Diffusion Weighted vGRASE (DW-vGRASE)

M. Engström[1], R. Bammer[2], and S. Skare[1]
[1]Clinical Neuroscience, Karolinska Institute, Stockholm, Sweden, [2]Radiological Sciences Laboratory, Stanford University, Palo Alto, CA, United States

Introduction

The GRASE[1] (GRadient And Spin Echo) pulse sequence was proposed about two decades ago for T2-weighted imaging. GRASE suffers however from image ghosting due to the T2-modulation of the data. A vertical GRASE pulse sequence (vGRASE[2]) was for that reason later introduced by Oshio, in which the EPI trains, following each RF echo, were modified to cover each a vertical instead of a horizontal swath (a.k.a. "blind") of k-space. As a result, the T2 and phase modulations become separated along the frequency and phase encoding encoding directions, respectively. Compared to conventional ss-EPI, vGRASE is less sensitive to off-resonance effects despite being a single-shot technique and hence also robust to motion. By combining parallel imaging and vGRASE, the geometrical distortions may be lowered even further. In this paper, we combine a Stejskal-Tanner diffusion preparation with a GRAPPA-accelerated vGRASE acquisition. With sequence modifications and phase correction techniques we address problems induced by the diffusion gradients, including spatially varying, echo train dependent, non-linear phase over the object caused by brain motion as well as interferences between stimulated echoes and spin echoes during the readout, as a result of that the diffusion gradients violates the CPMG condition.

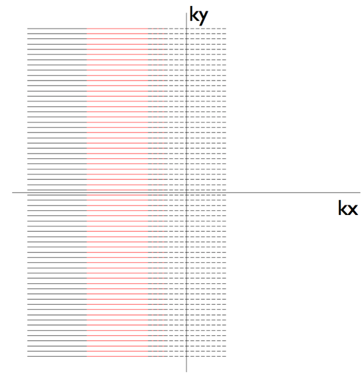

Figure 1. DW-vGRASE k-space trajectory. The solid black line is the 1st blind (1st EPI readout), the solid red line the 2nd blind, and the dashed black line the 3rd blind (last EPI readout)

Materials & Methods

A single-shot spin echo-EPI sequence was modified to allow for three RF-refocused EPI readouts per excitation (Fig. 1), positioned as three partially overlapping vertical blinds in k-space. Each blind was covering 48x192 (freq. x phase) pixels after GRAPPA reconstruction (R = 3). Slightly more than half of k-space was acquired and half-Fourier reconstruction (POCS) was used to synthesize the remaining (right) half of k-space. To minimize stimulated echoes, 8 ms long SLR-optimized 180° pulses and variations of the crusher gradient areas were employed. Phase correction of the diffusion weighted echoes was performed by calculating a phase difference map (ΔΦ) between the central blind (dashed black line, Fig. 1) in the T2-w (b0) acquisition and the central blind in the diffusion weighted acquisition. The ΔΦ map was used to correct the 1st and 3rd blind, while the conjugate of the ΔΦ (due to that the phase from bulk motion during DW gradients is changing sign[3] after 2nd 180°) was used to correct the 2nd blind. The blinds were gridded to a final resolution of 192x192 and the image was deapodized after Fourier transformation. DW-vGRASE data on a healthy volunteer was acquired on a GE 450 1.5T system (G = 50mT/m, SR = 200 T/m/s), 8-channel head coil, TEeff/TR = (60-90-120)/4000 ms, thk = 5 mm, FOV = 240 mm, b = 800 s/mm^2, NEX = 3, and 6 non-collinear diffusion weighted directions.

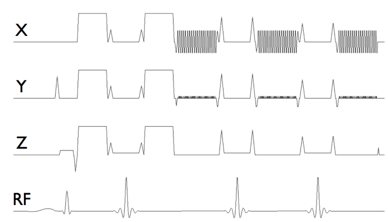

Figure 2. Diffusion weighted vGRASE using R=3 and a 192x192 target matrix

Results

In Fig. 3, reconstructed DW-vGRASE images are shown. The T2-w (b0) image (Fig. 3a) appears sharp with some low ringing in the R-L direction, caused by residual phase inconsistencies between the 1st/3rd and 2nd echo. The uncorrected ISO-DWI (Fig. 3b) shows a "double-image" effect due to phase differences between 1st/3rd and 2nd echo. The phase corrected ISO-DWI (Fig. 3c) shows no additional signs of phase errors, beyond what is seen in the T2-w image.

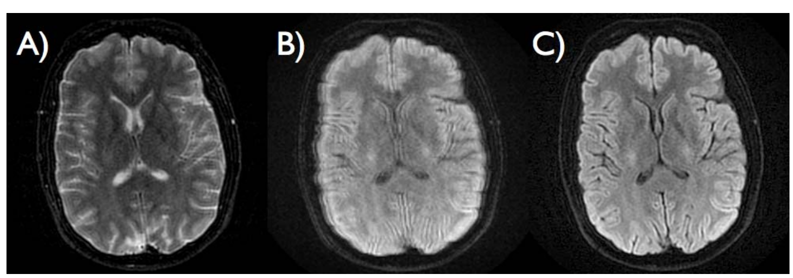

Figure 3. Matrix resolution=1,25mm2 A) T2-weighted image, B) ISO-DWI without phase correction, C) ISO-DWI with phase correction

Discussion & Conclusion

We have presented a high-resolution diffusion-weighted GRAPPA accelerated vGRASE-type sequence with quite low sensitivity to off-resonances. The k-space trajectory is similar to RS-EPI[4], with the difference that the blinds in DW-vGRASE are acquired in one excitation and that half-Fourier imaging is used in the kx direction. Destructive non-linear phase from bulk motion during DW gradients was successfully removed during the reconstruction. Being a single-shot technique, the entire brain can be covered within one TR, making retrospective 3D motion correction between DW image volumes straightforward. DW-vGRASE is efficient in the sense that the majority of the time between the excitation and the effective TE is used to acquire data, although the DW gradients and long 180° pulses increases TE, resulting in increased T2 shine through and reduced SNR. While DW-vGRASE is not as SNR efficient as ss-EPI, the distortion level is reduced by 2-3 times from the sequence (depending on the size and shape of the acquisition matrix) and another factor of R from parallel imaging. Future work involves improved removal of stimulated echoes.

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