Effects of maximal b value and sampling interval on water displacement profile in q-space imaging

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Introduction

q-space imaging (QSI) is an advanced diffusion-weighted imaging technique to explore the water displacement profile. It has been proposed to depict non-Gaussian water diffusion without any presumed models and may provide a remedy for delineating crossing fibers of white matter tracts in the brain as compared to the conventional diffusion tensor (DT) model [1]. Quantitative measurements, such as mean displacement (MD) and zero displacement probability (ZDP) maps, on ex vivo animal studies indicated the potential of early detection of white matter abnormalities and neuronal degeneration [2]. Although some previous report demonstrated the important role of QSI in providing valuable information and better sensitivity to the alteration of the brain microstructure in vivo [3,4], relative long acquisition time of sampling entire q-space data for calculating water displacement profile restricts its clinical application. Fortunately, most MR signals obtained with high b–value gradients in q-space is relatively lower, which in corporation with specific mathematical manipulation may provide some possibility for undersampling of the data with more efficient acquisition [5]. As a result, the purpose of this study is to assess the effects of maximal b value and sampling interval on water displacement profile in simulation and validate it in clinical application of the brain.

Theory & Method

In QSI, there exists a Fourier relationship between the q-space data and displacement profile of water diffusion Although insufficient sampling of q-space data could lead to truncation artifact resulting in under- or over- estimations of the MD and ZDP maps, mathematical manipulation, such as zero-filling and extrapolation, could alleviate these errors. Based on this concept, we first simulated the q-space data with maximal b-values of 10000, 5000, 3300, 2000, 1000, respectively, to evaluate the effect on water displacement profile. After obtaining an appropriate maximal b value, the effect of sampling interval was subsequently investigated. The proposed sampling pattern of QSI was performed on an asymptomatic volunteers without any known or suspected brain pathology in supine position at 3.0T (TIM TRIO, Siemens Medical Solutions, Erlangen, Germany) with a thirty-two channel knee coil for the validation. More specifically, a spin echo diffusion-weighted 2D EPI imaging sequence were performed with b values ranging from 0 to 3300 s/mm2 with an interval of 100 s/mm2. Other imaging parameters were as follows: TR/TE = 4100/110 ms, FOV = 230x230 mm^2, matrix size = 196x196, slice thickness = 5 mm, slice gap = 1.5 mm, # of slice = 20, Asset = 2, NEX = 4, and total scan time less than 30 min. After data acquisition, a 2D median filter was performed first to alleviate the noise effect due to lower SNR of high b-value images. QSI-related parametric maps were then derived based on the abovementioned concepts.

Results

The demonstration of the water displacement profiles derived from a series of maximal b-values in simulations were shown in Figure 1. Although maximal b-value was reduced to 3300s/mm^2, similar diffusion profiles were obtained with less than 3% differences. Significant decreases of the ZDP values were noticed with maximal b-values of 2000 and 1400 s/mm^2. On the other hand, displacement profiles derived from simulated data with 5% noise level and different sampling intervals were illustrated in Figure 2. 5-fold undersampling of the q-space data provides an over-estimated MD value, but ZDP value remains good. Results of in vivo application of the brain QSI was shown in Figure 3. The derived MD and ZDP maps show great consistence even in the data with five-fold undersampling, on which less than 8 and 5 % errors on brain tissues were observed, respectively.

Discussion

This present study demonstrated the effects of maximal b-value and sampling interval in QSI and indicated the feasibility of accelerated measurements of the water displacement profile in in vivo brain. Although the difference on MD values was over-estimated on the displacement profiles with sampling interval of 500 s/mm^2, similar probability of zero displacement was shown from the data in simulation, suggesting the better ability of ZDP map to differentiate discrepant brain structures and disease as well. Less than 10% discrepancy of the MD and ZDP values were observed in the in vivo images using the proposed sampling method as compared to the values from more densely sampled q-space data, validating the ability to speed up the measurements of displacement parameters. In conclusion, our preliminary finding demonstrated that the proposed sampling pattern provides an alternative to obtain QSI images and reliable MD and ZDP measurements with a shorter acquisition time, which may be helpful in the implementation of in vivo brain q-space imaging in clinical application.

Reference

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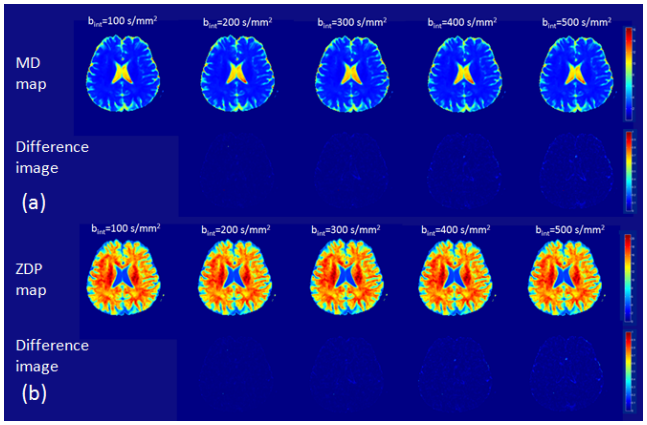

Figure 3 Mean displacement (a) and zero displacement probability (b) maps as well as their difference images derived from discrepant sampling intervals, respectively.

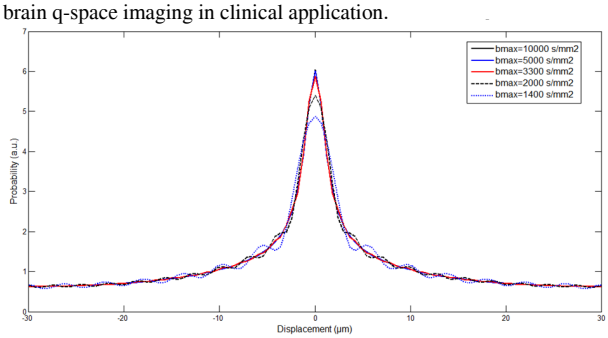

Figure 1 Effects of maximal b value on water displacement profile.

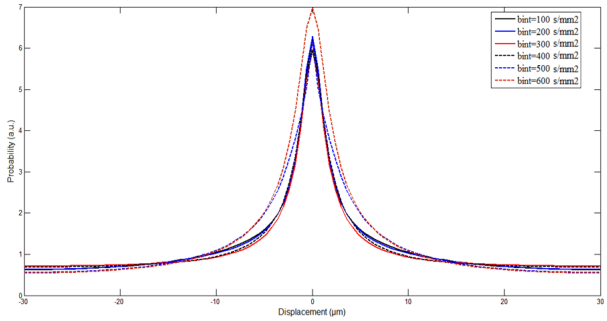

Figure 2 Effects of sampling interval on water displacement profile.