# Macroscopic B0 inhomogeneity corrected QSM based on a field mapping algorithm using a single-scan 3D z-shim multi-echo GRE.

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**Purpose** Quantitative Susceptibility Mapping (QSM) based on phase data of gradient echo (GRE) is a novel technique for measuring susceptibility differences of the tissue. However, the macroscopic $B_0$ inhomogeneity due to air/tissue boundary causes artifacts which is a common drawback of the GRE[1]. Furthermore, the effect of the macroscopic $B_0$ inhomogeneity become worse as the echo time increases, and this is critical to QSM studies which have long echo times. To overcome this problem, we propose a 3D z-shim multi-echo GRE pulse sequence which can generate $B_0$ inhomogeneity compensated QSM and a simple robust algorithm for $B_0$ inhomogeneity compensated field map.

**Methods** The z-shim $G_z$ gradient timing diagram of the proposed pulse sequence is shown in Fig 1a. For odd echoes, the conventional 3D multi-echo GRE data are acquired while for even echoes, 3D z-shimmed multi-echo GRE data are obtained. All z-shim gradients in each even echo apply the same amount of $G_{zmax}$ which is the maximum $G_z$ gradient for phase encoding. Scan was performed in 3T Siemens Tim Trio with 104 slice/slab, voxel size: $1\text{x}1\text{x}1\text{mm}^3$, TR:60ms, TE=7.30+(j-1)x4.21ms for 9 echoes (j=1,2...9), flip angle: $12^o$, BW: 391Hz/px. Conventional 3D multi-echo GRE data was also acquired with same parameters for performance comparison.

Even though $B_0$ inhomogeneity compensated data can be acquired, additional problems such as phase wrapping (z-shim does not mitigate wrapping), accrued phase offset due to z-shim gradient, low SNR of each echo data and to the issue of combining odd echo data set and the z-shimmed data set robustly. To overcome these problems, we propose a simple algorithm for $B_0$ inhomogeneity compensated field map using the proposed pulse sequence.

***Step 1***. Acquire the multi-echo data using the proposed 3D z-shim multi-echo GRE sequence.
***Step 2***. Multiply $j^{th}$ complex conjugated echo signal with $j+2^{th}$ complex echo signal.
(i.e. $\Omega(j) = S^*(j) \times S(j+2)$)
***Step 3***. Complex summation of all $\Omega(j)$.(i.e. $\Omega_T = \Sigma\, \Omega(j)$)
***Step 4***. Unwrap phase of $\Omega_T$ and divide by $2\Delta TE$.

By processing *Step 2*, phase wrapping effect can be mitigated as presented in Fig 2. Furthermore, additional phase offset due to z-shim gradient is also canceled out because of all z-shim gradients in each even echo have the same magnitude. From *Step 3*, issues of SNR and combining problems are addressed. At *Step 4*, PRELUDE (in FSL) was used for phase unwrapping which required process time of 2~3min. To obtain the QSM results, we used PDF[2] for background field removal and L1 regularized QSM[3].

**Results** Fig 1.b and c show the results of the restored signal from the z-shimmed echo in the macroscopic $B_0$ inhomogeneity dominant region. The SNR improvement from the z-shimmed echo is not only represented in magnitude, but also in phase as shown in Fig 1.c. Fig 3a represents the results after background field removal and Fig 3b shows QSM results for both the conventional 3D multi-echo GRE data and the proposed 3D z-shim multi-echo GRE. The empty regions (white arrow in left images of Fig 3.a and b) which are masked due to low SNR caused by macroscopic $B_0$ inhomogeneity are apparently filled in both field maps and QSM using our proposed approach.

**Conclusion** We have presented a macroscopic $B_0$ inhomogeneity compensated QSM. The method uses a multi-echo GRE approach acquiring both conventional echo set and z-shimmed echo set. A simple robust algorithm for $B_0$ inhomogeneity corrected field map is presented which leads to increased signal in regions of high inhomogeneity thereby enabling QSM reconstruction in these regions. The method uses multi-echo data thus can obtain $B_0$ inhomogeneity compensated $R_2^*$ map[4] simultaneously.

