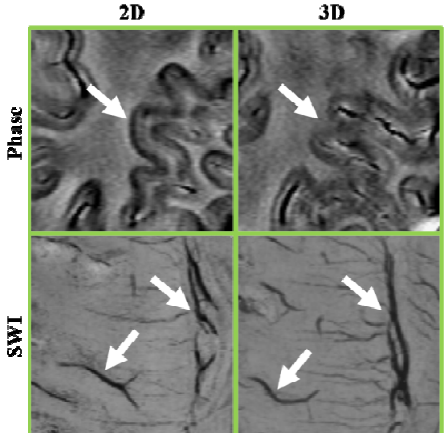

Figure 3. A 2D scan (left) and a 3D scan (right) from two volunteers. It is noted that gyri and veins (arrows) are better visualized on 2D phase image (top row) and mIP of SWI (bottom row).

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