Kissing or crossing: Validation of DTI tractography in ground truth hardware phantoms

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Introduction

Diffusion Weighted MRI combined with fiber tracking is a widely used technique to study white matter architecture. One of the major problems in fiber tracking is validation of the resulting fibers, particularly in regions of low anisotropy, which may represent "kissing" or "crossing" nerve fibers. For ground truth validation, a DTI straight phantom consisting of Dyneema wire bound together by a shrink wrap tube was proposed [1]. We developed ground truth phantoms containing branching ("Y-phantom") and crossing ("X-phantom") fiber bundles, to test the performance of two types of fiber tracking algorithms in regions of low anisotropy. Streamline fiber tracking allows for visualization of fiber bundles, while a probabilistic algorithm may link confidence to the traced bundles.

Methods

Phantom construction A branching and a kissing phantom (left figure) were constructed following the method of [1]. Ø 10µm Diolen fibers (KUAG, Germany) were wound to a bundle. A 14mm (pre-shrinking) shrink wrap tube was placed over the bundle under water. Hereafter the phantom was placed in boiling water for at least 180s. For the crossing phantom, 16 bundles of 500 and 9 bundles of 1000 fibers were interdigitated arbitrarily. Each leg consists in total of 8500 fibers. The branching phantom consists of two bundles of 7000 fibers. The phantoms were placed in a container filled with water.

Acquisition DW-EPI measurements were performed using a 3T Siemens Allegra system. TR/TE 5900/77ms, 50 2mm slices. b-value=750s^2/mm, 54 measurements (6 b_0 , 48 directions DW). Voxel size 2×2×2mm. Two independent measurements were performed at room temperature.

Data processing the data was analyzed in two fiber tracking algorithms: a conventional streamline algorithm [2], implemented in in-house *C++* software in combination with BrainVoyager (Brain Innovation, NL). Fractional Anisotropy (FA) stopping threshold was 0.15, integration step size 0.5mm. No threshold was applied on ADC values. Seed points were placed according to figure 2.II. Fibers were traced from ipsi-lateral ROIs and contra-lateral ROIs via the middle ROI. A probabilistic algorithm: FSL-FDT (Image Analysis Group, Cambridge University, UK) is tested on the data with default parameters [3] and ROIs at similar locations as the streamline tracking. Performance of the algorithms was evaluated visually.

Results

Figure 2.I shows a boxoid visualization of the diffusion tensor of one of the data sets. Boxoids are color coded according to direction of the major eigenvector. FA in both phantoms is high enough (>0.15) to enable streamline fiber tracking. Figure 2.II and 2.III show the green bundle is correctly traced in the X-phantom, but the blue bundle bends upwards after passing the crossing region. The pink bundle diverges into two bundles. FSL-FDT results from ROIs at top and bottom terminate at crossing level, and the distribution inside the crossing region, obtained with a ROI inside the region, shows no extension into the legs of the phantom (Fig. 2.IV).

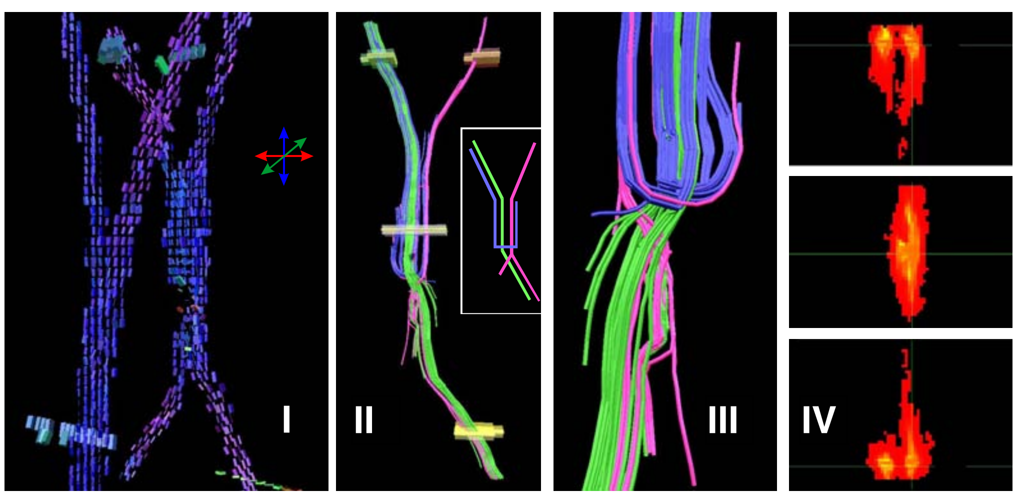

Figure 2, from left to right: I. boxoid visualization of diffusion tensor, showing 'Y' and 'X' phantom. Color according to orientation. II. ROIs and stream-line fiber tracking of the X phantom. Shown tracts are dissected. The inset shows the major fiber paths. III. Detailed view of the center of the X-phantom seen from the opposite side as II. IV. FSL-FDT probabilistic map. Yellow=high, red=low probability. Orientation similar to panel II.

Conclusions

Despite sufficient angular and spatial resolution in the DWI acquisition, both a streamline and a probabilistic fiber tracking algorithm could not fully retrieve the underlying fiber structure of the phantoms. We believe this is due to the relatively small size of the interdigitated bundles relative to the DWI resolution. Future work includes construction of hardware phantoms with larger interdigitating sub bundles. This might lead to better estimates about bundle sizes, which can be detected in hardware phantoms, and by extension in the human white matter.

References [1] Fieremans, E. et al, ISMRM 2005 [2] Westin, CF et al, *Med Image Anal*, 6:93-108, 2002 [3] Smith, SM et al, FMRIB, 2004