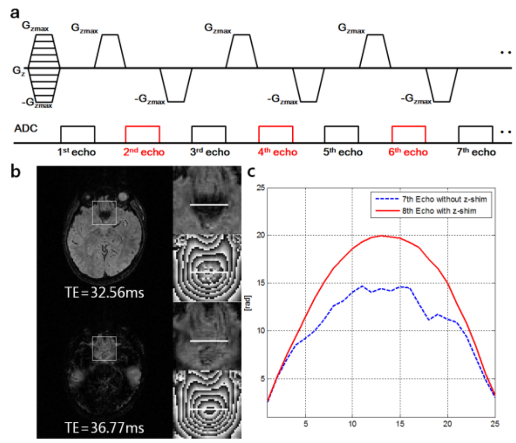


**Figure 1. a.** The proposed pulse sequence timing diagram showing the compensation gradient $G_z$ and ADC. The rest of timing diagram is identical to normal 3D GRE. **b.** Acquired magnitude and cropped phase from the 7th echo (conventional) and 8th echo (with z-shim). **c.** Spatially unwrapped phase profile of white line in both phase data of b showing improved profile using z-shim.

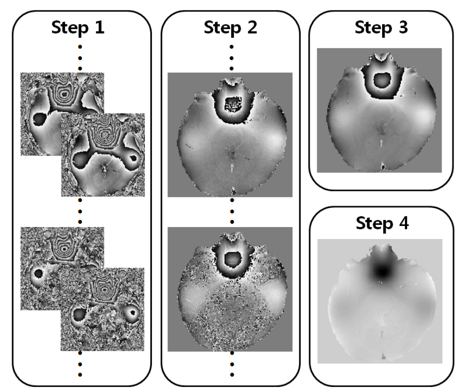


**Figure 2.** Schematic view of the proposed algorithm. Upper set in Step 1,2 is the results of odd echo set (without z-shim), lower set is the results of even echo set (with z-shim).

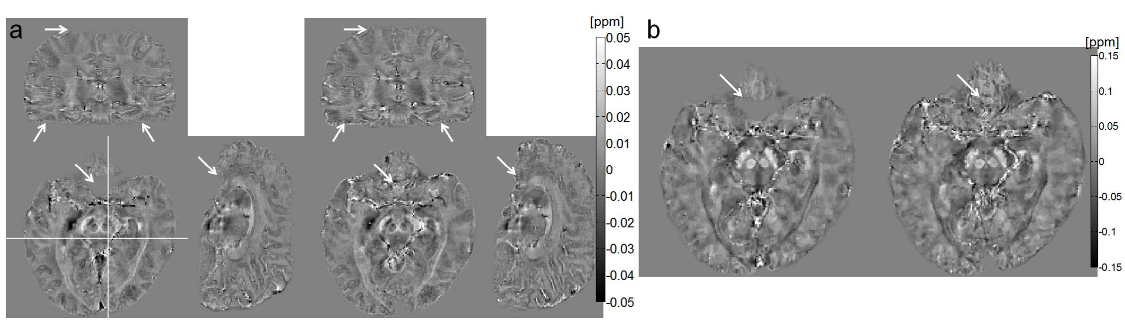


**Figure 3.** Local field maps (**a**) and QSM (**b**) from the conventional 3D multi-echo GRE data (left) and the proposed 3D z-shim multi-echo GRE data (right). Arrows show regions where phase maps and QSM were reconstructed due to the elevated signal level of our proposed method.

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**References** 1. Jurgen R, et al. JMRI 1997; 7:266-279, 2.Tian L, et al. NMR in Biomed 2011; 24:1129-1136, 3.Berkin B, et al. NeuroImage 2012; 59:2625-2635, 4.Nam Y et al. NeuroImage 2012; 64:1790-1799.