Six is Enough? Examining the Controversy of 6 versus 30 Diffusion Encoding Directions for Deterministic Tractography of Human Brain

C. Lebel[1], T. Benner[2], and C. Beaulieu[3]
[1]Biomedical Engineering, University of Alberta, Edmonton, AB, Canada, [2]Athinoula Martinos Center for Functional and Structural Biomedical Imaging, Harvard University, Boston, MA, United States, [3]Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada

Introduction: Early diffusion tensor imaging (DTI) studies used six non-collinear diffusion-encoding directions and one non-diffusion weighted acquisition — the minimum needed to fully estimate the tensor. Simulation studies show more robust estimates of fractional anisotropy (FA) and mean diffusivity (MD) and less directional bias for tractography using DTI data with more than 6 directions[1-7], and given its availability on modern scanners, the use of more than 6 directions has become increasingly prevalent. Although other simulations suggest there may be little advantage to more directions[8,9], there is a prevalent view that 6 direction data, even with high SNR, is inadequate (as opposed to not quite as good) for deterministic tractography. Some ROI analyses in human brain report FA differences between 6 and more directions[10,11] while others do not[12,13]. Interestingly, inter-subject and inter-scan variability appear to be much greater than variability associated with number of directions[14]. Tractography is often used in clinical studies to define a 3-dimensional volume for quantitative comparison of diffusion parameters, yet an evaluation of 6 versus higher directions for this purpose has not been reported. The goal of this study was to determine the effect of a typical DTI acquisition with 6 versus 30 diffusion-encoding directions on deterministic tractography quantitative measures in human brain.

Methods: DTI acquisition used single shot spin-echo EPI on a 1.5T Siemens Sonata, 40 3mm slices (no gap), b=1000s/mm^2, TE/TR=100/6900ms, 128x128 matrix, 75% phase partial Fourier, 220x220 mm^2 FOV, scan time 8:11. Five healthy volunteers 23-31 years received two protocols: (A) 6 diffusion-encoding directions, 1 b0 image and 10 averages, and (B) 30 directions, 5 b0 images and 2 averages (both had 70 acquisitions/slice). The genu, body, and splenium of the corpus callosum (GCC/BCC/SCC), superior/inferior longitudinal fasciculi (SLF/ILF), superior/inferior fronto-occipital fasciculi (SFO/IFO), uncinate fasciculus (UF), corticospinal tract (CST), anterior limb (ALIC), cingulum (CG), and fornix (FX) were delineated using a previously described semi-automated tractography method[15]. FA and MD were averaged over all voxels along the tract; each voxel counted once. Mean FA, MD, volume, and number of streamlines were compared with paired t-tests; standard deviations were compared with F-tests ($p<0.05$ uncorrected).

Results/Discussion: In general, the color maps and tracts derived from both acquisitions appear similar (Fig 1), with minor qualitative differences. Quantitative analysis over all subjects showed that FA and MD had one tract each with mean differences and one that differed in standard deviation; two tracts had different mean volumes (Fig 2). FA, MD, and volume differences were small, and cannot be interpreted as robust as none would survive multiple comparison correction. Note that inter-subject variability is much greater than mean differences between the groups, and that differences between tracts are consistent (e.g. SCC FA > UF FA, etc). For number of streamlines, 7/12 tracts had significantly different means, while the UF had different standard deviations (Fig 2); notably, these differences are not consistent (30>6 for 3 tracts, 6>30 for 4 tracts). Given these results, 6 direction DTI studies (mostly on-going multi-year studies or those without new scanner upgrades) should be considered adequate for the purpose of diffusion parameter measurements from deterministic tractography if a sufficient number of scans is acquired to attain good SNR[8,14,16]. However, the advantages shown by simulations (e.g. reducing within-subject variability and directional bias) and the ability to use advanced analyses (e.g. probabilistic tractography) encourage the use of more diffusion directions for new studies.

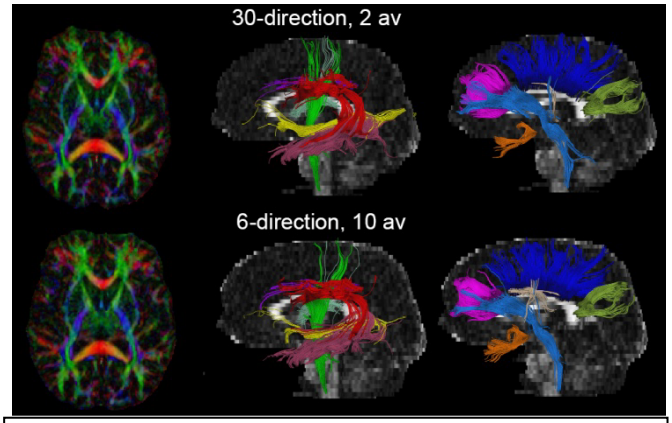

Figure 1: Color maps and all 12 tracts reconstructed from each acquisition shown in one volunteer. While several tracts appear "fuller" with 30 directions, the volumes are not different (Fig 2C), except the GCC/SCC.

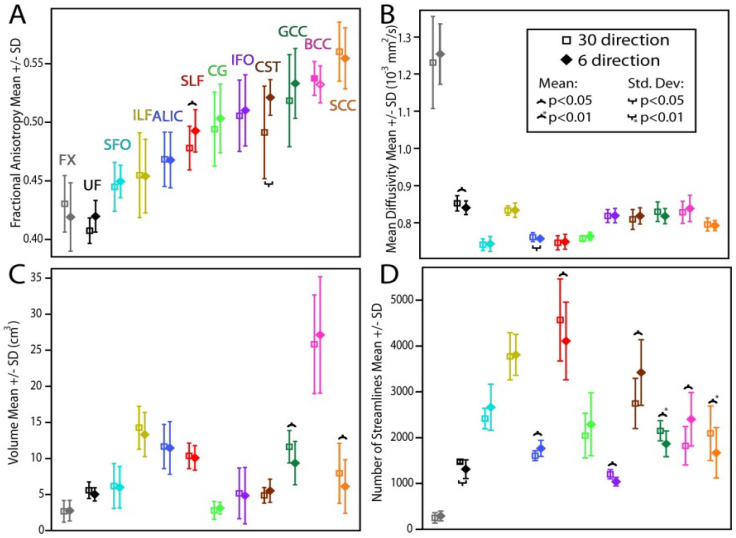

Figure 2: (A) 11 of 12 tracts show no significant difference in FA or (B) MD. (C) Tract volume, which reflects the number of voxels queried for FA/MD, is the same for 10/12 tracts. (D) There are 7/12 tracts with differences in the number of streamlines. but the effects were not consistent.

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