SNR Dependence of DTI Fiber Tracking Protocols

M. Aksoy[1,2], B. Acar[3], R. Bammer[2]

[1] Department of Electrical Engineering, Stanford University, Stanford, CA, United States, [2] Lucas Center, Department of Radiology, Stanford University, Stanford, CA, United States, [3] Department of Electrical & Electronics Engineering, Bogazici University, Istanbul, Turkey

Introduction: DTI based tractography promises to become a useful tool in basic clinical neuroscience and studying abnormalities in various diseases like schizophrenia, multiple sclerosis and neoplasms. Current imaging protocols that produce high fidelity DTI data for tracking are prohibitively long for clinical settings. The objective of this study was to determine whether or not DTI protocols that are fast enough to be used for routine clinical work-up provide results that are comparable to a gold standard defined by a high SNR DTI protocol.

Methods: We defined two outcome measures: 1) The deviation of the closest tracking endpoint between the gold standard (GS) and the protocol proposed for clinical use, and 2) a metric that characterizes the overall deviation between fibers computed with the GS and the clinical protocol. Specifically, we used "Closest Point Euclidean Distance", "Closest Point Harmonically Summed Euclidean Distance", "Closest Point Hausdorff Distance" and "Curve Fitting to Closest Point Distance" as the similarity measures between the fibers derived from the gold standard and the proposed clinical protocol. The endpoint distance, which is defined as the Euclidean difference between the endpoints of the fibers, is especially robust against the differences in fiber lengths; however, it does not take into consideration the path history or the entire fiber trajectory. Closest Point Euclidean distance gives a similarity measure that takes into account the entire evolution of a fiber path. Closest Point Harmonically Summed Euclidean Distance takes a harmonic sum over the set of points on a pair of fiber and is especially preferred for its robustness against outliers. Hausdorff distance, which is defined as the maximum distance between two curves, is a very intuitive metric that is often used in measuring the similarity between two curves. Curve fitting methods, which cover the Line Fitting and Exponential Curve Fitting algorithms, assume the existence of a deviation of two fibers either in a linear or an exponential fashion, which is mostly a reliable assumption in the vicinity of the seed point.

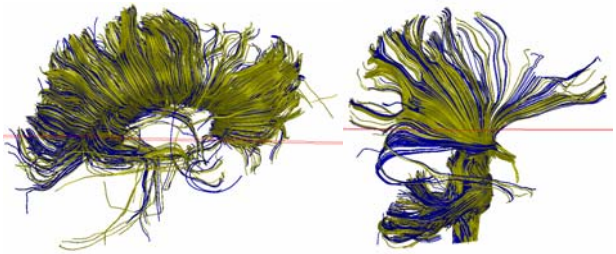

Figure 1 – The fibers from the NEX 1 data (blue) and the gold standard (gold) in the same visualization window for Corpus Callosum (left) and Corticospinal Tract (right)

Whole brain DTI scanning was conducted on a 1.5T unit with 50mT/m maximum gradient strength. The scanning parameters were as follows: FOV=25cm, slice thickness/gap=3mm/0mm, 24 encoding directions, b=850s/mm^2. The total scanning time per average was less than 2.5min. To study the influence of SNR on the tracking results the protocol was repeated six times. For DTI postprocessing, repetitions were averaged that correspond to a NEX range from 1 to 6 (GS). Fibers from the corpus callosum (CC) and the cortico-spinal tract (CST) were selected for further analysis.

