Optimization of Diffusion Spectrum Magnetic Resonance Imaging for Clinical Scanner

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Abstract

Diffusion spectrum imaging (DSI) has been proposed to define tract orientations of neural fibers [1]. The technique typically requires large gradient pulses that are not attainable in clinical scanners. By using longer and weaker gradient pulses in the clinical scanner, DSI images would be subject to truncation artifacts and produce unstable results. The goal of this study is to determine the optimum parameters of DSI in clinical scanners. We proposed a method to calculate the reproducibility of the DSI vectors in the areas with different complexity. Optimum parameters, including cutoff b value, sampling number in q-space, and number of excitation (nex) were determined. Using the optimum parameters in an echo planar imaging (EPI) sequence, we obtained the whole human brain scan with spatial resolution of 2.3 x 2.3 x 3 mm^3 in 20 minutes. Our results showed that DSI performed in the clinical scanners produced reasonable tract orientations in both simple and complex white matter regions.

Introduction

DSI technique probes probability density function (PDF) of the water molecular diffusion by sampling diffusion weighted images (DWI) in 3-dimensional space of spatial modulation **q**. The technique typically requires large gradient pulses that are not attainable in clinical scanners. By using longer and weaker gradient pulses in the clinical scanner, DSI images would be subject to truncation artifacts and produce unstable results. To apply this technique to clinical study, it is necessary to investigate the feasibility of DSI in clinical scanners. Therefore, the goal of this study is to determine the optimum parameters, including cutoff value of diffusion sensitivity b, sampling number in q-space, and number of excitation (nex), and obtain DSI with optimum parameters in a clinical scanner. Specifically, the effects of different cutoff b values, different sampling density in the q-space with the same cutoff b value combined with different nex's to attain the same scan time were studied.

Methods

It has been validated that DSI can detect fiber crossing, which is inaccessible to conventional diffusion tensor imaging (DTI) [2]. The reproducibility of the DSI primary and secondary vectors can be used as an index to determine the optimum parameters. We assume that there is no head motion in the subject during twice continuous scans. The deviation angles in the areas with different diffusion complexity between two scans can be measured. Then we used the standard deviation of the deviation angle distribution to quantify the bias produced by the noise or artifact when using different parameters. The diffusion complexity [3] is an index that can distinguish the anisotropy from Gaussiantity of the water molecular diffusion between different tissues. When the distances of DSI primary and secondary vectors differ significantly, the primary vector may correspond to the fiber orientation and the secondary vector may be produced by noise or artifact. We compare each of them with themselves to get the deviation angle distribution. If the DSI primary and secondary vectors have similar distances, both vectors may correspond to individual fiber orientations. We used cross comparison to determine the deviation angle distribution.

The data were acquired using 1.5T Sonata system (Siemens, Erlangen, Germany). In the study of the optimization of cutoff b-value, we used a spin echo diffusion weighted EPI sequence with 203 diffusion-encodings to obtain DSI of human brain. The images were acquired with TR/TE = 500/140~160 ms, and number of excitation (nex) =2. The cutoff diffusion sensitivities (b_{max}) in DSI were incremented from 3000 to 10000 mTm^{-1}. 8 sets of images with spatial resolution of 4.2 x 4.2 x 5 mm^3 were obtained in about 54 minutes.

In the studies of the optimization of number of sampling in q-space and nex, the images were acquired with TR/TE = 500/145 ms, the cutoff diffusion sensitivities (b_{max}) = 4000 mTm^{-1}. The images of DSI were acquired with 203, 515, 925, 2109 diffusion-encodings. These encodings are comprised of isotropic 3D grid points in the q-space contained within a spherical volume of 3.7, 5, 6, 8 radial increments. For fair comparison, the nex = 10, 4, 2, 1 were used, respectively. The total scan time for DSI with spatial resolution of 2.3 x 2.3 x 3 mm^3 was about 67 minutes.

Results

In the result (Fig. 1) of optimization of cutoff b value, the minimum standard deviation of the deviation angles can be found to be 16.8° in the low diffusion complexity area, i.e. white matter, in the cutoff b value = 4000 s/mm^2. The optimum cutoff b-value can't be estimated in the high complexity area, i.e. gray matter, may caused by the partial volume effect duo to slice thickness.

In the study of the optimization of sampling number in q-space, we used the sampling points of 2109 as reference standard, and compare DSI primary and secondary vectors of each sampling points, 203, 515, 925, with 2109 in gray and white matter regions (Fig. 2). Our results showed that there is no significant difference given that the sampling intervals met the Nyquist criteria. Considering the total scan time, the 203 and 515 sampling points are better choices than 925.

In the study of the influence using different nex, we used the maximum nex as reference standard. We compared DSI primary and secondary vectors of nine nex increments, namely, 1 to 9, with those of nex=10 in gray and white matter regions (Fig. 3). As expected, the deviation angle became smaller as the nex increased.

Using the optimum parameters in an echo planar imaging (EPI) sequence, we obtained the whole human brain scan with spatial resolution of 2.3 x 2.3 x 3 mm^3 in 20 minutes (Fig. 4). The results showed reasonable tract orientations in both simple and complex white matters.

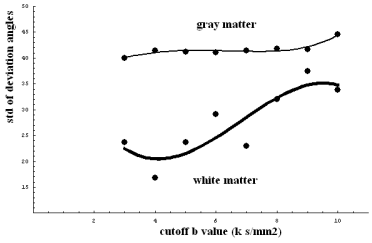

Fig.1 Optimum cutoff b value at about 4000 s/mm^2.

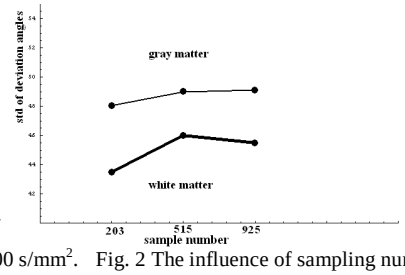

Fig. 2 The influence of sampling number in q-space.

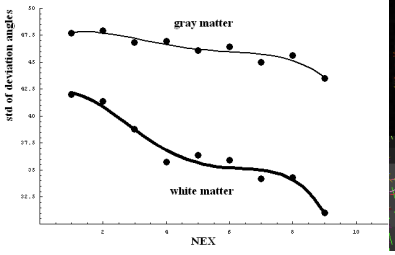

Fig.3 The influence of nex.

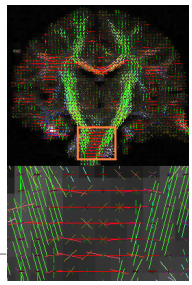

Fig.4 DSI result.

Conclusions

We proposed a method to establish the optimum parameters of DSI. The effects of different parameters of imaging were also discussed. Using the optimum parameters in an echo planar imaging (EPI) sequence, the whole human brain scan with high spatial resolution can be obtained in 20 minutes. Our results showed that DSI was feasible in clinical scanners, and might be potentially useful in neural science research and clinical application.

References

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