Arcuate fasciculus delineation by means of diffusion compartment imaging based tractography

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Purpose: The arcuate fasciculus (AF) is a crucial language pathway in the human brain connecting Broca's area in the frontal lobe to Wernicke's area in the temporal lobe. Using tractography to analyze the AF, investigators have identified anomalies in a variety of diseases[1]. Currently, white matter fiber tractography is most commonly implemented using the principal diffusion direction of the diffusion tensor (DT)[2]. At the resolution of diffusion weighted imaging (DWI) acquisitions, many voxels contain multiple fibers crossing, branching and fanning which infringe the assumption of a single fiber population per voxel imposed by the DT. Thus tractography algorithms based on the DT can follow false tracts or can prematurely stop due to isotropic tensors or to major orientation inconsistencies between neighboring voxels. For instance, tractography of the AF based on a DT model, due to crossing with the superior longitudinal fasciculus III (SLFIII) in the pars opercularis, terminates prematurely instead of extending anteriorly to the pars triangularis. In this work, we evaluated the ability of diffusion compartment imaging (DCI)[3] based tractography to recover the complete length of the AF and compared it with that achieved by DT tractography.

Methods: Fifteen healthy volunteers (nine male; mean age 9.1 years; SD 3.3; range 5-15) were imaged on a Siements 3T Skyra scanner using a 64 channel head coil. The study was approved by the institutional review board (IRB) and all participants provided informed consent. The MRI protocol included the acquisition of a structural T1w MPRAGE sequence and a DWI acquisition consisting of a CUSP90 sequence[3] which includes 30 diffusion-encoding gradients on a shell at b=1000s/mm^2 and 60 extra gradients in the enclosing cube of constant TE with b-values up to 3000s/mm^2. Eddy current distortion was minimized using a twice-refocused spin echo sequence. The DWI were aligned to the T1w MRI with rigid registration (using the mean b=0 image as moving image) and the gradients were reoriented appropriately. The DT model was estimated using a robust least squares algorithm[4] . The DCI model was estimated following Scherrer et al.[5]. Finally, a whole brain tractography for both DT and DCI models were generated using a deterministic and probabilistic algorithm described elsewhere[1]. The AF tracts were selected from the corresponding whole brain tractography using specified regions-of-interest (ROI) described in Lewis et al[1]. Additionally, we used the T1w scan to automatically segment the pars opercularis (PO) and triangularis (PT) as described in Akhondi-Asl et al[6]. The resulting AF tracts were automatically inspected to evaluate if fiber terminations reached both the PO and PT ROI's.

Results: Tractography based on DCI, was able to derive AF tracts that reach both the PO and PT (Figure 1) in all 15 subjects. Contrarily, DT based tractography consistently failed to reach the most anterior portion of Broca's area (PT) in all volunteers.

Conclusion: The DCI model is able to characterize the different tensor components present at the subvoxel level, resulting in a precise characterization of fiber crossings (Figure 1h) compared to the DT model (Figure 1d), which allows for the tractography algorithm to derive the full extent of the AF. Further, qualitative evaluation of results derived using tractography based in a DT model, shows how the obtained AF does not only terminates prematurely, but also follow false tracts extending anteriorly to the tip of the superior temporal gyrus, instead of stopping at Wernicke's area (Figure 1a).

References

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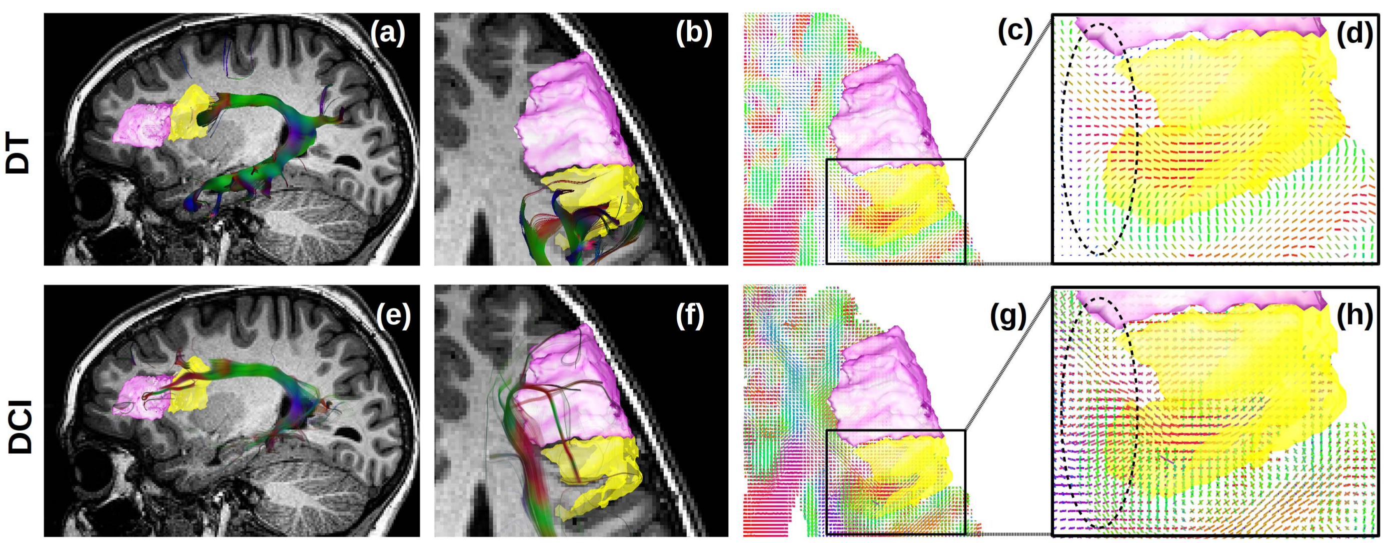

Figure 1: First column: AF reconstruction in sagittal plane based in DT model (a) and DCI model (e), yellow and purple ROIs show the PO and PT automatic segmentation respectively. Second column: Detail of AF reconstruction on axial plane, (b) DT model based tractography terminates prematurely at the level of the PO compared to (f) DCI model based tractography which reaches the anterior section of Broca's area (PT). Third column: Estimated DT model (c) and DCI model (g). Fourth column: (d) Detail of the estimated DT model, observe how it failed to characterize the fiber crossings between the AF and SLFIII at the PO resulting in an early termination of the tractography algorithm (b). In contrast, the estimated DCI model (h) is able to capture the complex anatomy which produce an AF reconstruction which reaches the PT.

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