B0 inhomogeneity compensated Susceptibility Mapping using Single-scan Multi-echo 3D z-shim method

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Introduction: Image phase has unique information about tissue composition such as gray and white matter structures [1]. Phase imaging is used for various imaging methods such as susceptibility weighted imaging and quantitative susceptibility mapping (QSM) [2,3]. To obtain phase image, long echo time is needed to acquire sufficient phase shift. However, there is limitation due to the B0 inhomogeneity artifacts (i.e. signal loss in the frontal and sinus regions). One method to solve this problem in 3D imaging is the 3D z-shimming method [4].

We propose to solve the above problem for obtaining the phase image by using a single-scan 3D multi-echo z-shimming sequence and image reconstruction method.

Materials and Methods: We used a 3D single-scan multi-echo sequence to obtain the k-space data. The odd echoes are same to the general 3D gradient echo sequence but, applying compensation gradient at the even echoes (in this study, the intensity of the compensation gradient is 50% of the maximum slice-direction phase encoding gradient and their sign alternatively changes) to obtain the shifted k_z-space data. (Fig. 1)

Multi-channel data were combined through the method in Ref. [5] at their respective echo. And for the combining the multi-echo phase image, magnitude weighting and time weighting were applied.

To obtain the phase image, we used laplacian method for phase unwrapping [3], sphere mean value filtering to remove the background phase [7]. These multi-echo data were normalized to their respective TE to make the frequency shift. To remove the noisy component from imperfect masking process that was used at the background phase removing step, magnitude weighting process was applied to each echo's frequency map. The magnitude weighting factors were obtained applying the Walsh's method [6] that is a method to make the sensitivity profile using each echo's channel combined image. Time weighting (i.e. each echo time/ longest echo time) was multiplied to each echo's frequency map because the phase proportional to their TE. Following averaging all of the echo's frequency map to make the combined frequency map. Direct voxel-by-voxel division method [8] for obtaining the QSM.

To verify the reconstruction performance, we compared the reconstructed results of the simple averaging method using phantom (a ping-pong ball filled with air in the agarose gel) and in vivo data.

Phantom and in vivo data were collected using a 3T Siemens Tim Trio MRI scanner (*Phantom*: TR = 150 ms, First TE = 4.714 ms, Echo Spacing (ES) = 3.57 ms, FOV = 192 x 192 mm^2, Voxel size = 1.0 x 1.0 x 1.0 mm^3, *In vivo*: TR = 48 ms, First TE = 7.16 ms, ES = 4.21 ms, FOV = 256 x 256 mm^2, Voxel size = 1.0 x 1.0 x 1.2 mm^3, *Both*: Flip angle = 15^o, Number of slices = 88, Number of echoes = 9, Number of channel = 4). All data reconstruction were performed using MATLAB R2009b.

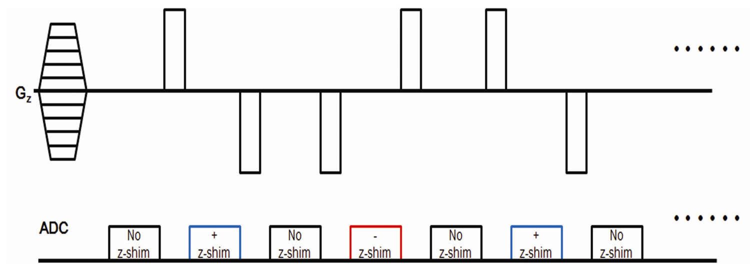

Figure 1: Single-scan multi-echo 3D z-shim sequence diagram.

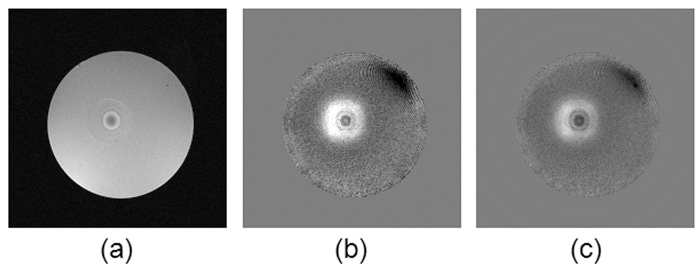

Figure 2: Reconstructed (a) magnitude image (echo 3), (b) combined frequency map by simple average method, and (c) combined frequency map by proposed method.

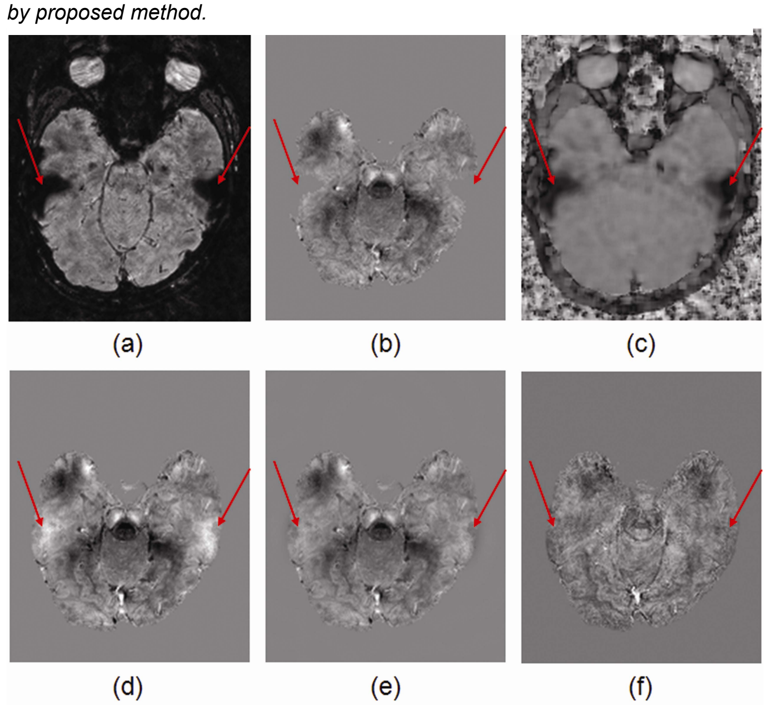

Figure 3: (a) Magnitude image (echo 5), (b) Phase image (echo 5), (c) Magnitude weighting factor (echo 5), (d) Combined frequency map by averaging, (e) Combined frequency map by proposed method, and (f) QSM.

Results: In Fig. 2, reconstructed phantom images are shown. The figure shows the slice above the ping-pong ball's location. Reconstructed image using simple average method has intensified regions. As expected, the lost signal due to the air inside the ping-pong ball, can be recovered by proposed method. Note that severe B0 inhomogeneity exists in this region. Our approach partially corrects the macroscopic inhomogenetity.

Fig. 3. shows the reconstructed in vivo images. Reconstructed image by simple averaging method shows some overwhelmed intensity regions, however, our proposed method mitigates this effect and delineates the signal drop-out regions that are pointed by arrows at the magnitude image.

Conclusion: In this work, we propose the phase image combination method from single scan 3D z-shim multi-echo data. Through this work, we can obtain the phase imaging and QSM information even if at the signal drop out regions. A post processing correction method for phase imaging has been developed which shows improvement than previous method.

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