Motion Artifact Correction in 3D Multishot EPI-DTI with Real-Time 2D Navigators

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INTRODUCTION Subject motion during the diffusion gradients can cause shading and ghosting artifacts in the resultant diffusion weighted (DW) images [1-3], and consequently result in reduction of the accuracy of DTI measurement in multishot DW imaging. Typically, DW images are acquired with multiple signal averages to improve SNR. Any discrepancy in subject position between averages would result in blurring of the averaged image. We hypothesized that any motion might decrease the accuracy of DTI measurement in multishot or multiple averaging singleshot DTI. In this report, a motion artifact correction scheme for multi-shot 3D EPI-DTI with one EPI readout per kx-ky or kx-kz plane is described. This technique can be used to reduce artifacts caused by subject motion during diffusion gradients or subject motion between shots or averages and, therefore, to improve the accuracy of DTI measurement.

METHODS Data acquired by multi-shot DTI pulse sequences can be corrupted by two principal types of motion: motion during diffusion gradient application (intra-shot motion) and motion between shots (inter-shot motion). Intra-shot motion can cause a significant signal loss when even small motion can cause partial or complete dephasing or an additional phase factor in image space [1]. Inter-shot motion caused by global changes in subject position results in additional phase term in k-space data (translation) or k-space data shift (rotation). Both types of motion can be identified and corrected if multi-dimensional navigators are acquired together with the imaging data. A 3D multi-shot EPI-DTI pulse sequence with a limited FOV preparation and 2D navigators was implemented. In the sequence, two techniques were used to resolve the motion: (1) real time (RT) navigation of data acquisition and (2) correction of inconsistencies between shots using 2D navigators. The first technique, RT navigation, can be used to monitor/identify the shots corrupted by substantial motion, and direct the pulse sequence to reacquire data for those shots. The second method can identify and remove inconsistencies caused by small motions between shots and can identify and correct the resulting subject position changes. The method for motion artifact correction in 3D multi-shot DTI with 2D navigator echoes is schematically described in Fig.1. The input data for the technique are the dataset with excessive motion corrupted echoes reacquired in real-time. The measurement data were obtained using 3D multi-shot EPI-DTI pulse sequence with limited FOV preparation. The imaging parameters were: b=500 sec/mm^2, TR/TE=4000/75 ms, ETL 33, 192x33x8 imaging matrix, and 4 averages. The first average was treated as the acquired data, while the remaining 3 averages were considered as the reacquired data to simulate RT navigation. The agar phantom was intermittently moved predominantly in the vertical or horizontal direction during the acquisition to mimic physiologic motion. The algorithm described in Fig.1 was used to correct the phase inconsistency between shots. First, 2D navigator echoes $N_{kz}(k_x,k_y)$ were Fourier transformed and the corresponding 2D phase maps $\varphi_{kz}(x,y)$ were constructed. These maps were combined with the associated imaging echoes as $I'(x,y,k_z) = I(x,y,k_z)e^{i\varphi_{kz}(x,y)}$ [1]. Inter-shot in-plane motion (translations (R_{kz}^x, R_{kz}^y) and rotation (θ_{kz}) in x-y plane) can be estimated from the 2D navigator image, $A_{kz}(x,y)$ using the methods described in [3]. The corrected dataset was used for image reconstruction.

RESULTS Fig.2 illustrates the real-time reacquisition of the imaging echoes corrupted by excessive motion. The shot where the peak of the associated 2D navigator k-space data is shifted noticeably were replaced by the corresponding shot from next average (RT navigation). The resulting dataset was used for the phase-correction. Fig.3 shows the images reconstructed from the original dataset (row 1), the dataset after RT navigation (row 2), and the dataset after phase inconsistency correction (row 3). The images from row 1 in column b and c are corrupted by motion artifact. The reacquisition of data by RT navigation improves image quality significantly (row 2 of fig.3) but leaves some residual ghosting in the slice direction, especially in images corrupted by vertical motion. These residual artifacts are removed after phase correction (row 3 of Fig.3). The horizontal banding in all images is a systematic artifact arising from the shape of the RF profile used for reduced FOV preparation and does not affect the DTI processing as it presents in all images.

