Probabilistic Tracking can improve the delineation of cortico-spinal tract for neurosurgical planning

M. Mandelli[1], M. S. Berger[2], J. I. Berman[3], B. Amirbekian[3], E. C. Maccagnano[1], and R. G. Henry[3,4]

[1]Department of Neuroradiology, Istituto Neurologico C. Besta, Milano, MI, Italy, [2]Department of Neurological Surgery, UCSF, San Francisco, [3]Department of Radiology and Biomedical Imaging, UCSF, San Francisco, CA, United States, [4]Graduate Group in Bioengineering, UCSF, San Francisco, CA, United States

Problem: White matter fiber tracking based on diffusion MRI is the only technique able to localize the white matter pathways in the brain in vivo. There has been tremendous recent interest in utilization of diffusion MRI fiber tracking for mapping eloquent regions during brain surgery. While some manufacturers have begun to address this demand, the algorithms used tend to be the most basic determinsitic tracking. Furthermore, there is very little data supporting the accuracy of any fiber tracking method in this context where the pathways could be damaged or displaced. Intra-operative electrical stimulation (IES) provides a clinical gold standard for the existence of a functional motor pathway that can be used to determine the accuracy of fiber tracking algorithms. Probabilistic fiber tracking algorithms explore other "high probability" pathways. Residual bootstrap is a non-parametric statistical technique based on data resampling that has been showed to be useful in probabilistic tractography and in assessing DTI methods. In this work we used IES data to evaluate the importance of probabilistic versus deterministic tractography, seeding density, and choice of seed regions.

Methods: We determined the accuracy of probabilistic and streamline DTI methods using 16 subcortical and 7 cortical motor intra-operative electric stimulation (IES) stereotactically identified in nine patients (5M/4F, mean age 41 years) who underwent a craniotomy for resection of a cerebral glioma. The MR images were acquired using a 1.5-tesla Signa scanner (General Electric Medical Systems). The DT imaging was acquired using a single-shot spin echo–echo planar pulse sequence with six diffusion gradient directions (b = 1000 second/mm2). High-resolution T2-weighted (axial FSE pulse sequence) and post-contrast T1-weighted (SPGR sequence) anatomical MR images were also acquired for the stereotactic surgical navigation system.

Diffusion MRI fiber tracks of the motor tract were generated post-operatively in these patients using two different algorithms: the deterministic Fiber Assignment by Continuous Tracking (FACT) method and the probabilistic residual bootstrap DTI technique. We drew three regions ipsilaterally to the brain tumor for the fiber tracking: in the cerebral peduncle, in the posterior limb of the internal capsule, and in the precentral gyrus; the fiber tracks passing through the logical AND of the three drawn regions were retained as pyramidal fiber tracks. We used alternatively both the cerebral peduncle and precentral gyrus as seed regions.. We first defined experimentally a fixed threshold for anisotropy and for angle, and then we delineated the tract, varying the seeding density.

The coordinates of the stimulation points were defined from the screen saves of the anatomical images used onto the StealthStation stereotactic surgical navigation system (Medtronic, Inc.) during resection and registered to the diffusion images used for the fiber tracking. The distance between the stimulation site and the closest in-plane border of the diffusion imaged fiber tracks was measured for the subcortical stimulations. A General Linear Model analysis was performed using the algorithm (probabilistic versus streamline), the seed region (cerebral peduncles versus precentral gyrus), and the seeding density as parameters, in order to evaluate their effect on the tracking. In a secondary analysis, we determined the ability of the algorithms to predict trajectories to the cortical stimulation sites in order to evaluate the feasibility of the two algorithms with varying seed regions and the seeding density.

Results: 16 subcortical motor simulation points (8 in the face/mouth motor sites, 4 in the upper extremity motor sites, and 4 in the lower extremity motor sites) and 7 cortical stimulations points (2 in the face and mouth motor sites, 5 in the upper extremity motor sites) were identified.

A statistically significant difference was found between the two methods in assessing the distance between the DTI tracks and the subcortical stimulation sites. The probabilistic method delineated tracks closer to the stimulation points compared to the deterministic method, when starting either from the motor cortex or from the cerebral peduncle. With the probabilistic tracking method we also observed increasing proximity to stimulation points with increasing seed density; at low seed densities (27 per voxel) the probabilistic algorithm gave similar results to the deterministic algorithm, but improved results at high densities (125 per voxel) [Fig 1].

Using the cortical stimulations we found that with both of the methods it was possible to reach the motor sites for the upper extremities except for hand and forearm and not for the face and mouth; whereas only with the probabilistic method starting from the motor cortex, enabled tracking for hand and the forearm stimulation points.

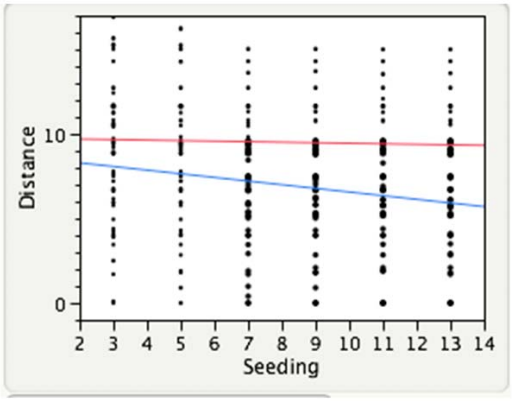

Fig 1: The graph shows the increasing proximity to stimulation points with increasing seed density with the probabilistic tracking method (blue line) compared to the deterministic method (red line).

Conclusions: We demonstrated that the residual bootstrap probabilistic fiber tracking is a promising method to estimate the actual subcortical size of the cortico-spinal tract, but requires sufficient power by increasing the seeding density. In addition, this method was able to define the tracts directed to the hand and to the forearm motor sites with diffusion data acquired only with 6 directions, overcoming the limitations of the deterministic FACT method. The face and mouth motor sites were not feasible with these data and algorithms. High-angular resolution data or more sophisticated tracking algorithms may be needed to track these areas. For the validation and improvement of fiber tracking algorithms for neurosurgical planning, the use of electrophysiological data and functional image guidance can be very useful, especially under difficult pathological conditions.