

# Optimization of Body-Centered-Cubic Encoding Scheme for Diffusion Spectrum Imaging

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## Introduction

Mapping complex fiber orientations with diffusion spectrum imaging (DSI) technique has been demonstrated as a potentially useful neuroimaging tool for investigating the brain structural connective network [1]. To sample DSI data, a large number of diffusion-weighted images are needed to be acquired for filling the 3-dimensional (3D) q-space. However, such sampling scheme prolongs the total scan time and limits the use of DSI on clinical study. In previous study, a systematic approach was proposed to determine the optimal diffusion sensitivities for different reduced-sampling schemes and investigate the relationship between angular precision, signal-to-noise ratio (SNR) and angular resolution [2]. Although potentially useful, the scan time of optimum reduced-sampling scheme is still too long, approximately 30 minutes, to be applied for clinical studies. Therefore, an efficient sampling scheme, called body-centered-cubic (BCC), was proposed to further reduce the scan time and preserve the accuracy of mapping fiber orientations [3]. To determine the optimum parameters and evaluate the accuracy of BCC sampling scheme, a systematic analysis was performed in two phases, *in-vivo* data simulation and verification studies. Further, the half-sampling schemes of DSI and BCC based on the concept of q-space symmetry were specifically discussed in this study.

## Materials and Methods

A total of five and four normal volunteers were studied in simulation and verification studies, respectively. All MR experiments were performed on a 3T MRI system (Tim Trio, Siemens, Erlangen, Germany). To reduce the eddy current effect, twice-refocused balanced echo diffusion EPI sequence was used to acquire MR diffusion images [4]. For simulation study, a total of 515 diffusion images with maximum b-value ( $b_{max}$ ) of 6000 s/mm<sup>2</sup> were acquired for DSI reconstruction (DSI515) and used as the full sampling reference. Nine slices were acquired covering the middle cerebrum with TR of 2000 ms. Diffusion image at the in-plane resolution and slice thickness of 2.5 mm was obtained with TE minimized to 144 ms. Four kinds of reduced-sampling schemes were investigated in this study, i.e. DSI with 203 encoding points (DSI203), BCC with 181 encoding points (BCC181), DSI with 102 encoding points (DSI102) and BCC with 91 encoding points (BCC91) (figure 1). Note that all the reduced-sampling schemes were interpolated from DSI515 with  $b_{max}$  from 1000 to 5000 s/mm<sup>2</sup> with a step size of 1000 s/mm<sup>2</sup>. An angular analysis was used to determine the optimum values of  $b_{max}$  for different reduced-sampling schemes. An angular index was used for evaluation, namely angular precision ( $P_a$ ) [2]. The *in-vivo* data verification was applied to confirm the results of simulation study. For verification study, one full sampling reference, DSI515, and either of DSI203 and BCC181 with three different  $b_{max}$  from 3000 to 5000 s/mm<sup>2</sup> were acquired for each subject. Those two half-sampling schemes, i.e. DSI102 and BCC91, were obtained by re-sampling the acquired DSI203 and BCC181 accordingly. The reduced-sampling schemes with minimum echo times were also investigated to evaluate the effect of TE. The minimum TE values were 113, 125 and 135 ms, corresponding to  $b_{max}$  values of 3000, 4000 and 5000 s/mm<sup>2</sup>, respectively. All the grid DSI data was reconstructed by Fourier transform (FT) [5,6] and by generalized q-space imaging (GQI), a method that enabled direct reconstruction of Cartesian or non-Cartesian grid samples [7], whereas BCC data was reconstructed only by GQI.

