Visualizing fiber pathways in regions with complex white matter architecture

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Introduction

Fiber tractography (FT) can be used to create *virtual* reconstructions of white matter (WM) fiber bundles, based on diffusion MRI data. Initially, diffusion tensor imaging (DTI) based fiber tracts were displayed as streamlines or streamtubes, giving a three-dimensional representation of the reconstructed pathways [1]. For additional visual cues, tracts can be color-encoded according to any type of local tensor properties, such as the principle diffusion direction or the trace, giving a more informative picture of the local diffusion characteristics along their trajectory [2]. Other FT visualizations have been proposed, including hyperstreamlines, tract ribbons, and streamsurfaces, enhancing the interpretation of the underlying DTI data in different ways [2-4]. None of these techniques, however, is able to visualize tracts in combination with information from the underlying complex fiber architecture, such as the orientation of interdigitating fiber populations. In this work, we present a new fiber tractography visualization for high-angular resolution diffusion imaging (HARDI) data that captures the local configuration of "crossing fibers" and displays it along the fiber trajectory. This tract visualization object can be considered as the continuous envelope of voxel-based three-dimensional HARDI glyphs along the fiber pathway (also known as a hyperstreamline), combining the *local* diffusion information derived from these glyphs, such as the fiber orientation distribution (FOD) or its principal fiber orientations, with the *global* anatomical information obtained from tractography.

Methods

Simulations: A toy example of four fiber bundles was simulated as described previously (Fig. 1a) [5].

Acquisition: A diffusion MRI dataset was acquired from a healthy female subject (25y) on a Philips 3T Achieva MR system using a single-shot spin echo EPI sequence, with 6 B0-images and 60 gradient directions acquired at a b-value of 2500 s/mm^2 [6], using a SENSE acceleration factor of 2. The acquisition matrix of 112×112 was reconstructed to 128×128 with a field-of-view of 224×224 mm^2, and 70 axial slices with thickness 2.0 mm were acquired without gap.

Image processing: FODs have been calculated based on constrained spherical deconvolution (CSD), with maximum harmonics of order $L = 8$ and an FOD peak threshold of 0.1 [7], and CSD-based tractography was performed in ExploreDTI [8,9]. To clearly demonstrate the additional information conveyed by our new visualization method, we show fibers of the arcuate fasciculus (AF), traversing through a region with known "crossing fibers", i.e., the lateral projections of the corpus callosum (CC) and the inferior-superior oriented cortico-spinal tracts (CST) [10]. Finally, by reducing the FOD glyphs to their principal fiber orientations, we can use "streamribbons" as an efficient alternative display approach given its lower rendering complexity [4].

Results

Examples of the HARDI hyperstreamlines and streamribbons are shown in Fig. 1. The FOD glyphs in b) illustrate the local microstructure, where the blue and red colors indicate the orientation of fibers crossing this specific tract (i.e., inferior-superior and right-left, respectively). The FOD amplitude perpendicular to the tract direction is visualized by the hyperstreamline in c), and the peak directions of the fiber population are visualized as a streamribbon in d). In e), a fiber tract from the arcuate fasciculus is shown as a streamribbon, with the boxed region enlarged as streamribbon in f) and as hyperstreamline in g). Both enlargements illustrate the orientations of the fiber populations crossing the AF in accordance with the known architecture in that region, i.e., crossings between the AF, CC, and CST. A different view of the same fiber pathway of e) is shown in h), visualizing the amplitude of crossing populations of the CC and CST more clearly. The streamribbon of e) also demonstrates anterior-posterior oriented fiber populations, corresponding with the inferior fronto-occipital fasciculus, intersecting the AF at its posterior part, and is shown enlarged in i) [11].

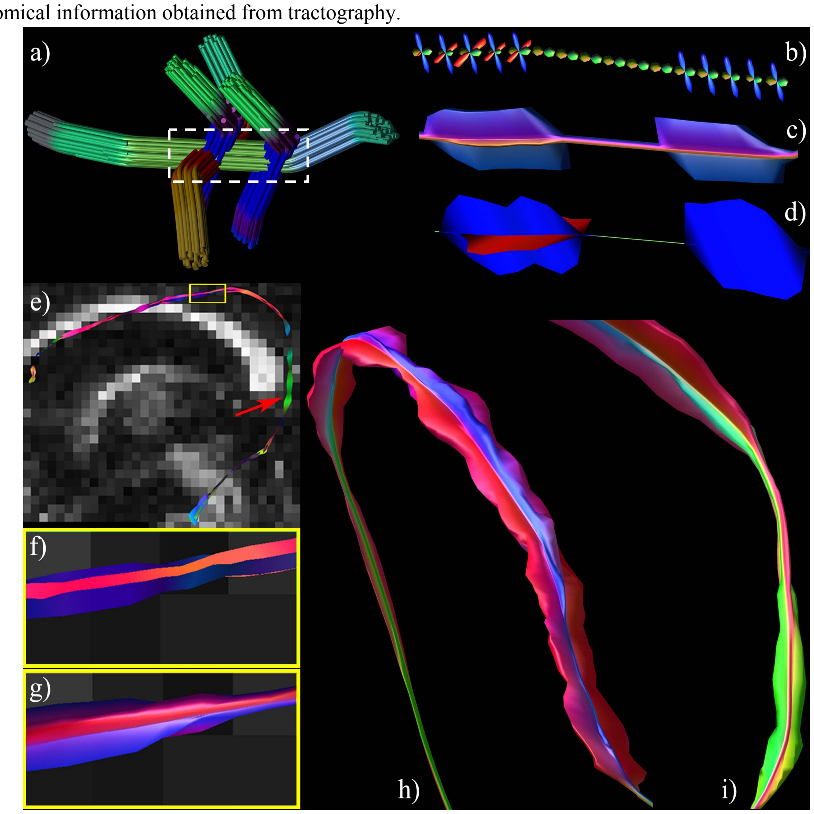

Fig. 1: For the indicated segment of the horizontal bundle shown in a), the FOD glyphs are shown in b), and the HARDI hyperstreamline and HARDI streamribbon derived from these glyphs in c) and d), respectively. A single tract from the arcuate fasciculus (AF) is visualized as a streamribbon in e), with streamribbon (f) and hyperstreamline (g) enlargements of the boxed region. In h), the hyperstreamline is shown along its posterior part from anterior to posterior, clearly illustrating the fiber populations of the corpus callosum (red) and cortico-spinal tracts (blue) crossing the AF. A posterior region – indicated by the red arrow in e) – is enlarged in i), showing anterior-posterior oriented fiber populations crossing the AF.

Conclusion

With this new visualization approach, the information of the local fiber architecture can be combined with the global anatomical information from fiber tractography, creating a more complete visualization, especially for tracts that traverse through areas of complex fiber configurations. These HARDI-based hyperstreamlines and streamribbons greatly enhance the interpretation of tractography data, aiding in our understanding of the white matter architectural configuration. Although we present this hyperstreamline method with HARDI data to visualize crossing fibers, it can be extended to any diffusion glyph shape.

References

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