Systematic assessment of effects of noise and resolution on metrics of DTI tractography

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Introduction

Fiber volume and fiber count are two important metrics derived from DTI tractography and have become widely used quantitative measures of white matter in neuroscientific and clinical studies [e.g. 1-3]. It is well known that the tractography is sensitive to the noise and partial volume effects. However, little systematic study on the relationship between these two measures and noise or resolution has been reported so far. In this abstract, by establishing DTI datasets with different SNR and resolution, we traced in all generated datasets the left cingulum which is less interfered with crossing fiber issue with a widely used streamline fiber tractography [4]. Fiber count and fiber volume were measured for traced tracts. Our results indicate that although both fiber volume and fiber count are sensitive to SNR and resolution, resolution plays a more important role on both measures. With a normal range of SNR from 42dB to 100dB, both measures are almost constant for a resolution ranging from 1.5x1.5x2mm^3 to 3x3x3mm^3. Fiber count of very high resolution data 0.8x0.8x2mm^3 is more sensitive to SNR compared to lower resolution data. Compared to fiber count, fiber volume is a more stable measure as multiplying larger voxel size may compensate the reduction of the fiber count with resolution decrease.

Methods:

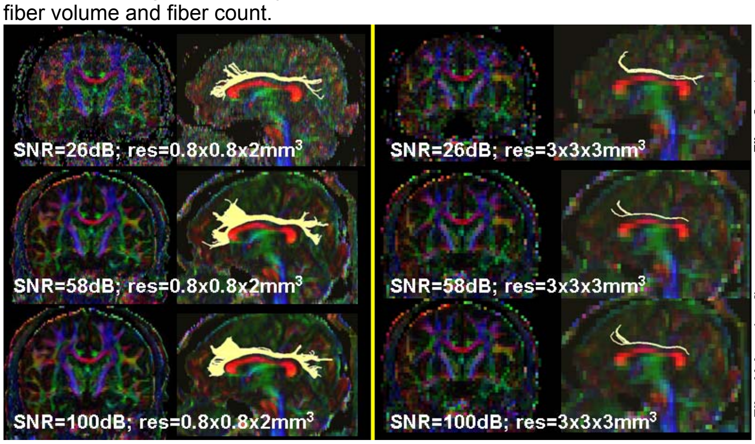
Data acquisition*:** A healthy volunteer was scanned in 3T Philips Achieva MR system to obtain high resolution and high SNR data. DTI data was acquired using a single-shot echo-planar imaging (EPI) sequence with SENSE parallel imaging scheme (reduction factor =2.3). DWI parameters were: FOV=212/212/140mm, in plane imaging matrix = 128× 128 reconstructed to 256x256, axial slices thickness = 2 mm without gap, 30 independent diffusion-weighted directions with b-value = 700 sec/mm^2, TE=97ms, TR=7.6s. The data acquisition was repeated four times to increase SNR. ***Generation of datasets with different SNR and resolution: Gaussian noise with different standard deviation and zero mean was added to the k-space data of the high SNR and high resolution diffusion weighted images (DWI) to get DWI with SNR=26, 42, 58, 71, 87, 100dB. These high resolution DWI images at different SNR were further downsampled to get the images with resolution of 0.8x0.8x2, 1.5x1.5x2, 2x2x2, 2.5x2.5x2.5 and 3x3x3mm^3. For each data group with the same SNR and resolution, three datasets were constructed. All of these were done using in-house software written in IDL. ***DTI tractography:*** For all 90 DTI datasets of DWIs, we first fit the tensor with DTIstudio [4] to get the fractional anisotropy map and primary eigenvector map. A standard protocol [5] of human brain tractography was then used to trace the left cingulum, which is well isolated from other white matter tracts and anatomically well documented. Numbers of cingulum fibers were counted by DTIstudio and fiber volume was calculated by multiplying the number of fiber voxels to the voxel size.

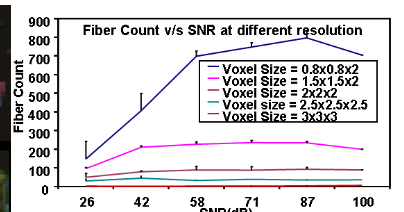
Results

Fig. 1 shows the colormaps and traced fibers with the generated DTI data of highest (0.8x0.8x2mm^3) and lowest resolution (3x3x3mm^3) and three SNR levels at 26dB, 58dB and 100dB. It is clear to see in Fig. 1 that resolution has larger impact than SNR on fiber count or fiber volume. From the left panel of Fig. 1, fewer fibers were traced with DTI data at very low SNR (26dB) and there is little change of traced fibers with SNR from 58dB to 100dB for high resolution data. Low resolution data is quite insensitive to the SNR level from the right panel of Fig. 1. For data of both resolutions, SNR level from 58dB to 100dB where most DTI images are normally acquired has little impact on traced fibers (Fig. 1). This insensitivity to the SNR has been further confirmed with the plots of fiber count and fiber volume at different SNR and resolution, shown in Figs. 2 and 3. From these two figures, it can be observed that at most resolution levels, i.e. 1.5x1.5x2mm^3 to 3x3x3mm^3, both fiber count and fiber volume reach a plateau after SNR rises to 42dB. By comparing Fig. 2 and Fig. 3, we found that fiber count is more sensitive to the resolution than fiber volume. Fiber volume for all data resolution except the very low resolution 3x3x3mm^3 has little change, clustering around 4000 to 5000mm^3 for SNR ranging from 42dB to 100dB.

Conclusion and discussion

In this study, we systematically assessed effects of noise and resolution on two quantifications of fiber tractography, fiber volume and fiber count. These two metrics are both affected by noise level and resolution to some degree. Therefore, cautions need to be taken when using these two measures. Both metrics are more sensitive to resolution than noise level. In fact, at the normal SNR range, there is a plateau of both measures for each resolution. As the SNR decreases to a very low level, the fiber count and fiber volume decrease accordingly. At very low SNR, the DWI signal is very close to the value of the noise level and diffusion tensor cannot be fitted correctly. Hence the FACT algorithm fails to trace the fibers with wrongly fitted tensors. However, for a normal range of SNR, tractography is quite robust to noise. Influence of resolution on interpreting the tractography results has been reported in the literature [6]. As the resolution decreases, the partial volume effects and intra-voxel heterogeneity contribute to the decrease of fiber count. A more direct reason of fiber count decrease is that fewer voxels are occupied by a specific white matter tract. By multiplying the voxel size, the decrease of fiber count is compensated by the increase of the voxel size, resulting in a more stable fiber volume compared to fiber count. To draw a more general conclusion, we are including forceps major of corpus callosum and another streamline tractography method [7] to examine the effects of noise and resolution on fiber volume and fiber count.





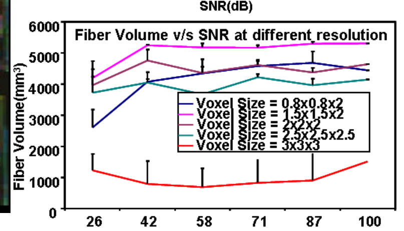


Fig. 1 (left): The coronal DTI colormaps and tractography of the cingulum bundle. The middle vertical yellow line separates the images of highest resolution (0.8x0.8x2mm^3) on the left and lowest resolution (3x3x3mm^3) on the right.

Fig. 2 (upper right): The plot of fiber count vs. SNR at different resolutions.

Fig. 3 (lower right): The plot of fiber volume vs. SNR at different resolutions.

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