Diffusion imaging and tractography on a hardware model of the human optic chiasm

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Introduction

The human optic chiasm is an interesting, highly complex fiber structure, but hard to image in vivo, because of subject motion and cardiac pulsation [1]. The anatomy is known quite well. In [2], a detailed report was made of high spatial resolution ex-vivo Diffusion Tensor Imaging (DTI) and fiber tracking at ultra-high field (9.4T), including an attempt to quantify the number of fibers running ipsi- and contralaterally from the optic nerve to the optic tract. About 75% of the total amount of fibers should pass from the optic nerve to the contralateral optic tract (and hence cross in the chiasm), but only 0-10% were found, likely due to the inability of DTI to represent intra-voxel fiber crossing. Based on the anatomy, a DW-MRI phantom was constructed. The phantom offers the possibility to quantify tractography results on complex realistic fiber-configurations with little limits on imaging time, thus increasing SNR, and does not suffer from motion or cardiac pulsation artifacts.

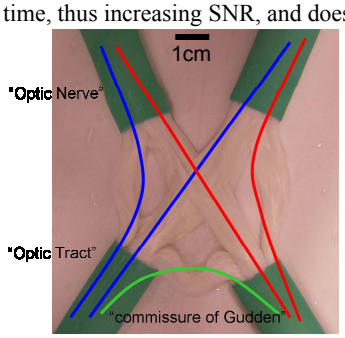


Fig 1: phantom before shrinking. Size is reduced after shrinking.

Methods

- Phantom (fig 1) constructed as described earlier [4,5] by wrapping 10 µm KUAG Diolen™ 22dtex 18 fibers in shrink tube. The crossing is made up of 38 interdigitated bundles of 7200 fibers, 19 for each leg (76% of the total fiber count in the "optic nerve", 61.2% in the optic tract). Ipsilateral (non-crossing; right-right/left-left) bundles of 43,200 fibers (24% of total in the "optic nerve", 19.4% in the optic tract). 'Commissure of Gudden (green)': 43,200 fibers (19.4%). Dimensions of the phantom are 20x20x6mm.
- The phantom is immersed in demi-water + 4 g NaCl/l for coil loading + 0.03 g $MnCl{\cdot}4H_2O$/l to adjust T_1 and T_2.
- MRI scans on a Siemens Allegra 3T, birdcage coil. Doubly refocussed DW SE-EPI; b=1000 s/mm^2, 2x2x2mm voxels, FOV 128x128mm, 22 slices roughly perpendicular to legs. TR/TE = 2300/75ms, 106 diffusion directions, NEX=4. Acquisition time ~30 mins.
- CSD reconstruction (Constrained Spherical harmonics order 10) and probabilistic fiber tracking using MRTrix[6], 1000 generated fibers; Tensor calculation in BrainVoyagerQX 2.0.8, Tensor visualization and streamline fiber tracking (FT) using in-house C/C++ tools. ROIs in slices 2 and 21, 7x7x1 seed points/voxel for streamline FT. Stopping criterium FA>0.15, step size 0.2mm, angle-threshold 120 deg

Table 1: Quantitative tracking results: each entry shows nr of fibers (found %/**true %)** CSD fiber count as fractions (#fibers selected / #samples needed)

Streamline DT fiber tracking

From\To	Left nerve	Right Nerve	Left tract	Right tract
Left nerve	-	0 (0%/**0%**)	41 (84%/**24%**)	8 (16%/**76%**)
Right nerve	0 (0%/**0%**)	-	13 (17%/**76%**)	65 (83%/**24%**)
Left tract	31 (50%/**19.4%**)	8 (13%/**61.2%**)	-	23 (37%/**19.4%**)
Right tract	22 (25%/**61.2%**)	45 (50%/**19.4%**)	22 (25%/**19.4%**)	-

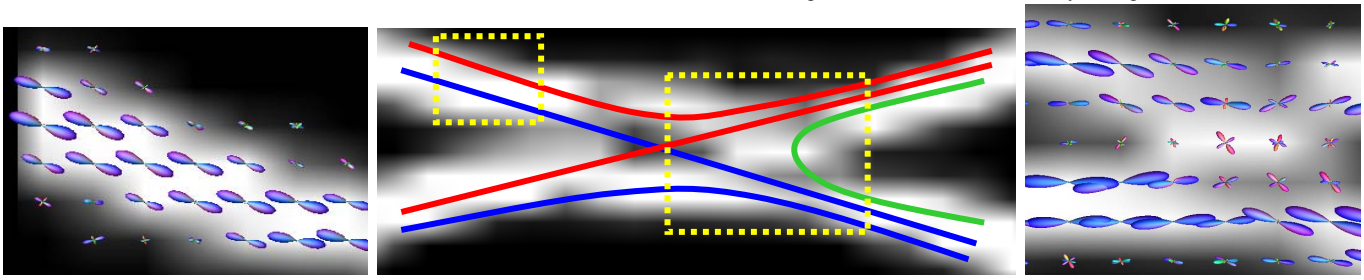
CSD Probabilistic tracking

From\To	Left nerve	Right nerve	Left tract	Right tract
Left nerve	-	<0.001(0%/**0%**)	0.07(58%/**24%**)	0.05(42%/**76%**)
Right nerve	<0.001(0%/**0%**)	-	<0.001(0%/**76%**)	0.16(100%/**24%**)
Left tract	0.14(35%/**19.4%**)	0.09(24%/**61.2%**)	-	0.16 (41%/**19.4%**)
Right tract	0.10(36%/**61.2%**)	0.06(21%/**19.4%**)	0.12(43%/**19.4%**)	-

Results

- CSD Profiles in fig 3: single fibers in legs, complex crossing-fiber structures detected in central regions.
- Table 1: Streamline DT FT: larger contribution from ipsi-lateral bundles than from crossing fibers, not consistent with phantom architecture. "commissure of Gudden" fibers detected.
- CSD-Prob FT: more balanced (and gold-standard correct) contributions of crossing and non-crossing fibers when tracking from the "R/L tracts". Tracking from the "R nerve" does not result in fibers crossing, and tracking from "L nerve" over-estimates the number of crossing fibers, but not as much as streamline DT-FT.

Fig 3: detail of CSD profiles. L: leg of phantom ("nerve") R: complex fiber structure retreived by CSD profiles.



Discussion

The phantom is suitable for investigating complex realistic fiber structures inspired by known anatomical structures, with the ability to quantify the results in terms of the percentage of fibers with the correct start and end point.CSD profiles show multiple lobes in the complex center, and single lobes in the legs of the phantom. A more realistic fiber count is achieved for crossing using CSD FT than using streamline FT. The crossing fibers from R-nerve to L-tract are under-represented, possibly due to the low FA in the central crossing region of the phantom. Complex realistic diffusion phantoms form ideal test objects to improve and validate imaging and DW-MRI tractography on complex fiber structures such as the optic chiasm.

References 1. *NeuroImage*:47(2009)1244–1251 **2.** *NeuroImage*:39(2008)157–168 **3.** *NeuroImage*:35(2007)1459–1472 **4.** *Proc ISMRM 15* (2007) 1479 **5.** *Proc ISMRM 16* (2008) 1819 **6.** http://www.brain.org.au/software/