Results: The results for these 6 different types of measures are summarized in Table 1 and Figure 2. With increasing SNR the endpoint and similarity measures increase to match the GS. The parameters extracted from these models give an intuition about the speed of the deviation, which of course is expected to be higher for low SNRs due to an increased uncertainty in the eigenvector estimation. For different number of averages table 1 shows the results for 5 different types of metric used, averaged over all the fibers emanating from the seed regions in the CC and CST:

Table 1 – Resultant Mean Metric Values for Fibers Starting from Corpus Callosum (CC) and Corticospinal Tract (CST) for different number of averages used

	Endpoint Distance (mm)		Closest Point Euclidean Distance (mm)		Closest Point Harmonically Summed Euclidean Distance (mm)		Closest Point Hausdorff Distance (mm)		Line Fitting Analysis – Slope of line	
	CC	CST	CC	CST	CC	CST	CC	CST	CC	CST
NEX1	2.3680	2.0016	2.4683	6.9410	0.6638	0.9433	8.2347	20.7605	0.0516	0.1261
NEX2	1.5525	1.3941	2.3742	5.6961	0.5629	0.6777	8.4741	17.8812	0.0466	0.1017
NEX3	1.0048	1.0001	1.9163	4.9331	0.3897	0.5370	7.3479	15.7320	0.0405	0.0875
NEX4	0.8310	0.6820	1.6710	4.2479	0.3168	0.4316	6.5830	13.9338	0.0348	0.0736
NEX5	0.4554	0.2211	1.2702	3.1833	0.1441	0.2710	5.3535	10.6699	0.0259	0.0549

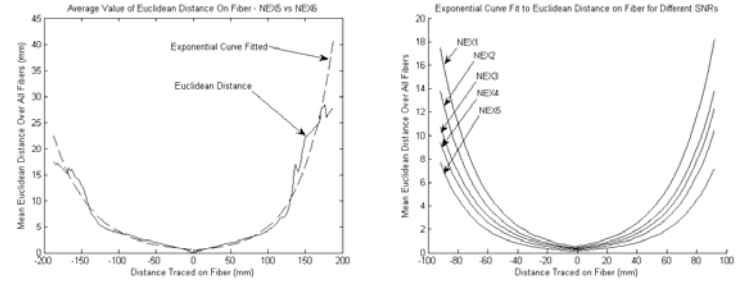

Figure 2 –* Left*: The Euclidean Distance between the points on fibers from the NEX1 data set and the gold standard as a function of the distance traversed along the fiber away from the seed point. The dotted line shows the Exponential curve fitted to this data.* Right*: The Results of the Exponential Curve fit using different number of averages for tracts in Corticospinal Tract

Conclusion: In this study, it has been found that increasing the number of scans and thus increasing the SNR indeed helps in constructing more accurate fiber trajectories. In the endpoint distance analysis used, it is found that the mean distance between the endpoints of the fibers derived from GS and the clinical protocol decreases by more than 75% if we go from 1 average to 5 averages (Table 1). The same is also true for the similarity between the fibers, where the error decrease in most of the similarity measures is on the order of 50% or more. It can be seen that deviations accumulate with tract length. The deviations become increasingly apparent in areas of lower FAs, such as juxtacortically, where reduced SNR can lead to a higher likelihood of incorrect estimation of fiber orientation. The results from this study cannot be generalized and are region and protocol dependent. It seems that clinical protocols suffice to map major fiber bundles. Mapping of more juxtacortically located fibers, however, warrants a higher SNR. Future work will include a more accurate assessment of the exact minimum affordable SNR for a reliable fiber tracking and the consideration of the behavior of fibers in different regions of interest.

References (1) Bammer R, Acar B, Moseley ME., "In vivo MR tractography using diffusion imaging.", Eur J Radiol. 2003 Mar;45(3):223-34. (2) Bammer R, "Basic Principles of diffusion-weighted Imaging", European Journal of Radiology 45 (2003) 169-184. (3) Mori S., C. M. van Zijl P., "Fiber Tracking: Principles and Strategies – a technical Review", NMR in Biomedicine, 2002;15:468-480. (4) Pajevic S., P. J. Basser, "Parametric and Non-parametric Statistical Analysis of DT-MRI data", Journal of Magnetic Resonance 161 (2003) 1-14 **Acknowledgements:** This work was supported in part by the NIH (1R01EB002771), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, and Oak Foundation.