Tract-specific Mapping of Diffusion Anisotropy Index

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Introduction

Tractography reconstructed from diffusion spectrum imaging (DSI) data has been shown to render tract morphology accurately even in tract-crossing regions [1]. This capability is crucial to clinical application, especially in patients with brain tumors. Indeed, DSI tractography has been demonstrated to provide reliable results of the white matter tracts and their relationships with the tumors [2]. Current RGB color-coding visualization method provides information about tract orientation only. Such representation method is subject to the selection of the reference coordinates, and seems redundant to visualize a 3D object. Tract-specific mapping of diffusion anisotropy (DA) index could reveal the integrity of underlying axonal fibers, and should be effective in localizing pathological changes of individual tracts [3]. In this study, DA was coded with grayscale and was mapped onto each segment of the selected tracts. This visualization method was applied to patients with brain tumors to assess the integrity of the tracts, specifically, to see whether the tracts were infiltrated by tumors or not.

Materials and Methods

Patients with intracranial tumors suspicious of involving corticospinal tracts (CST) were scanned with a 3T MRI system (Trio, Siemens, Erlangen, Germany) before surgery. An echo planar imaging (EPI) diffusion sequence with twice-refocused balanced echo was used to acquire diffusion-weighted images. Isotropic spatial resolution was obtained by making both in-plane and through-plane resolution to be 2.7 mm. The DSI experiment was performed by applying 203 diffusion gradient vectors, each corresponded to one of the isotropic 3D grid points in the q-space. The maximum diffusion sensitivity bmax = 6000 s/mm^2, and TR/TE = 6500/150 ms. 45 transaxial slices were acquired encompassing the whole brain. The experiment completed in 30 min.

DSI analysis was based on the relationship that the echo signal $S(\mathbf{q})$ and the diffusion probability density function $P(\mathbf{r})$ were a Fourier pair, i.e., $S(\mathbf{q}) = FT\{P(\mathbf{r})\}$ [4]. The orientation density function (ODF) was determined by computing the second moment of $P(\mathbf{r})$ along each radial direction. The main orientation of diffusion probability was then determined by the local maximum vectors of ODF [5;6]. Tractography was based on a simple algorithm that was adapted for DSI data. The first three DSI vectors of each voxel over the whole brain were used as the seeds. All fiber orientations of the nearest voxels were used to decide the proceeding orientation for the next step; the most coincident orientation less than 45° was chosen. A new starting point was then obtained to repeat tracking procedure. The proceeding length for each step was 0.5 voxel length. Tracking stopped if there was no coincident orientation in the nearest voxels [7].

To describe diffusion anisotropy (DA), standard deviation of radial mean squared lengths of the normalized PDF was computed [3]. Normalized DA values were coded in grayscale on each segment of the visualized tracks to map the anisotropy change along the tracks.

Results

Corticospinal tracts were segmented by specifying a region-of-interest (ROI) in the cerebral peduncles at the mid brain level. Fig.1 shows tractography of a patient with astrocytoma involving right fronto-parietal lobe. The tractography of CST with RGB color-coding showed that right CST was displaced medially and posteriorly by the tumor (Fig.1a). Such representation cannot differentiate whether the CST was merely displaced or had undergone microscopic change. The DA-coded tractography of the same patient showed marked reduction of DA in the upper portion of right CST (Fig.1b), suggesting that the right CST was not only displaced but also underwent deterioration of integrity at microscopic level. Figure 2a shows tractography of a patient with brain abscess in right parietal lobe. Right CST was displaced anterior by the perifcoal edema. The DA-coded tractogrpahy showed that DA values along the right CST were rather constant and comparable with those in left CST. Only a few fiber tracks that passed through the perifocal edema showed focal reduction of DA.

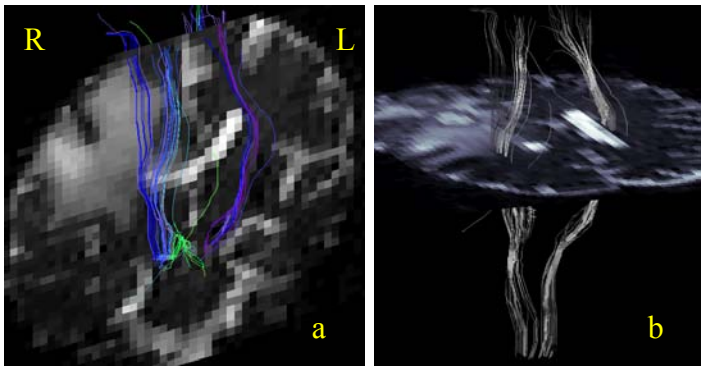

Figure 2. Corticospinal tract of a patient with brain abscess in the right parietal lobe. a: Track orientation is color-coded by RGB representation and the right CST is displaced anteriorly by the perifocal edema. b: The intensity of each segment of the tracks is coded by the normalized DA values. Note that DA of the right CST is rather constant along the tract and is comparable with the left CST. The patient had full functional recovery after excavation of the abscess.

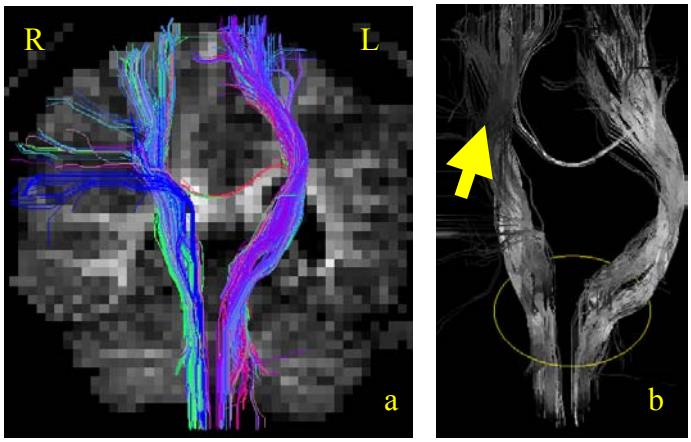

Figure 1. Corticospinal tracts of a patient with astrocytoma in right fronto-parietal lobe. a: Track orientation was color-coded by RGB representation (red: transverse; green: anteroposterior; blue: axial). The right CST was displaced medially and posteriorly. b: The intensity of each segment of the tracks was coded by the normalized DA value. Focal reduction of DA is noted in the cephalic portion of right CST (yellow arrow), where the tracts pass through the tumor.

Conclusions

Using DA-coded visualization method, DSI tractography provides additional information about the tract integrity at microscopic level. DA-coded method might be useful in predicting post-surgical functional recovery. Further distinction of different microscopic changes such as edema, tumor cell infiltration, or demyelination in terms of alteration of diffusion characteristics warrants further investigation.

Reference

[1] Wedeen et al., ISMRM2005, p584. [2] Kuo et al., ISMRM2005, p1064. [3] Kuo et al., ISMRM2003, p592. [4] Callaghan: Principles of nuclear magnetic resonance microscopy. Oxford Science Publication, 1991. [5] Wedeen et al., MRM. 2005 Oct 24. [6] Lin et al., NeuroImage. 19:482-95, 2003. [7] Kuo et al., ISMRM2005, p1311.