Motion Artifacts for Diffusion Spectrum Imaging

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Abstract

Current diffusion spectrum imaging (DSI) [1] requires long scanning time, and so involuntary head motion is inevitable especially in patients. Since DSI is a 6-dimensional technique which contains structural images and spectral data of molecular motions, global motion may introduce artifacts to both of these two domains. In this paper, we presented a novel concept for DSI motion artifacts and evaluated the effects on local fiber orientations by simulating motion on *in vivo* DSI data. We concluded that rotations with standard deviation of 2.0 degrees are tolerable in current DSI process.

Introduction

We assume that (1) there is only rigid-body motion; (2) the sensitivity within the coil is uniform; (3) the probability density function (PDF) of tissue is invariant of global motions; (4) there is only motion that introduce artifact, and (5) there is only slow motion. Based on these assumptions, the received signal will not change during the time when gradients are not applied. As a corollary, it is possible to decouple the motion artifacts into image and q-space domains for DSI because imaging gradients and diffusion gradients are not applied at the same time in current DSI sequence.

Here we will focus on the motion artifacts in the q-space domain. In the lab coordinates, diffusion gradients do not rotate with the head motion. However, in the material coordinates, the imaged subject is stationary and the diffusion gradients can be treated as rotated to a new direction with the same amount of head motion. Fig. 1 illustrates the resulting phase change if the positions of imaged subject are inconsistent when two diffusion gradients are applied. Under this condition, the received DWI could be modeled as a structural image with a phase factor, and the signal magnitude of the structure image is modulated by altered diffusion contrast:

$$S_\Delta(\bar{k},\bar{g}_1,\bar{g}_2) \equiv \bar{S}_\Delta(\bar{k},\bar{q}_1,\bar{q}_2) = \int \rho(\bar{r}) \exp\left\{ j2\pi[\bar{k} + \bar{q}_2 - \bar{q}_1]\cdot\bar{r} \right\} d\bar{r} \times \int P_s(\bar{R},\Delta) \exp[\, j2\pi\bar{q}_2 \cdot \bar{R}] d\bar{R}$$

where $\bar{r}$ represents positions on DWI, $\bar{R}$ represents net displacement of molecular, ρ is density function, and P_s is PDF. We can approximate $\bar{q}_1$ and $\bar{q}_2$ to be equal if these two positions are close. Therefore, the phase change in the first term of this equation could be ignored, and we can find that there is change of sampling position in q-space in the second term.

It follows that the positions of the sampled data in the q-space will deviate from the positions that were originally designed. Consequently, we may get improper results if we perform regular FFT over received q-space data without considering motion.

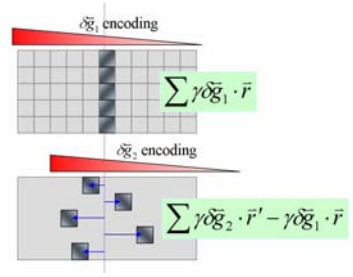

Fig.1 Effective diffusion gradient caused by inconsistent positions and its resulting phase change.

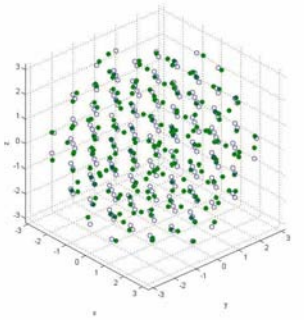

Fig. 2 Blue circle: standard sampling lattice; green dots: disturbed coordinates (203 sampling points).

Materials and Methods

DSI data was acquired from one healthy volunteer with a 3T MRI system (Trio, Siemens, Erlangen, Germany) using twice-refocused balanced echo diffusion EPI sequence. 925 diffusion-encodings were used with b_{max} = 9000 s/mm^2, TR/TE = 2900/150 ms and homogeneous Cartesian lattice over the q-space to acquired 15 slices of DWIs comprising middle portion of the brain with isotropic voxel size of 2.9 mm. 203/515 out of 925 q-space data with b_{max} = 3250/6250 s/mm^2 were selected to serve as standards. Random numbers of normal distribution were generated to disturb the standard 203/515 sampling coordinates with rotations about the center of the q-space (Fig. 2). New q-space data were generated using spline interpolation from the standard q-space data according to these disturbed sampling coordinates to serve as the experimental sets. The standard and these experimental sets were hamming filtered and then calculated to find the local maxima of orientation distribution functions (ODF) as the most likely directions of fibers. Finally, in addition to intensity of each voxel of each b-value, these directions were compared with the standard one as well.

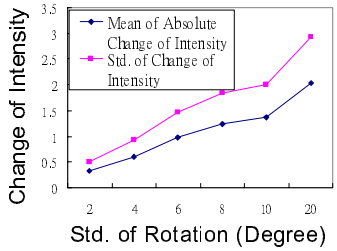

Fig. 3 Change of intensity vs. different amount of rotations (515 sampling pts).

Results

Statistically, there is trivial change over intensity for every DWI and every position on it (Fig. 3). However, these small differences magnified the deviation angle between standard and experimental groups with surprising amount (Fig. 4). In Fig. 4 (a)(b), the angular deviation between experimental sets and standard one increases with increasing standard deviation of rotations. In Fig. 4 (c)-(f), we can see that the angular deviation will increase if magnitudes of 1st and 2nd ODF are similar.

Comparing Fig. 4 (c)(d) and (e)(f), we found that DSI with 515 sampling points had lower deviation angle than DSI with 203 one for crossing-fiber voxels. However, as for single-fiber voxels, there is no significant difference over deviation angle between 515 and 203 sampling points.

Discussion

In this study, we found that rotations of 2.0 degrees of standard deviation are acceptable for current DSI. This is because the change of intensity of DWI due to motion is around noise level. After hamming filtering, which was previously used for reducing local maximums of ODF, these intensity changes will be suppressed and therefore result in acceptable ODFs under small angles of rotations. Though motion is almost inevitable in longer scan time, we found that 515 sampling still outperforms 203 one over the same amount of motion.

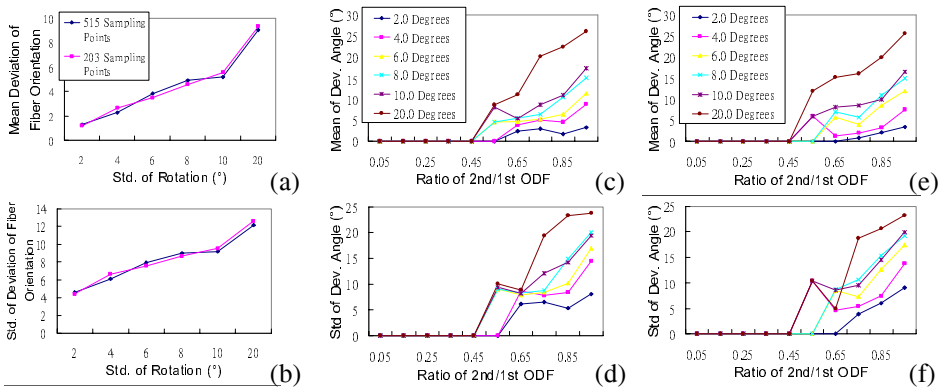

Fig. 4 (a)(b) Mean value and Std. of deviation angle vs. different Std. of rotations for single fiber voxels; (c)(d) Mean value and Std. of deviation angles vs. different ratios of 2nd/1st directions for crossing fiber voxels (203 sampling points); (e)(f) Mean value and Std. of deviation angles vs. different ratios of 2nd/1st directions for crossing fiber voxels (515 sampling points).

Reference

[1] Van Wedeen et al, ISMRM, 2000