Generalized MAGSTE with Improved Diffusion-Weighting Efficiency

J. Finsterbusch[1,2]

[1]Dept. of Systems Neuroscience, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [2]Neuroimage Nord, Hamburg-Kiel-Lübeck, Germany

Introduction

Background gradients hamper the accurate determination of diffusion coefficients in MR experiments because their cross term with the diffusion-weighting gradients causes an additional, usually unknown diffusion weighting. While the cross terms of macroscopic background gradients, e.g. caused by magnetic field inhomogeneities, can be compensated for by averaging acquisitions performed with opposite polarities of the diffusion gradients, microscopic background gradients, e.g. due to susceptibility differences within a voxel, are inert to this approach. For diffusion-weighting experiments based on stimulated echoes which are often used if the desired diffusion times are long compared to T_2, several gradient schemes have been presented that inherently null background gradient cross terms [1–3]. Here, it is shown that the diffusion-weighting efficiency of the generalized MAGSTE technique [3] can be improved by introducing an additional gradient pulse without sacrificing the cross-term compensation.

Methods

Figure 1a shows the basic pulse sequence of the generalized MAGSTE technique. For an appropriate ratio η' of the gradient amplitudes, cross terms of background and diffusion gradients are nulled in the preparation and readout interval independently [3]. For the long δ_1 present in EPI acquisitions, η' usually is well above 1, i.e. the longer gradient is applied with a reduced amplitude and the diffusion-weighting efficiency of the gradient scheme is not optimal. In the proposed extension (Fig. 1b), the lower gradient is replaced by two gradients with full magnitude but opposite polarity. For this combination, cross terms with background gradients vanish if $\delta'' = \delta + \delta_1 - \sqrt[3]{4[\delta_3 + (2\delta + \delta_1)^3 - 2\delta^3 + 6\delta\delta_2(2\delta + 2\delta_1 + \delta_2)]} \big/ 2$. Analytical calculations show that the gradient integral (k) accumulated in the preparation or readout interval is larger than for the sequence shown in Fig. 1a.

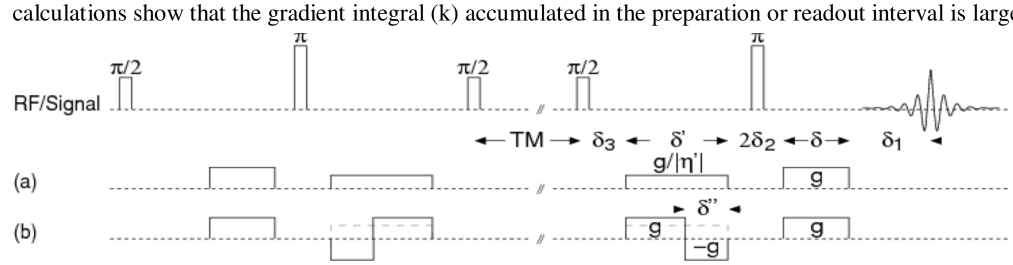

Figure 1: Basic pulse sequence for diffusion-weighted imaging based on a stimulated echo preparation using(a) generalized MAGSTE and (b) the proposed extension. Both schemes compensate cross-terms with background gradients in the preparation and readout interval independently.

The numerical and analytical calculations were obtained with Maple 10. Measurements were performed on a 3T whole-body MR system (Siemens Magnetom Trio) using a standard twelve-channel head coil. To demonstrate the cross-tem compensation pulsed gradients were switched in the preparation and readout interval to simulate the effect of background gradients. An EPI trajectory with an in-plane resolution of $3x3mm^2$ was used for the image acquisition. Apparent diffusion coefficients (ADC) were calculated based on acquisitions with b values of 500 and 1500 s mm^2 obtained for three orthogonal directions at a diffusion time of about 375 ms.

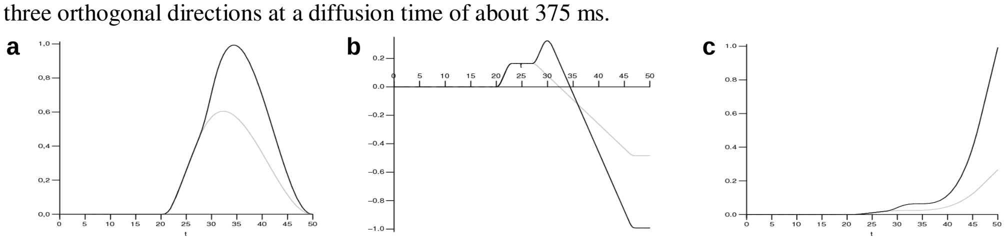

Figure 2:. Example plots of the (a) cross-term with a constant background gradient, (b) the gradient integral, and (c) the *b* value for the preparation interval of the generalized MAGSTE sequence (gray) and the proposed extension (black). The plots for the readout interval are achieved by appropriate mirroring.

Results and Discussion

For both preparations, cross terms with a constant background gradient (Fig. 2a) are nulled at the end of the preparation as well as at the end of the readout interval. However, the proposed extension yields much higher gradient integrals (Fig. 2b) and *b* values (Fig. 2c), i.e its diffusion-weighting efficiency is improved. For the diffusion parameters used, about half of the gradient amplitude was required for the proposed extension to achieve the desired *b* values.(Fig. 3a and b). The ADC values obtained (Fig. 3c and d) are very similar and do not change significantly when applying pulsed gradients to simulate the effect of background gradients (Fig. 3e and f) demonstrating the cross-term compensation capability of both sequences.

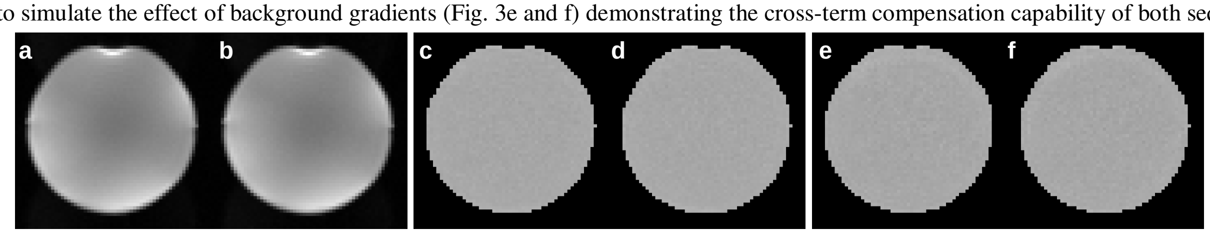

Figure 3: Experimental results obtained in a water phantom with (a,c,e) generalized MAGSTE and (b,d,f) the proposed extension which required less than half of the gradient amplitude: (a,b) diffusion-weighted images and (c–f) ADC maps acquired (c,d) without and (e,f) with pulsed gradients (with different amplitudes in the preparation and readout interval) to simulate background gradient effects.

References

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