Optimization of B-Value and Gradient Orientation for Diffusion Tensor MRI

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Introduction

Diffusion-Tensor MRI is a powerful tool for mapping fiber tracts in the human brain [1]. In this technique, contrast between fiber tracts and surrounding tissues arises from diffusion anisotropy, calculated from a set of diffusion-weighted images acquired with different b-values and diffusion-gradient orientations. An optimal combination of these parameters is desired for a given acquisition time to maximize image quality. In this study, we systematically investigated different b-values and number of gradient orientations (N) on normal human volunteers. Image quality was quantitatively analyzed in terms of contrast ratio (CR) and contrast-to-noise ratio (CNR) between major tracts and surrounding tissue.

Methods

To implement the study, a diffusion-tensor pulse sequence was developed based on a prototype provided by GE Medical Systems (Milwaukee, Wisconsin). This sequence is a variation of a single-shot EPI sequence in which multiple diffusion-gradient orientations can be used in a single acquisition. Raw diffusion-weighted images were acquired from human subjects on a 1.5 T GE Signa NV/i scanner. The acquisition parameters were TE = minimum, TR = 4 sec, matrix = 128^2, FOV = 24 cm, and slice thickness = 5 mm, with varying b-values and multiple N as discussed below. The diffusion images were processed with GE's FuncTool Analysis package, using singular-value decomposition to calculate the diffusion tensor elements and generate the diffusion anisotropy maps.

The lowest N used in this study was 6, the minimum needed to determine the diffusion tensor elements [2]. Eight signal averages (8 NEX) were required to achieve sufficient signal-to-noise ratio for evaluation, leading to a total scan time of ~4 minutes (including acquisition of a base image with b = 0). Data sets with larger N were acquired for comparison, with correspondingly decreased number of averages, chosen to keep acquisition time constant at 4 minutes. An iterative algorithm was used to calculate the orientations, (θ,ϕ) weighted equally by solid angle. A representative set (N = 28) is shown in Fig. 1.

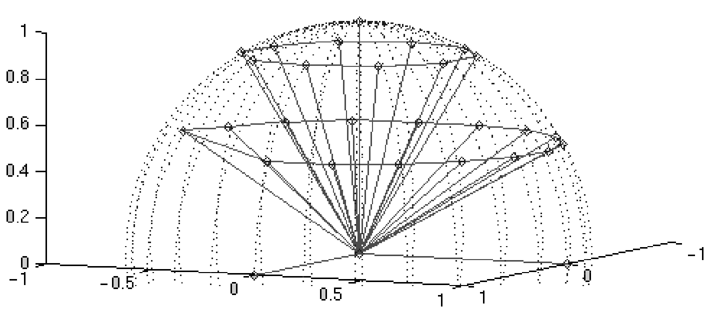

Figure 1: Gradient Orientations for N = 28.

The b-value was varied from 500 to 3000 s/mm^2 in 250 s/mm^2 increments for N = 6 (8 NEX) and 55 (1 NEX). For N = 9, 14, and 28, a smaller range of b-values (1250 to 1750 s/mm^2) was selected with the corresponding averages (6, 4, and 2 NEX, respectively) chosen to normalize the acquisition times.

CR and CNR were computed for several regions of interest: splenium, left/right internal capsule, and left/right arcuate fasciculus. Gray matter without tracts in the frontal lobe was used as a contrast reference.

Results and Discussion

The relationship between CNR and b-value at two different N (6 and 55) are summarized in Figure 2, with a polynomial fit to illustrate the trend. The experimental data suggest that increasing N lowers the optimal b-value required for maximum CNR. For N = 6 (8 NEX), the peak occurred at ~2500 s/mm^2, whereas for N = 55 (1 NEX) the optimum was between 750 and 1250 s/mm^2. Lower optimal b-values at higher N make high-quality diffusion-tensor images possible with reduced distortion [3].

