Single-scan T2* measurements with alternating compensation gradients for linear background gradients

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Introduction Accurate measurement of T_2* values, excluding the effects of macroscopic field inhomogeneity, is required in many applications. Macroscopic field inhomogeneity induces additional signal decay and leads to underestimated T_2* values. Using compensation gradients(G_c) in slice-selection direction, so called z-shim method, is an effective technique to restore additional signal loss due to macroscopic field inhomogeneity[1]. Therefore, T_2* measurements by using these compensation gradients raise the accuracy of T_2* values[2,3]. However, it requires additional scan time for different compensation gradients. In this study, we propose a post-processing technique with alternating compensation gradients in a single scan for accurate T_2* measurement.

Theory In conventional 2D GRE imaging, an additional signal decay due to macroscopic field inhomogeneity in slice-selection direction is problematic. Since its scale is relatively larger than voxel size, macroscopic field inhomogeneity can be modeled approximately as a linear field gradient(G_b). In the presence of G_b, it generates a phase dispersion within slice-selection direction and signal decay is weighted by the time profile of the excitation pulse. This unwanted signal decay can be corrected by additional scan with different compensation gradient(G_c) in slice-selection direction[1,2]. A signal model with linearly increasing G_c like bmGESEPI method[2] for correction of specific linear field gradient G_b can be described as following: $S(t)=M_0\exp(-t/T_2^*)A(G_b,G_c(n),t)$, $A(t)=|\mathrm{sinc}(\gamma(nG_i+G_b)t)|$ when sincRF is used for rectangular slice profile. In this model, the accuracy of the T_2* measuremnts depends on the difference between $G_c(n)$ and G_b at each voxel. Therefore, several scans with different G_c to cover the range of inhomogeneity are required for more accurate T_2* quantification.

Methods For the T_2* map, modified 2D multi-echo gradient images(3.0T Siemens Tim Trio, TR=500ms, TE=3.43+(n-1)x3.16ms for 24echoes(n=1,2,…,24), flip angle:30°, BW=391Hz/px, voxel size:0.9x0.9x5mm, G_c: +-nG_i, G_i=3.4% of the slice rephasing gradient) were acquired in 2 healthy volunteers. The time profile of the RF pulse used in this study was hanning windowed sinc function, so $A(t)=|0.5\mathrm{sinc}(\gamma(nG_i+G_b)t))(1+\cos(\pi\gamma(nG_i+G_b)t)))|$ was used for post-processing. Fig.1 shows an acquisition strategy with different G_c within a single TR. Data acquisition of every odd echoes is same as a conventional multi-echo gradient sequence but linearly increasing $G_c(nG_i)$s are added to every even echoes with alternating polarity. As a result, three different echo sets(compensation gradient: 0, G_c, -G_c) were acquired and can be modeled as following functions depending on time, G_b and $G_c(n)$.

1+2nth echoes: $S_0(t) = M_0 \exp(-t/T_2^*) A(G_b,0,t)$
2+4nth echoes: $S_1(t) = M_0 \exp(-t/T_2^*) A(G_b,G_c(n),t)$
4+4nth echoes: $S_{-1}(t) = M_0 \exp(-t/T_2^*) A(G_b,-G_c(n),t)$

The corrected T_2* values of each voxel were obtained by following post-processing steps:
Step 1. Select larger $S_e(t)$ from $S_1(t)$ and $S_{-1}(t)$.
Step 2. Interpolate $S_0(t)$ to match time point with $S_e(t)$.
Step 3. Find G_b* such that minimizes $\| S_0(t)/A(G_b,0,t) – S_e(t)/A(G_b,G_c,t) \|_2$.
Step 4. Determine T_2* values from corrected data set ($S_0(t)/A(G_b^*,0,t)$ or $S_e(t)/A(G_b^*,G_c,t)$).

When either $S_o(t)$ or $S_e(t)$ has very fast signal decay due to G_b, latter echoes have low SNR and sometimes zero crossing problem occurs. So the values of G_b* were found with different weighting factors according to TE(large for early echoes, small for late echoes). Numerical method[3] was used for fast T_2* calculation and non-linear curve fitting algorithm in MATLAB was used for finding G_b* values. T_2* values only using $S_o(t)$ were also calculated to compare with conventional multi-echo gradient sequence method.

