A method for macroscopic B0 field inhomogeneity compensated SWI using 3D z-shim multi-echo GRE

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Purpose Susceptibility weighted imaging (SWI) based on GRE provides enhancement of susceptibility difference which is useful for visualization of vein, micro-hemorrhage and iron deposition. However, GRE suffers from the macroscopic B_0 inhomogeneity due to air/tissue boundary and this effect is shown as SNR loss both in magnitude and phase. Previously, 3D z-shim multi-echo GRE (mGRE) pulse sequence[1] demonstrated that z-shimming can successfully recover both magnitude and phase SNR loss (Fig. 1 red arrow) due to B_0 field inhomogeneity. Here, an improved algorithm for B_0 field inhomogeneity compensated SWI, applicable to both magnitude and phase, is proposed using the 3D z-shim mGRE sequence[1].

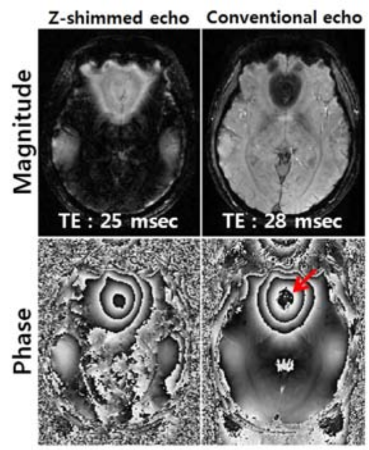

Figure 1. Acquired images from the 3D z-shim multi-echo sequence[1].

Methods The 3D z-shim mGRE sequence collects both conventional echoes (odd echoes) and z-shimmed echoes (even echoes) in a single-scan. Using these echoes, both magnitude and phase data without field inhomogeneity were generated by the proposed algorithm shown in Fig. 2.

Phase processing To acquire B_0 field inhomogeneity compensated field map, a phase combine method[1] between conventional and z-shimmed echo was used. Background field removal method (PDF[2]) was applied to acquire local field map (LFM). Then, local phase value at specific TE (echo time) was estimated using equation described in Fig. 2 (γ: gyromagnetic ratio, B_0 : 3 [T]). This local phase avoids wrapping artifact in SWI process (Fig. 3 phase mask).

Magnitude processing The field map obtained by the previous process is not only useful for acquiring accurate local field information but also for R_2^* fitting. This is because magnitude loss due to B_0 field inhomogeneity can be modeled as a function of the field inhomogeneity (e.g. voxel spread function (VSF) method[3]). The VSF method which is appropriate for 3D mGRE was modified to incorporate the z-shimmed echo signals and was applied for R_2^* fitting to acquire M_0 and R_2^* values. Afterwards, macroscopic B_0 field inhomogeneity compensated magnitude was estimated using a mono-exponential model as shown in Fig. 2.

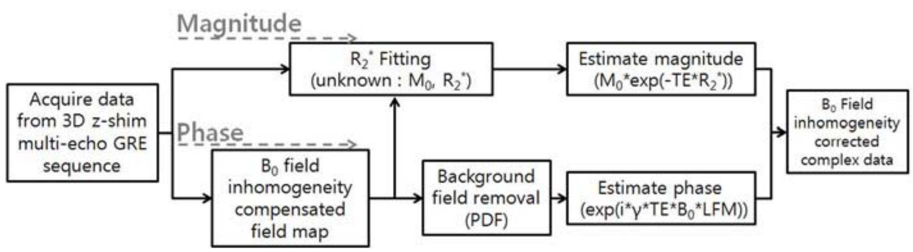

Figure 2. Diagram of the proposed algorithm which generates B_0 field inhomogeneity corrected magnitude and phase data.

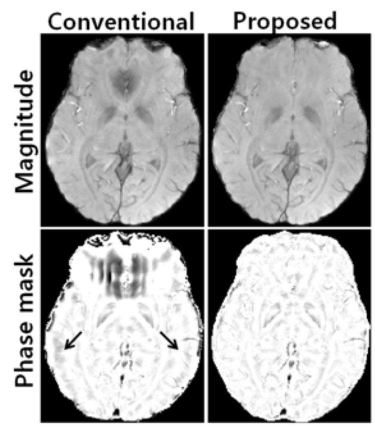

Figure 3. Improvement of the proposed method in magnitude and phase mask (4th power).