## Results

All the simulation results were consistent among the five normal subjects. As shown in figure 2, by comparing DSI and BCC schemes with comparable encoding points, i.e. DSI203 vs. BCC181 and DSI102 vs. BCC91, BCC schemes have lower  $P_a$ , i.e. better angular precision, than DSI schemes in both single-fiber and crossing-fiber groups. For single-fiber group, the optimum  $b_{max}$  values of BCC schemes (3000 s/mm<sup>2</sup>) were slightly lower than those of DSI schemes (4000 s/mm<sup>2</sup>). However, the optimum  $b_{max}$  values of DSI schemes (4000 s/mm<sup>2</sup>) were slightly lower than BCC schemes (4000 s/mm<sup>2</sup>) in crossing-fiber group. In verification results, the values of  $P_a$  were consistent in both experiments of same TE and minimum TE. Compared with simulation study, the values of optimum  $b_{max}$  in verification study were slightly higher in all the schemes, approximately an increase of 1000 s/mm<sup>2</sup> over those of simulation study. Similarly, the BCC schemes have better angular precision than comparable DSI schemes. For single-fiber group, the  $P_a$  of DSI203 was approximately 9°, slightly higher than 7° of BCC181. As for crossing-fiber group, the  $P_a$  values were approximately 34° and 32° for DSI203 and BCC181 schemes correspondingly. The comparison of half-sampled schemes, DSI102 and BCC91, showed the similar tendency as their corresponding full sampling schemes. Although the values of optimum angular precision were slightly worse than those of their corresponding full sampling schemes, they were still within the reasonable range of approximately 2° to 3° higher.

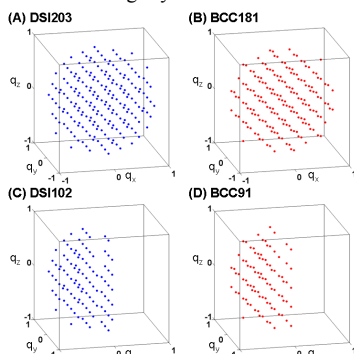


Figure 1. The reduced-sampling schemes investigated in this study. DSI102 and BCC91 were half-sampling schemes of DSI203 and BCC181 accordingly.

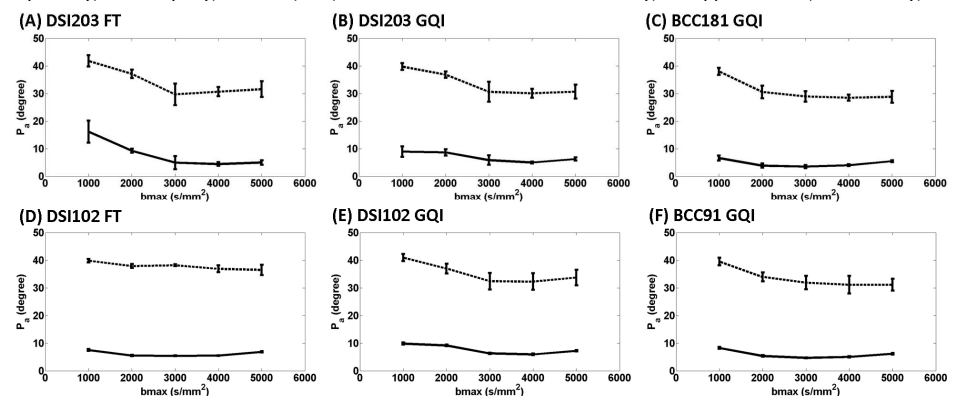


Figure 2. The plot of  $P_a$  against different  $b_{max}$  values of the simulation study for (A) DSI203 with FT, (B) DSI203 with GQI, (C) BCC181 with GQI, (D) DSI102 with FT, (E) DSI102 with GQI and (F) BCC91 with GQI. The plots of single-fiber and crossing-fiber groups were indicated in solid and dashed lines, respectively. The  $P_a$  values were averaged among those five subjects and the standard deviation value was indicated by the errorbar.

## Discussion and Conclusion

The present study investigated the optimum values of  $b_{max}$  for BCC sampling scheme and its capacity. However, no significant difference of the optimum  $b_{max}$  between DSI and BCC was found in verification study. As for the angular precision, under comparable or even slightly shorter scan time, our results showed that BCC had an incremental advantage over DSI, suggesting that BCC sampling scheme may be potentially useful for clinical applications and can be used as an alternate of DSI sampling scheme. Further, the capability of half-sampling schemes of both DSI and BCC was successfully demonstrated, which provides another efficient way to apply DSI on clinical scanners. **Reference** [1] Wedeen *et al.*, NeuroImage 41, p1267, 2008. [2] Kuo *et al.*, NeuroImage 41, p7, 2008. [3] Chiang *et al.* ISMRM, p965, 2006. [4] Reese *et al.*, MRM 49, p177, 2003. [5] Wedeen *et al.*, MRM 54, p1377, 2005. [6] Callaghan: Principles of nuclear magnetic resonance microscopy. Oxford Science Publication, 1991. [7] Yeh *et al.*, ISMRM, p365, 2009.