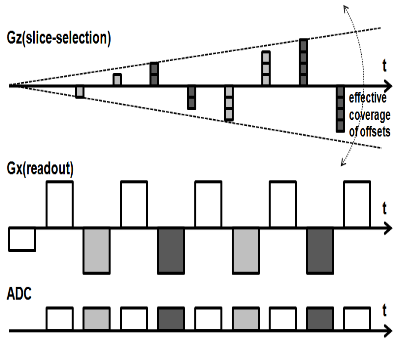

Figure 1 The acquisition strategy of this study. It gives 3 different echo sets(S_0,S_1,S_{-1}). The value of the G_i in the slice selection direction determines the range of G_b can be corrected.

Results Fig.2 shows the obtained echoes of three different voxels. $S_1(t)$ and $S_{-1}(t)$ have very similar signal decay when the G_b is small(Fig.2.b). But $S_1(t)$ or $S_{-1}(t)$ decays slower than $S_0(t)$ when the G_b is large(Fig.2.c,d) and their difference depends on the value of G_b. Fig.3 shows the corrected T_2* maps and calculated G_b maps. Most voxels were corrected with single scan but some voxels having severe linear field gradients still have artificially low T_2* values(Fig.3.g).

Discussion & Conclusion This proposed method with compensation gradients shows reliable T_2* maps, covering a large range of G_b, in most regions. The maximum G_b can be corrected is clearly limited by the value of G_c and the time profile of the excitation pulse. But this maximum G_b value is expected to larger than other post-processing technique with conventional multi-echo gradient sequence[4] by obtaining even echoes with compensation gradients.

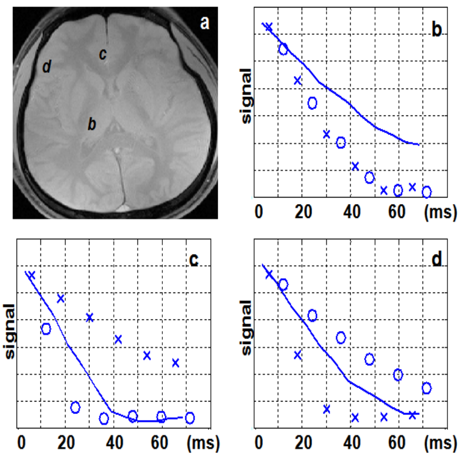

Figure 2 The sample echo sets of three different voxels. **a.** the magnitude image(3.43ms), **b,c,d.** the echo sets of each voxel(solid line:$S_0(t)$, x:$S_1(t)$, o:$S_{-1}(t)$).

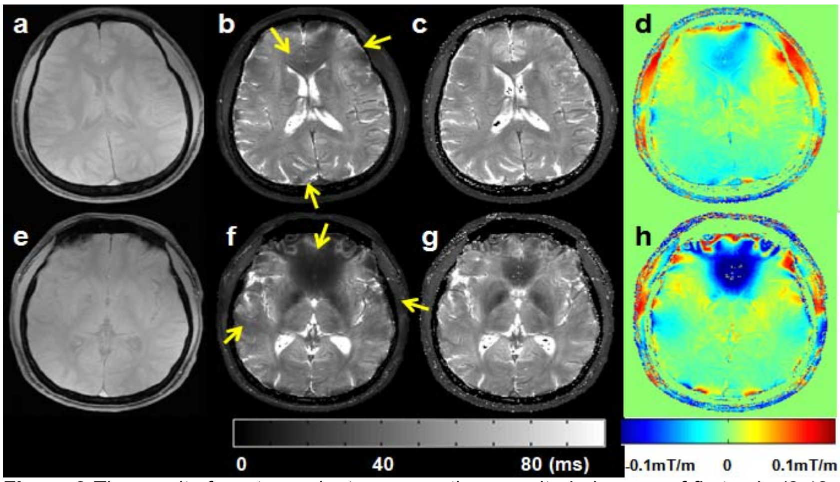

Figure 3 The results from two volunteers. **a,e.** the magnitude images of first echo(3.43ms), **b,f.** the T_2* maps using only $S_0(t)$, **c,g.** the corrected T_2* maps with a proposed method **d,h.** the calculated G_b maps.

Acknoledgements This work is financially supported by the Ministry of Knowledge Economy(MKE) and Korea Institute for Advancement in Technology (KIAT) through the Workforce Development Program in Strategic Technology, and by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government(MEST) (No. 2010-001538).

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