Assessment of local fiber plausibility using a HARDI based reference

Peter F. Neher[1], Bram Stieltjes[2], Ivo Wolf[3], Hans-Peter Meinzer[1], and Klaus H. Fritzsche[1,2]
[1]*Medical and Biological Informatics, German Cancer Research Center (DKFZ), Heidelberg, Germany,* [2]*Quantitative Image-based Disease Characterization, German Cancer Research Center (DKFZ), Heidelberg, Germany,* [3]*Medical Informatics, Mannheim University, Mannheim, Germany*

Purpose: Diffusion based tractography noninvasively provides insight into the course of white matter pathways in the living human brain. However, evaluation of tractography methods is challenging and existing approaches for automatic quantitative assessment mainly focus on measures of general tract overlap or the presence of anatomically plausible connections between brain regions[1,2]. In many applications however it is not only important where the fibers start and end but also whether the tractogram correctly resembles the underlying image data in the single voxels. Thus, we propose an evaluation of the local fiber direction plausibility on a voxel-wise basis. Furthermore many methods are restricted to the evaluation of phantom data that can only represent limited aspects of in-vivo datasets. This is owed to the complexity and diversity of fiber bundles in the brain as well as missing manually defined gold standard as employed in other segmentation tasks. Additionally, diffusion weighted imaging (DWI) in a clinical setting does often not allow for the acquisition of many diffusion shells or directions, resulting in an increased uncertainty in the image information. Using the proposed voxel-wise evaluation, we describe a validation procedure that rates the quality of tractograms obtained from in-vivo images of clinical quality regarding their voxel-wise consistency in comparison to high quality HARDI data.

Methods: As a proof of concept, we implemented two metrics for local comparison of clinical tractograms to a HARDI based reference (Fig. 1, a and b) and applied them to 10 healthy subjects and 11 different open-source tractography methods, ranging from simple deterministic tensor streamlining over probabilistic methods to global approaches. The first method (a) evaluates the mean angular error per voxel between the tracked fibers and the directions estimated from the diffusion signal. Reference directions not detected at all are treated as a 90° error. The second method (b) calculates the mean surface-to-surface error between the reference ODFs[2] and artificially constructed ODFs, obtained by a convolution of the local fiber directions with a single fiber prototype signal. The 10 datasets were acquired with 3 b-values (1000, 2000, 3000 s/mm^2) and 81 gradient directions on each shell. Images of clinical quality were subsampled from the original data by extracting 30 spherically distributed directions from the b=1000 s/mm² shell using an energy repulsion gradient reduction strategy.

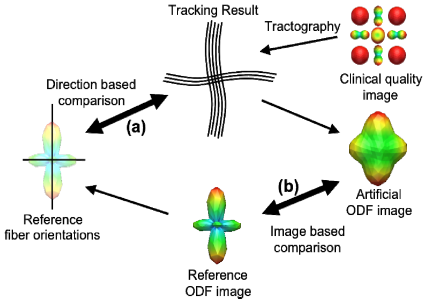

Fig. 1 Comparison of tractograms obtained from clinical DWI data to a HARDI based reference.

Results: We present the results obtained from ROIs containing crossing fiber configurations in the centrum semiovale and pons. We evaluated the mean angular error between the reconstructed and the reference fiber direction (Fig. 2a) as well as the surface-to-surface error between the reference and artificial ODFs (Fig. 2b). Fig. 3 shows a coronal slice through the centrum semiovale depicting the mean angular error per voxel of the two methods yielding the highest and lowest mean error respectively.

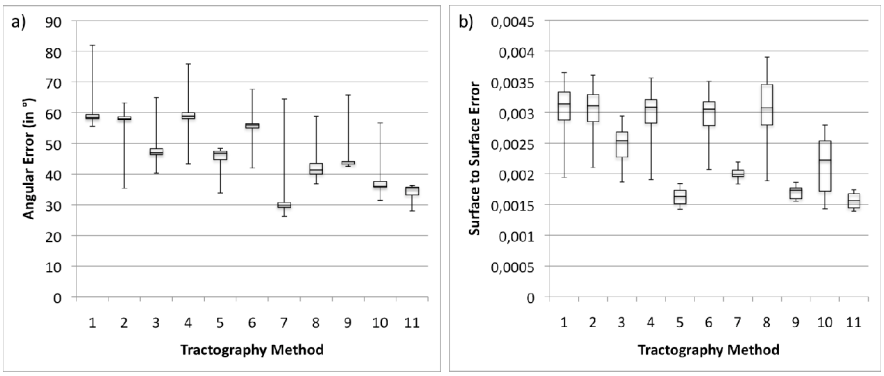

Fig. 2 Evaluation of angular (a) and surface-to-surface error (b) of the different tractography methods. The algorithms represented by the numbers can be retrieved from Tab. 1.

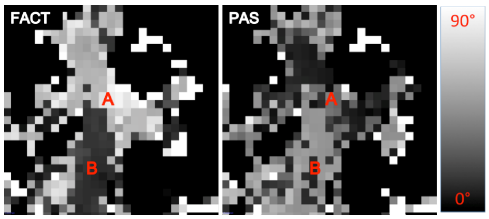

Fig. 3 Angular error of FACT (1) and PAS (7) in the centrum semiovale (A) and the corticospinal tract (B).

1. DTI FACT	7. PAS Streamline
2. DTI Runge Kutta	8. CSD Deterministic
3. DTI TEND	9. Two Tensor UKF
4. Single Tensor UKF	10. CSD Probabilistic
5. DTI Gibbs	11. Q-Ball Gibbs
6. Q-Ball Streamline	

Tab. 1 Algorithms used in our experiments.

Discussion and Conclusion: We proposed an approach to measure the local consistency of tractography results obtained from DWIs of clinical quality with the underlying fiber configuration based on a HARDI reference. The approach enables us (1) to enhance current global performance measures with local plausibility estimates along the tracts and (2) to perform automated reference-based validation directly on in-vivo datasets. Our method was applied to 110 tractograms (11 methods applied to 10 subjects) and well reflected some of the strengths and weaknesses of the approaches in a quantitative fashion. Fig. 3 for example clearly shows a lower angular error of algorithm 7 in the crossing regions of the centrum semiovale (A) as compared to simple FACT tractography, but it also reveals a higher angular error in the single fiber configuration of the corticospinal tract (B), indicating a tendency towards more chaotic fiber configurations even in relatively well-structured regions. The main parameters to be set when applying the proposed framework are the acquisition sequence for the reference images and the local HARDI modeling technique. Here we chose a multishell Q-Ball reconstruction, but the framework allows for an easy integration of other methods like constrained spherical deconvolution (CSD). One limitation of our method is a possible bias towards tractography methods that use a similar modeling technique as the framework. However, since the tractograms are generated on comparably low quality data sets that are subsampled from the reference (in our case 30 direction, b=1000 s/mm²), this bias is expected to be limited. In future, tractography evaluation systems like Tractometer[1] could benefit from the integration of the presented approach and it could help pushing the development of tractography applications that are optimized for neurosurgical planning.

References: [1] P. Fillard *et al.*, NeuroImage 56, 2011 [2] M-A. Côté *et al.*, MICCAI 2012 [3] I. Aganj *et al.*, Magnetic Resonance in Medicine 2010