SWI processing Using the above field inhomogeneity corrected magnitude and phase values, complex data at TE=22 ms was generated to apply to the SWI process. High pass homodyne filter (32x32) was applied to the corrected complex data and a phase mask was generated to eliminate the remaining low frequency term. Finally, an SWI image was generated by multiplying B_0 field inhomogeneity compensated magnitude with the fourth power of phase mask. A mIP (minimum intensity projection) was also performed over 4 adjacent slices (12mm). Comparison with conventional SWI was done from data at the same echo time.

In vivo experiment was performed with two healthy volunteers. Data were collected in 3T (Siemens Tim Trio) scanner with 40 slices/slab, voxel size : 1x1x3 mm^3, TR : 42.5 ms, 1st TE : 3.96 ms, ES : 3 ms, FA : 18°, BW for conventional echo : 240 Hz/Px, BW for z-shimmed echo : 1021 Hz/Px. A total 11 echoes were acquired (6 conventional echoes and 5 z-shimmed echoes).

Results Void regions due to field inhomogeneity in conventional magnitude images are recovered in the proposed magnitude images (Fig. 3). Furthermore, wrapping artifacts disappear with the proposed phase mask (Fig. 3). Improvements in the SWI and mIP are also shown in Fig. 4. Veins not shown in conventional images and void region (white arrows) appear in the proposed method results. Furthermore, dark artifacts (white arrow) near the boundary of brain in conventional images also disappear in the proposed method.

Discussion The R_2^* fitting process based on multi-echo inherently has a noise reduction effect[4]. Thus, the estimated magnitude image has higher SNR than magnitude from a conventional echo.

Conclusion We have presented a macroscopic B_0 inhomogeneity compensated SWI method by correcting both magnitude and phase using 3D z-shim multi-echo GRE sequence. This method would be useful for detecting hemorrhage located in frontal and temporal lobe.

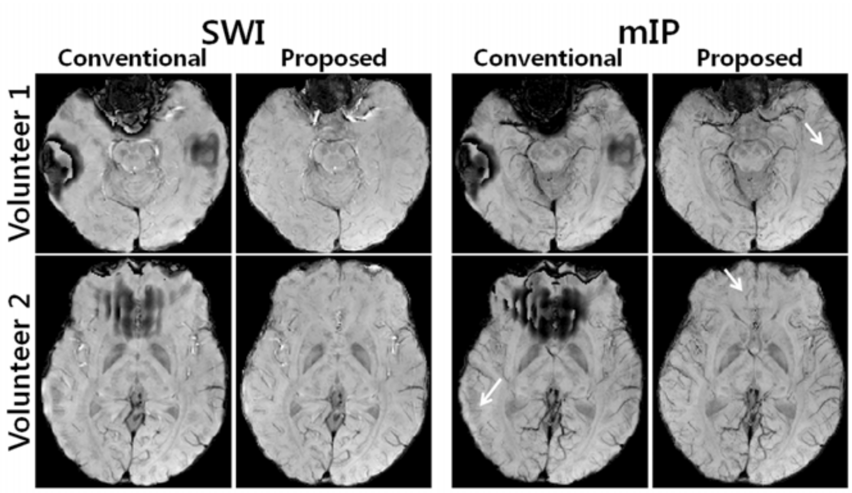

Figure 4. SWI and mIP results of two voluneteers.

References [1] Han D, 2nd Workshop on MRI Phase Contrast & Quantitative Susceptibility Mapping (QSM) 2013, [2] Tian L, NMR in Biomedicine 2011; 24:1129-1136, [3] Yablonskiy DA, MRM 2012; 70(5):1283-92, [4] Jang U, Neuroimage 2013; 70: 308-316.