2D-Navigator-Based Re-Acquisition for Motion Artefact Suppression in Multi-Shot, Diffusion-Weighted Imaging

D. A. Porter[1]

[1]MR Applications Development, Siemens Medical Solutions, Erlangen, Germany

Introduction

A number of multi-shot, diffusion-weighted sequences compensate for motion-induced, non-linear phase errors by performing a shot-to-shot signal phase correction using data from a 2D region at the centre of *k*-space [1-4]. However, if the data are severely corrupted, local signal voids can occur in the navigator images, corresponding to a shift of low spatial-frequency components outside of the *k*-space acquisition window, and a complete correction of the data is not possible. Techniques that incorporate some form of degenerate data sampling, such as self-navigated schemes with over-sampling in the central region of *k*-space, can usually address the problem by discarding unusable data sets during image reconstruction. For measurement techniques that do not inherently over-sample the centre of *k*-space an alternative, and possibly more robust, approach is to use an 'intelligent re-acquisition' scheme [5], in which the navigator data are evaluated during the measurement, so that corrupt acquisitions can be identified and re-measured. This paper describes the application of intelligent re-acquisition to the readout-segmented EPI method [4], providing an efficient acquisition strategy for avoiding the effects of severely corrupted data in multi-shot, diffusion-weighted imaging.

Methods

Sequence Design: The sequence uses two spin echoes to sample imaging and navigator data respectively using an EPI echo-train with a short echo-spacing. Each echo samples a subset of contiguous k_x points and the full extent of k_y. For the imaging echo the sampled k_x segment has a different offset from the centre of *k*-space at each shot and for the navigator echo the central k_x segment is sampled each time. The navigator data are used to perform a 2D non-linear phase correction in image space.

Re-Acquisition Scheme: Data acquisitions yielding unusable data are characterised by navigator images with a large non-linear phase error, corresponding to a widening of the signal distribution in *k*-space. A measurement of the width of this distribution in the k_x direction was used as the basis of a selection criterion for performing re-acquisition. The first step in the re-acquisition decision is to compare all shots for a given image and identify the shot with the smallest distribution width. This width is then used as a reference point for all the other shots and in each case a relative distribution width is calculated. Shots with relative widths exceeding an empirical threshold are marked for re-acquisition. The re-acquisition is then performed at the end of the standard measurement when all shots have been acquired for all b-values and diffusion-encoding directions. During re-acquisition, priority is given to readout segments close to the centre of *k*-space, where corrupt data has the greatest detrimental effect on image quality.

Implementation: The readout-segmented EPI sequence with 2D-navigator-based re-acquisition was implemented on a Siemens MAGNETOM Avanto system, operating at 1.5T. The standard head matrix coil was configured in CP mode, providing 4 receiver channels. Reconstruction of images using re-acquired data was performed on the scanner. In addition, raw data from the measurement was used offline to reconstruct images for comparison, which did not use the re-acquired data.

Volunteer Measurements: Images were acquired from healthy volunteers using the following protocol: FOV 230mm; matrix 224 x 224; pixel size 1.0mm x 1.0mm; number of slices 17; slice thickness 5mm; number of shots per image 11; echo-spacing 300µs; TR 3860ms; TE 82ms; one scan at b=0 and three at b=1000 in orthogonal directions; no cardiac triggering; maximum total measurement time (corresponding to the maximum of 9 re-acquisitions) 3min 25secs.

Results

Figure 1a shows navigator data from the central 7 shots of a diffusion-weighted data set before data re-acquisition (*k*-space centre is sampled at shot 6). The diffusion gradient direction is oblique to the imaging slice. Top row: navigator images; bottom row corresponding *k*-space data. Shot 8 has a signal void artefact in the navigator image, which is seen as a widened signal distribution in *k*-space. Figure 2a shows the corresponding data after re-acquisition. Data sets with wide *k*-space signal distributions have been replaced by newly acquired data. Figures 1b and 1c show artefacts that result when the corrupt data are included in the reconstruction of diffusion- and trace-weighted images respectively. Figures 2b and 2c show the corresponding artefact free images reconstructed using re-acquired data.

Figure 1:
Readout-segmented EPI without data re-acquisition
(a) navigator data
(b) diffusion-weighted image
(c) trace-weighted image

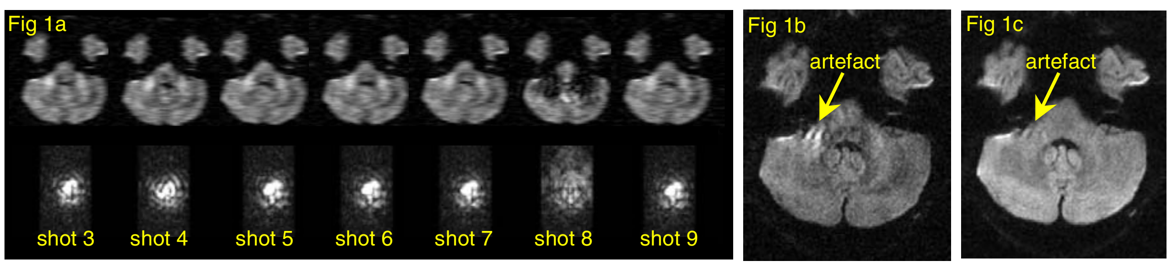
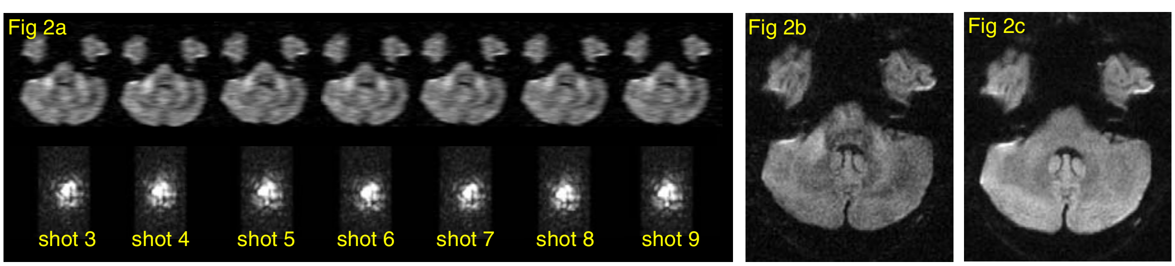


Figure 2:
Readout-segmented EPI with 2D-navigator-based data re-acquisition.
(a) navigator data
(b) diffusion-weighted image
(c) trace-weighted image



Discussion

Although non-linear 2D phase correction is normally effective at removing the artefacts that arise in multi-shot, diffusion-weighted imaging, the technique fails in the case of motion-induced phase errors whose high spatial-frequency components exceed the resolution of the 2D navigator data used for phase correction. In practice, the proportion of acquisitions for which this is the case is typically small, making it possible to avoid the effect on final image quality, without a large increase in scan time, by re-acquiring the small subset of scans that are unusable. To this end, a measurement of the width of the signal distribution in *k*-space is a robust way of identifying unusable scans and the parameter can be calculated rapidly for use during the measurement in the control of a re-acquisition procedure.

References

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[4] Porter et al. Proc. ISMRM, 12th Ann. Meeting, Kyoto, p442, 2004. **[5]** Q Nguyen et al. Proc. ISMRM, 6th Ann. Meeting, Sydney, p134, 1998.