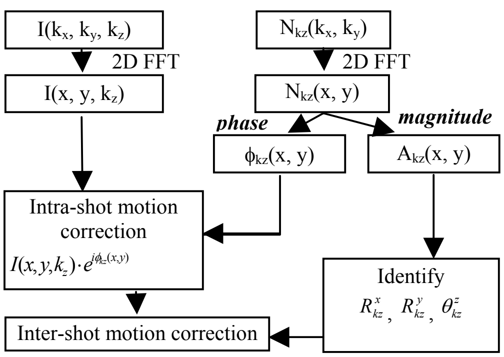

Fig.1 Motion artifact correction scheme for multi-shot 3D EPI-DTI with one shot per kx-ky plane. The input data is the measurement data with strongly motion corrupted shots reacquired. Combination of image data with the 2D navigator phase is used to suppress motion artifacts. Parameters R_{kz}^x, R_{kz}^y, θ_{kz}^z describe inter-shot translation and rotation.

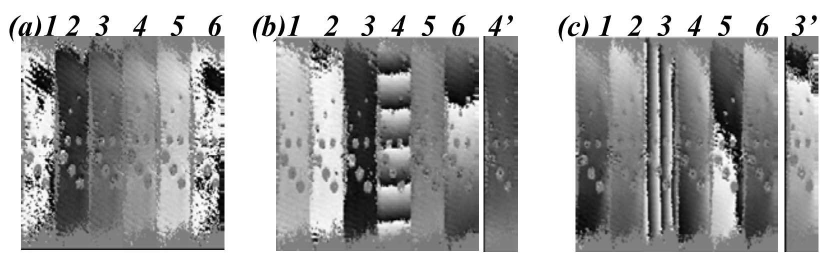

Fig.2.Simulation of RT navigation: phase maps of the 2D navigator echoes of an agar phantom with b=500 s/mm^2. Numbers on top represent shot number and the numbers with prime (4'and3') represent the reacquired shot. The phantom was (a) stationary or intermittently moved/rotated during the acquisition mainly in (b) vertical or (c) horizontal direction. The RT navigation directed the pulse sequence to reacquire the motion-corrupted echoes.

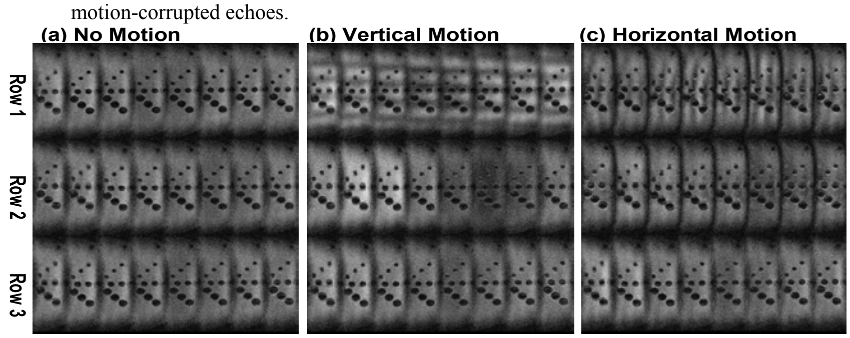

Fig.3. 3D DW images of 8 contiguous slices obtained with b=500 sec/mm^2 along the S/I direction (in/out-of the image plane). The phantom was stationary or intermittently moved vertically or horizontally during data acquisition. The DW images in the second row were reconstructed from the dataset where the motion corrupted EPI readouts were replaced by the corresponding readouts from next average dataset (simulation of RT navigation). The dataset after RT navigation was additionally corrected using 2D navigator phase information. The phase correction combining with the RT navigation gave substantially improved DW images.

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