Feasibility of ultra-short EPI navigator for DTI motion detection

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Introduction: Structural brain network can be revealed by the while matter fiber tracking derived from diffusion tensor imaging (DTI). It was shown that correcting the gradient vectors according to head motion during DTI acquisition is crucial for the accuracy of fiber tracking[1]. In DTI, Eddy current from high gradient field can distort the images, producing spurious motion effect from registration algorithms. For instance, by applying only a pure shearing of 0.1 in xy and performing Eddy current correction in FDT toolbox will result in rotation of 0.05 after decomposing the affine transformation matrix. Therefore, it is very challenging to extract information of true head motion, which is critical for rotating the gradient vectors. Recently, a low resolution EPI navigator has been proposed to estimate the head motion in real time, with an increase of ~15 ms in echo time (TE). As coil arrays are widely used, it is possible to use partial parallel imaging technique with a high accelerator factor to minimize the TE increase. In this work, we tried to explore the minimum data required for the navigator to obtain reliable information of head rotation. Before implementing the navigator in the DTI pulse sequence, the feasibility was tested first on normal EPI scans. Using real EPI imaging data, we compared motion correction parameters evaluated from navigator and from images. Our results showed that rotation can be tracked reliably by using only 3 K-space lines for the navigator, corresponding to a readout time of 2 ms.

Methods: One subject was scanned on the Siemens Tim Trio scanner using a 32-channel coil with iPAT acceleration factor (AF) of 2 (TR/TE = 2000/30, 29 slices, 10 volumes, 48 ACS lines). Raw imaging data were saved and read out by matlab codes and the full k-space of each volume was reconstructed using the GRAPPA algorithm. We then under-sampled the reconstructed full k-space to simulate navigator K-space with AF 5, 7, and 9. We decided to use GRAPPA operators to interpolate K-space of the navigator because it is more robust than normal GRAPPA reconstruction at higher acceleration factors[3]. A GRAPPA operator was derived for each readout direction (positive and negative) from the ACS data using 7 nearest neighbors and then applied to the simulated sparse K-space. Afterwards, the interpolated K-space underwent different levels of zero-filling while retaining only the central portion of k-space, which is equivalent to acquiring fewer K-space lines. Finally, images were reconstructed slice by slice and form navigator volumes. The navigator volume and image volumes were exported to SPM8 (Wellcome Department of Cognitive Neurology, London, UK) for realignment. The three rotation angles of head movement were extracted from SPM8 output. To characterize the accuracy of rotation estimation, we used the estimated rotation from the image volumes as a reference, and computed the error in rotation estimation E as the total variance between estimated angles A and the true values A^0.

$$E = \sum_{i=1}^{3}\sum_{j=2}^{10}\left(A_{ij} - A_{ij}^{0}\right)$$

, where i denote the index for angles in pitch, roll, and yaw; j denotes the image volumes.

Results: Fig. 1 shows the images reconstructed with AF 5, 7, and 9, with 1 K-space line and 11 K-space line respectively. The differentiation of gray and white matter is still reasonable for AF 9. There is a great loss of image features by reducing number of K-space line from 11 to 1. Fig. 2 shows the rotation parameters output from SPM8 for different AF and number of K-space lines. Most of the curves coincide well with the 'true' rotation except for those from one K-space line. For number of K-space line above 3, the performance of AF 5 and 7 is superior to that of AF 9, as confirmed by the analysis of total errors (Fig. 3). There is no much gain in estimating the head rotation by using K-space lines more than 3.

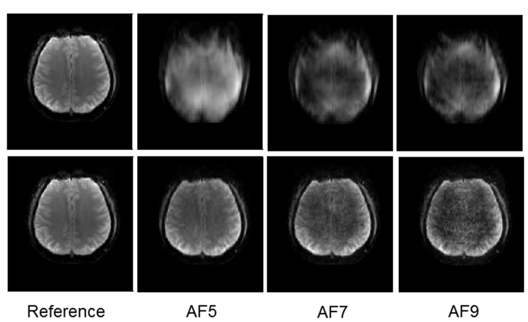

Fig. 1. Images reconstructed using high AF and few K-space lines. Top: 1 K-space line; bottom: 11 K-space lines.

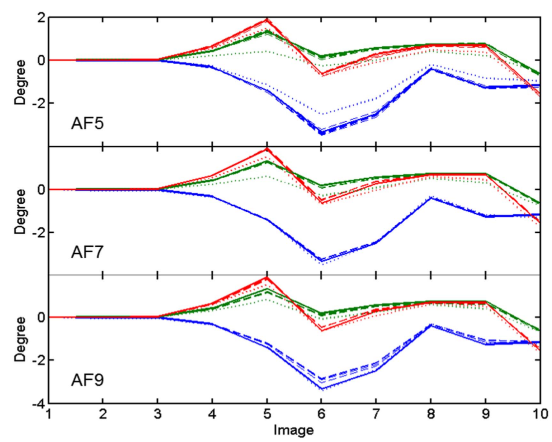

Fig. 2. Motion correction curves for rotation for AF 5, 7, 9. Blue: pitch; green: roll; red: yaw, with solid lines denoting the results from reference images; dashed lines denoting results for number of K-space lines from 3-11; dotted lines denoting results for 1 K-space line.

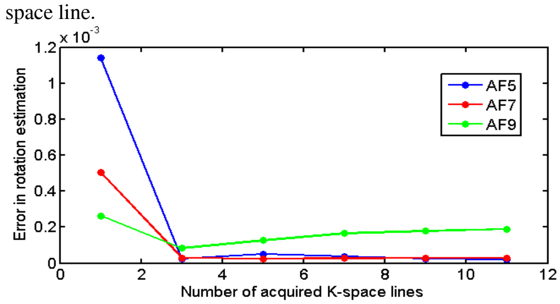

Fig.3. Errors in rotation estimation for different acceleration factors and number of K-space lines.

Discussion: Our results on normal EPI suggest that an ultra-short EPI navigator using few K-space lines is able to detect the head rotation with high accuracy. With three K-space lines, the net penalty of TE is very small. Our next step is implementing the navigator in the DTI sequence. The navigator will be inserted before the diffusion gradient. Therefore, reference scans with very short TE is needed in order to use GRAPPA operators. There are two ways of acquiring ACS lines. One is within one scan, which is achievable if few ACS lines are required (e.g., three K-space lines are used). The other way is segmented acquisition. DTI typically takes more than one image without diffusion encoding (b0 image), these images can be used to perform the ACS scans in a segmented manner without increasing much echo time.

References: 1. Leemans A and Jones DK, MRM 2009; 61:1336-49. 2. Bhat H et al., ISMRM 2012, p2911. 3. Griswold MA et al., MRM 2005; 54:1553-56.