An Improved Susceptibility Weighted Imaging Method using Multi-Echo Acquisition

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Introduction

Susceptibility weighted imaging (SWI) is a method to emphasize susceptibility difference among tissues in the brain and commonly used for venography [1]. To generate a SWI image, T_2^*-weighted image is multiplied by a filtered phase mask. However, nonlocal field inhomogeneity from air-tissue interface (e.g. nasal sinus and ear canal) introduces magnitude signal dropout and phase wrapping artifact in orbitofrontal and temporal cortices hampering the ability to visualize the structures in these areas (Fig. 2G). In this abstract, we propose a novel method to overcome these artifacts. Both magnitude and phase artifacts are compensated.

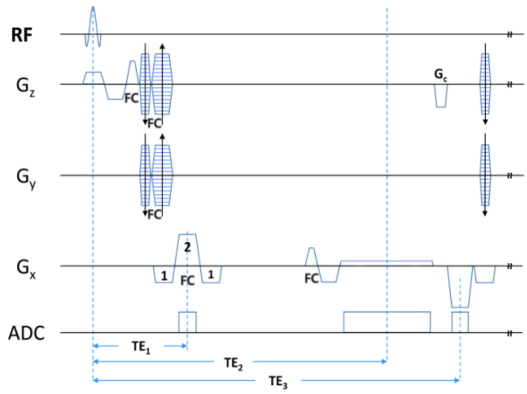

Figure 1 Proposed MRI sequence

Method

For the new SWI method, a sequence with z-shimming was developed (Figure 1). The sequence is based on a flow-compensated 3D GRE. Instead of acquiring a single echo, 3 echoes were acquired. Among them, the 2nd echo is the main echo that has the same TE and BW as conventional SWI. To compensate for flow artifacts, the 1st and 2nd echoes were flow-compensated (FC). The third echo was not flow-compensated to minimize a TR increase from the third echo. Before the 3rd echo, a z-shim gradient (G_c) was applied to compensate for the field inhomogeneity induced signal dropout.

***Phase processing*:** Figure 2 shows the phase processing steps for the proposed method. The 2nd echo phase was first unwrapped using Laplacian unwrapping (Fig. 2B) and then fitted with a Gaussian model (Fig. 2C) to remove large scale field variation ($\mathrm{argmin}_{\chi_B} \|W(f - G \otimes \chi_B\|$, where χ_B: the source distribution of Gaussian field, f: obtained phase and G: Gaussian field). After that, a conventional homodyne high-pass filter was used to refine the phase image (Fig. 2D) which was followed by a negative phase masking for SWI (Fig. 2E). This process significantly improves SWI image by removing phase mask induced image artifacts (Fig. 2G, blue arrow). However, the signal in the front lobe is still unrecovered due to magnitude (Fig. 2F).

