Volumetric R2* mapping using 3D z-shimmed single scan multi-echo gradient-echo imaging

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Introduction Accurate R_2^* ($=1/T_2^*$) value quantification is required for many applications [1]. Multi-echo GRE imaging method is generally used to evaluate R_2^* value. However, the main drawback of this method is the influence of macroscopic B_0 inhomogeneity which occurs as unintended phase dispersion. This unintended phase dispersion is transformed as signal loss in image space. Z-shim method using compensation gradient in slice selection direction is used to overcome the problem [2,3]. This method is usually performed in 2D GRE imaging. 3D GRE imaging is inherently less sensitive to macroscopic B_0 inhomogeneity than 2D GRE imaging, but they are still problematic in frontal region and long TE. To solve these problems, 3D z-shim method with extended k_z-space sampling was introduced [4]. In this study, we propose 3D z-shim method using multi-echo GRE imaging for volumetric R_2^* quantification. The method uses a multi-echo approach, therefore no additional scan times are required compared to 3D GRE sequences.

Theory & Methods Figure 1 shows the k_z-space acquisition trajectory during echo time and G_z gradient timing diagram of our proposed 3D z-shim multi-echo GRE pulse sequence. For odd echoes, the acquisition trajectory is the same as normal 3D GRE imaging, but for even echoes, we acquire shifted k_z-space data in positive k_z direction. Note that since the influence of macroscopic B_0 inhomogeneity increases as the echo time increases, the z shim gradient is increased for subsequent echoes. This is represented in the shifted increase of k_z-space coverage for even echoes.

3D z-shim multi-echo GRE images (3.0T Siemens Tim Trio, 32 slice/slab, voxel size: 1.2x1.2x2.5mm^3, TR:40ms, TE=4.476+(n-1)x3.880ms for 9 echoes (n=1,2...9), flip angle: 12^o, BW: 389Hz/px, scantime:4m) using the proposed acquisition strategy were acquired from a healthy volunteer. To generate R_2^* map, we divide into two echo sets. One using even echoes (2,4,6,8 echoes) and the other using odd echoes (1,3,5,7,9 echoes). In other words, we calculate R_2^* using even echoes in the regions with macroscopic B_0 inhomogeneity, and calculate R_2^* using only odd echoes in homogeneous regions. Afterwards, we combine the two R_2^* maps evaluated for each region to create whole R_2^* map. A mono-exponential fitting was used for R_2^* calculations.

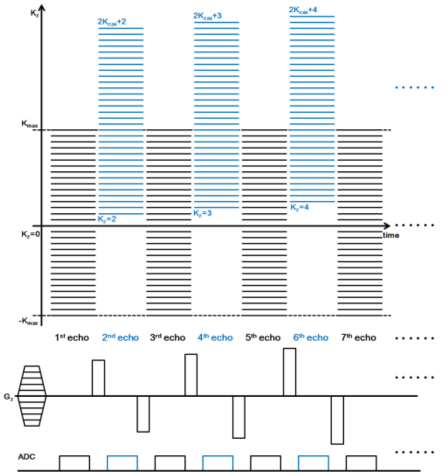

Figure 1. The acquisition strategy in k_z-space and pulse sequence timing diagram showing the compensation G_z and ADC. The rest of timing diagram is same as a normal 3D GRE method.

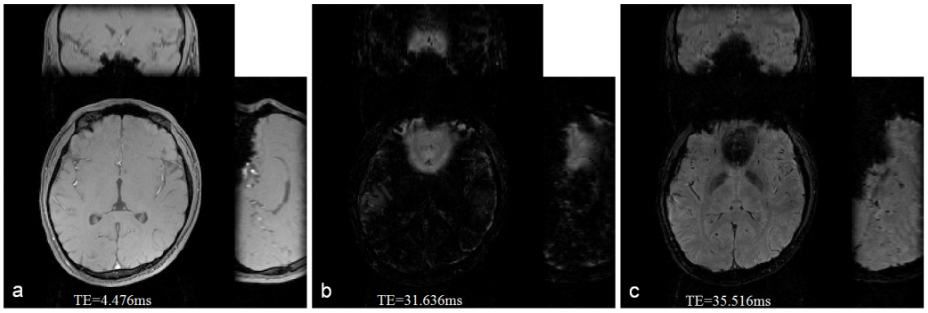

Figure 2. Magnitude images acquired using the proposed method. **a.** First echo image (at 4.476ms), **b.** Eighth echo image (at 31.636ms), **c.** Ninth echo image (at 35.516ms).

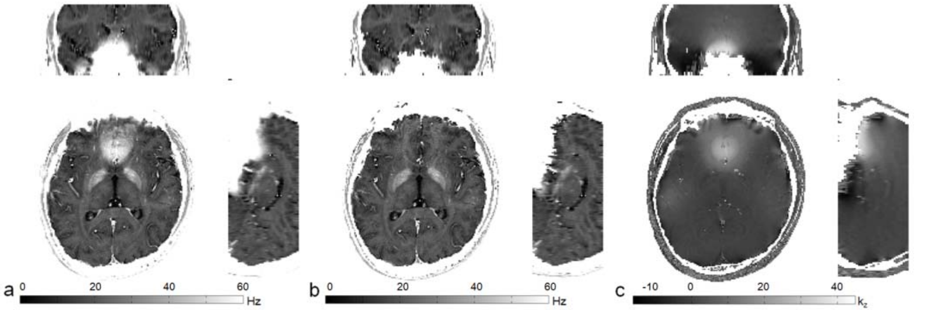

Figure 3. a. Uncorrected volumetric R_2^* map, **b.** Corrected volumetric R_2^* map, **c.** The evaluated k_{zoff} map at 35.516ms.

Results Figure 2 shows the acquired magnitude images from the proposed 3D z-shim pulse sequence. Figure 2a and c correspond to normal 3D multi-echo GRE images. Thus, two images show volumetric signal losses in regions of B_0 inhomogeneity. However, Fig 2.b shows that the proposed 3D z-shim method successfully restores the volumetric signal losses in the frontal and temporal regions.

The uncorrected volumetric R_2^* map is shown in Fig 3a. Overestimation of the R_2^* values is apparent in regions of B_0 inhomogeneity. Corrected R2* maps using the proposed approach is shown in Fig. 3b for the volumetric region showing improved quantification. The effective shift of k_z center (at TE=35.516ms) is shown in Fig. 3c. Our results show that we can correct k_{zoff} shifts, in the range of approximately -10 to 40 echo shift in k_z-direction, as shown in Fig. 3c. However, the present method cannot correct for k_{zoff} shifts that exceed this maximum coverage.

Conclusion We have presented a volumetric R_2^* map including which corrects for macroscopic B_0 inhomogeneity. The methods use a multiecho GRE approach with increasing field inhomogeneity compensation gradient and does not require additional scan time.

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