The dependence of maximum CNR on N is given in Figure 3. The results broadly suggest that CNR is higher at larger N. This implies that increasing N is more effective than signal averaging at reducing noise and preserving contrast. Two relative diffusion anisotropy images are compared in Fig. 4.

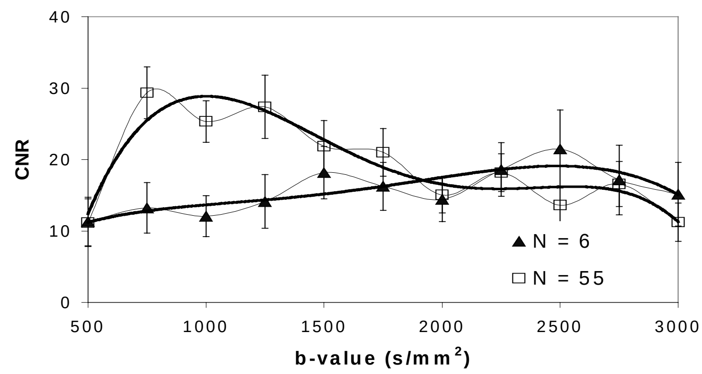

Figure 2: Maximum Observed CNR vs. b-value for N = 6 and N = 55.

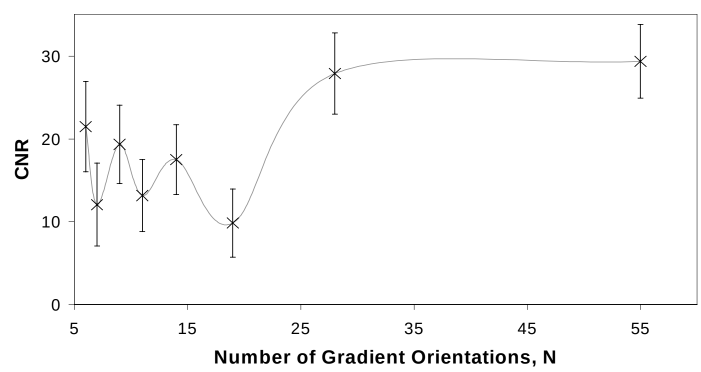

Figure 3: Observed CNR vs. Number of Gradient Orientations.

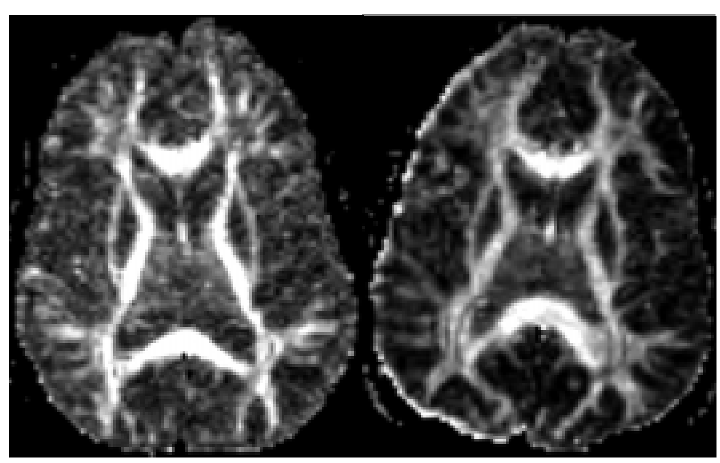

Figure 4: Comparison of Diffusion-Tensor Images. Left image: N=6, NEX=8, b=2500 s/mm^2. Right image: N=55, NEX=1, b=1000 s/mm^2.

Conclusions

Initial analysis of our data suggests that a larger number of gradient orientations have an advantage over signal averaging. Continued investigation is under way to construct a viable theoretical model.

References

1. Pierpaoli et al., *Radiology* 201:637-648 (1996).
2. Basser et al., *Magn. Reson. Med.* 39:928-34 (1998).
3. Zhou et al., *Proc. 5th Int'l. Soc. Magn. Reson. Med.*, pg.1722 (1997).