Reduced Blurring in Diffusion-Weighted EPI using a Dual-Shot, Reverse-Gradient Sequence with Asymmetric k-space Splicing and Inherent Distortion Correction

Wei Liu[1], Kun Zhou[1], and David A. Porter[2]
[1]Siemens Shenzhen Magnetic Resonance Ltd., Shenzhen, Select, China, [2]Fraunhofer MEVIS, Institute for Medical Image Computing, Bremen, Germany

Purpose: In conventional single-shot, diffusion-weighted echo-planar imaging (DW-EPI), partial *k*-space acquisition is useful to reduce TE and improve the SNR due to reduced T_2 signal decay. The technique typically acquires slightly more than half the *k*-space data by sampling k-space asymmetrically in the phase-encoding direction. In the case of diffusion-weighting, a common way to reconstruct the partially sampled dataset is to zero fill the missing *k*-space samples. However, this decreases the image resolution and results in significant blurring in the phase-encoding direction. In order to improve the image quality, the missing *k*-space data can be filled with non-zero values using methods based on conjugate synthesis[1-2]. However these methods are often not robust in the presence of the motion-induced phase errors experienced in diffusion-weighted imaging (DWI). In this study, we introduce a dual-shot DW-EPI sequence, which achieves full *k*-space sampling by combining two partially sampled data sets, acquired with opposite phase-encoding gradient polarities. The resulting images have reduced image blurring compared to the standard zero-filled case. In addition, the method of image combination inherently incorporates a standard technique for correcting geometric distortion using the reverse-gradient approach[3-5].

Methods: Fig.1 shows the proposed asymmetric *k*-space splicing method, which is used to generate a fully-sampled data set. The central part of the figure depicts the two acquired data sets, which sample *k*-space in opposite directions along k_y by using opposite gradient polarities for the blipped phase-encoding gradient. The two acquisitions sample data from a common region at the center of *k*-space and complementary asymmetric regions of outer *k*-space points. Both acquisitions have the same TE value as the standard partial *k*-space scan because, in both cases, the central common region is sampled first, followed by the respective outer *k*-space region. The actual TE value is determined by the partial Fourier fraction (PPF), which specifies the proportion of sample points that are omitted by the asymmetric sampling window. Depending on the polarity of the phase-encoding gradient, the images will be either locally stretched or compressed along the phase-encoding direction due to the effect of B_0 inhomogeneity on the EPI readout, which has a low bandwidth per pixel in the phase-encoding direction. Consequently, the two acquisitions with opposite phase-encoding polarities have correspondingly opposite spatial-distortion patterns, which have to be corrected before combining the data. This is achieved by spatially registering the distorted images to an undistorted image, which is estimated from the two oppositely distorted images using a standard reverse-gradient technique. Subsequently, motion-induced phase errors between the two acquisitions are removed by image-domain 2D phase correction using the low-spatial-frequency components from the commonly sampled region at the center of *k*-space (labelled as 'overlay data' in Fig. 1). The data from the two acquisitions are then transformed back to *k*-space, where the data are combined to provide a fully sampled *k*-space dataset. This dataset is used to generate a distortion-corrected image with reduced blurring artifact compared to the standard partial Fourier acquisition. During the data combination, data samples in the commonly sampled 'overlay data' region at the center of k-space are averaged to improve SNR in the final image.