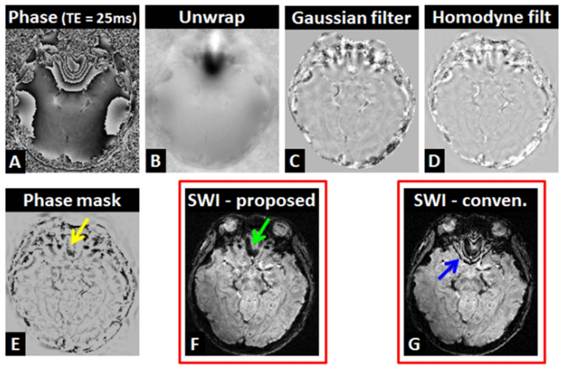

Figure 2 Phase processing

***Magnitude processing*:** To further improve SWI images, magnitude signal was processing using the three echoes (Fig. 3). The brain region was divided into two regions with or without the susceptibility artifact using the unwrapped phase image. For the region with no artifact, the 2nd echo image was used. In the region with the susceptibility artifact, the signal was estimated from a non-linear curve fitting using the three echo magnitude images. In this process, M_0, R_2^* and $G_{z,sus}$ (a gradient by susceptibility in through-plane z direction) were estimated iteratively in each voxel ($S(TE) = M_0 \cdot \exp(-TE \cdot R_2^*) \cdot A((G_{z,sus} - G_{c,eff}) \cdot TE)$) [2]. Then the signal at the 2nd echo time (TE = 25 ms) was calculated. Once the magnitude images were generated in each region, they were combined (summed) to generate an artifact free image (Fig. 3F). Since the magnitude signal drop out area has no phase information, the resulting SWI does not have a susceptibility-weighted phase mask in the area. In our method, the phase mask in this area was separately generated from the first echo phase (the 3rd echo phase was less reliable although it has more susceptibility weighting). The first echo phase was processed the same as the 2nd echo (Fig. 2) after scaling the phase image by TE2 / TE1. Then the new phase mask was used for the susceptibility artifact region (the area in Fig. 3D) whereas the phase mask from the 2nd echo was used for the other regions of the image. Hence the resulting SWI images had similar susceptibility-weighting in all regions. Finally, SWI image was generated from the multiplication of the magnitude image (Fig. 3F) and 4th power of the combined phase mask. The MR images were obtained at a 3T scanner (ISOL, Korea) from 17 subjects (IRB approved). The imaging parameters were as follows: TR = 50 ms, TE = [8.7, 25.0, 32.1, 35.9] ms, matrix size = 220 x 220 x 48, FOV = 220 x 220 x 57.6 mm³.

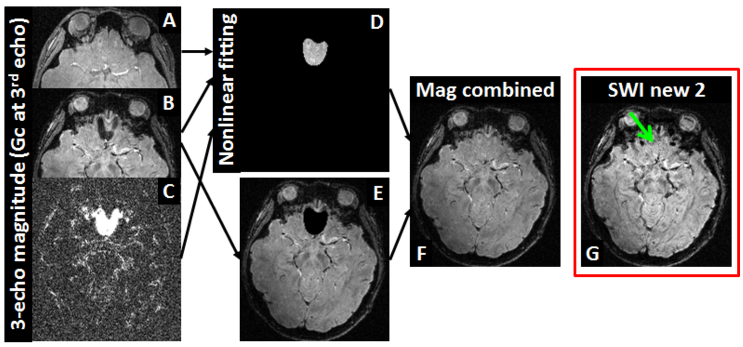

Figure 3 Magnitude processing

Results

The new phase processing removed the phase wrapping artifacts (Fig. 2F vs. Fig. 2G, blue arrow). The combined magnitude image (Fig. 3F) shows no dropout area in the orbital frontal cortex. By using these results and the phase mask (from the first echo) in the artifact region, an improved SWI image is generated (Fig. 3G). Figure 4 shows minimum intensity projected images from the conventional SWI and the proposed method. A vessel (red arrow in Fig. 4B and D) in the orbitofrontal area is not visual in the conventional SWI but is clearly distinguished in the proposed method (Fig. 4A and C).

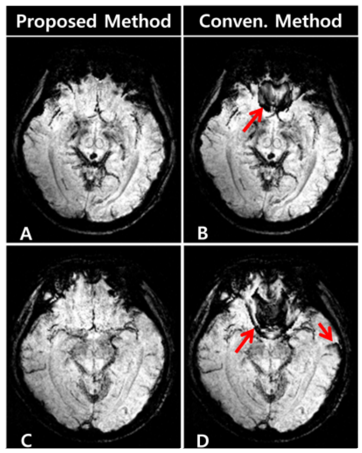

Figure 4 mIP images

Discussion

One of the advantages of the new sequence is the flow compensation up to the 2nd echo which reduced image artifacts (image not shown). Another important advantage is a minimum increase in the total scan time. The time for the G_c gradient and 3rd echo is only 3.2 ms. When a minimum TR is used, the increase in scan time is approximately 10%. Hence the proposed method substantially improves the quality of SWI at a nominal increase in scan time.

References

[1]Haacke et al., MRM, 2004, [2] Nam et al., NeuroImage, 2012