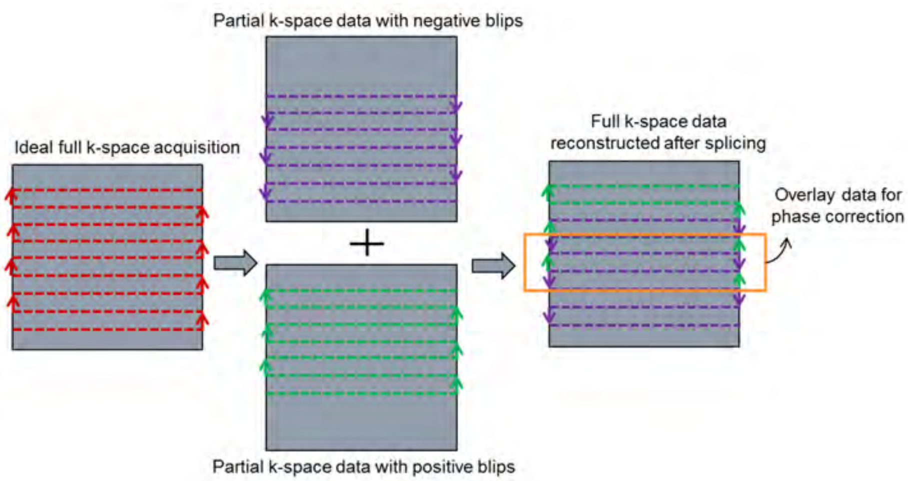

Fig.1 Summary of the asymmetric k-space splicing

Experiments and Results: All measurements were performed on a commercial 3T scanner (MAGNETOM Aera, Siemens Healthcare). Experimental data were obtained from a healthy volunteer using a non-product, dual-shot DW-EPI sequence. The imaging parameters for DW-EPI were as follows: TE/TR = 96/5600 ms, FOV = 230×230 mm^2, slice thickness = 5 mm, matrix = 192×192×20, PPF = 5/8, three diffusion directions, bipolar diffusion encoding with two RF refocusing pulses, b = 0/1000 s/mm^2, 2 averages, GRAPPA factor = 2. An additional T_2-weighted SE scan was performed for anatomical comparison; imaging parameters were as follows: TE/TR = 92/5000 ms, FOV = 230×230 mm^2, slice thickness = 5 mm, matrix size = 192×192×20, 2 averages, GRAPPA factor = 2. Fig.2 compares the uncorrected and corrected DW-EPI data with the SE T_2-weighted image at the same slice position. Contours generated from the SE image are overlaid on the EPI images to allow easy comparison. The distortion and local signal compression caused by B_0 inhomogeneity are significantly improved in the distortion-corrected images (Figs. 2c-d). Fig 2d shows an image which is both distortion corrected and processed with the *k*-space splicing method, demonstrating a marked reduction in blurring compared to the zero-filled, original images (Figs. 2a-b) and to the unspliced, zero-filled, distortion-corrected image (Fig. 2c). The reduced blurring is demonstrated more clearly in the corresponding magnified image (Fig. 2i).

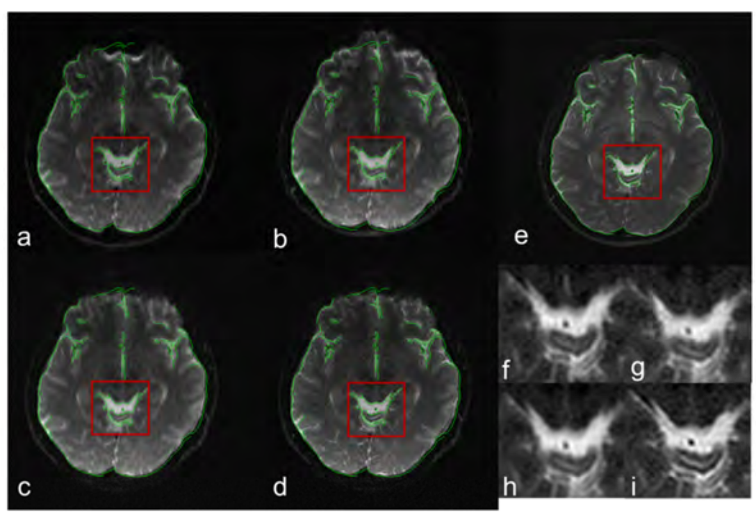

Fig.2. (a)-(b) EPI images with negative/positive blips; (c)-(d) distortion corrected images without/with k-space slicing; (e) SE image as anatomical reference; (f-i) magnified regions from (a-d) respectively.

Conclusion: We have demonstrated that image blurring due to zero-filling of partial *k*-space data in DW-EPI can be avoided by using a *k*-space splicing method with a dual-shot EPI sequence. The method preserves the short TE of the standard partial *k*-space acquisition and incorporates an inherent correction for spatial distortion due to B_0 inhomogeneity. In some cases, the new scheme will permit a reduction in TE compared to standard partial Fourier acquisitions, because the *k*-space splicing method allows the PPF to be reduced without a corresponding increase in image blurring.

References: **1**. Feinberg DA et al. Radiology.1986, 161(1): 527-531. **2**. Noll DC et al. IEEE Trans Med Imaging. 1991, 10:154-163. **3**. Andersson JL et al. Neuroimage. 2003, 20:870-888. **4**. Holland D et al. NeuroImage. 2010, 50(1):175-192. **5**. Gallichan D et al. MRM. 2010, 64:382-290