Visualization of the cingulum bundles in-vivo using optimized MR diffusion spectrum imaging

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Introduction

Previous DTI studies of age-related mild cognitive impairments, which are known to increase the risk for developing Alzheimer's disease (AD) found substantial abnormalities in the cingulum bundle that were even more prominent than the well-established MRI finding of hippocampal atrophy in AD [1]. These observations raise the possibility that diffusion measurements at the tract level of cingulum fibers might yield a powerful marker of incipient AD pathology. However, DTI results can be ambiguous, especially in areas of crossing nerve fibers [2, 3]. Diffusion spectrum imaging (DSI) is more powerful than DTI and likely more sensitive to alterations of the cingulum bundles in AD. Our aim in this in-vivo 4T study on humans was therefore to optimize DSI parameters, especially spatial resolution and diffusion encoding to be able to accurately resolve the cingulum bundles for tract level measurements of diffusion.

Method

DSI using simultaneous echo refocusing (SER) [4] (TR/TE=2800/130, NEX=1, 32 slices to cover the brain) was implemented on a 4T MR medical system (Bruker) using a single housing RF transmit and 8-channel head array coil for signal detection. Fifteen healthy human subjects were scanned to optimize DSI measurements for visualization of the cingulum bundles. Optimizations were carried out by tracing the cingulum bundles primarily as a function of maximal b-value (diffusion sensitizing), the number of q-sampling (diffusion encoding) and spatial resolution (or SNR) of EPI without compromising scan time. Starting initially with b_{max} = 12,000 s/mm^2, 515 diffusion encodings over a full sphere, but relatively low resolution of 3.8x3.8 mm^2 and a long acquisition of 25 min for sufficient SNR, we converged to a more practical setting for human studies using maximal b values in the range between 5000 – 8000 s/mm^2, 258 diffusion encodings over a half sphere, and a resolution between 3.5 and 3.0 mm^2 at a maximum scan time of about 12 minutes. The sequence was also optimized for bandwidth (1502 Hz/pixel), partial Fourier encoding (PFE=6/8) and minimum SNR of about 18:1. Diffusion time was fixed to t_D = 50 ms with Δ/δ=66/60. The optimum setting was determined by repeated DSI measurements on subjects and SNR estimations, fiber tractrographs, and anatomical appearance of the cingulum bundles using trackvis (see trackvis.org). Visual inspections were augmented by quantitative analyses based on track counts, mean length and mean value of the orientation distribution function (ODF), all normalized to voxel resolution. The mean ODF quantifies diffusion in the main direction of the local fibers.

Results

The table shows the results of the quantitative cingulum bundles analysis based on data from 3 subjects. The small standard deviation between subjects shows the reproducibility of the experiments and fiber tracking. The analysis shows that experiments dsi 3&4 yielded simultaneously high track intensity (track counts per area) and long mean length, but the highest mean ODF value was achieved using dsi3. This was also consistent with the best visualization of the cingulum bundles shown in the figure. The fibers are detected by selection of two disks as ROI on the superior and temporal cingulum where the normal orientation to the center of the disks is shown. The human cingulum bundles revealed with the dsi3 setting were also visually comparable with the cingulum fibers of monkey brain as reported in reference [5]. Remarkably, FA values from DTI also increased for higher spatial resolution (dsi 3&4) as expected.

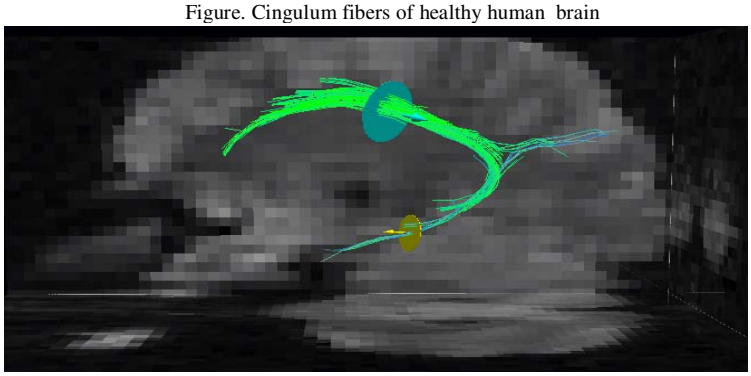
Conclusion

Although it is generally expected that DSI provides high angular resolution of fiber bundles, this study demonstrates that high fiber resolution requires careful tailoring of acquisition parameters, especially spatial resolution and diffusion sensitization. Other fibers with different properties may require different parameter settings. Nonetheless, the data demonstrate excellent and reproducible identification of the cingulum bundles based on DSI acquisition of only 12 minutes duration. We plan to use the gold standard DSI setting for studying the cingulum fibers in aging, mild cognitive impairment and Alzheimer's disease.

Table. Evaluation of Cingulum bundles using trackvis

Meas.(b-value s/mm^2, In-plane res mm^2)	track volume (mm^3)	voxel counts	track intensity (mm^{-2})	mean length (mm)	FA	mean ODF (stradian^{-1})
dsi1(8000, 3.8x3.8)	54.87	82	76.4 ± 2	58.2 ± 7	0.29 ± 0.02	0.12 ± 0.05
dsi2(5000, 3.8x3.8)	54.87	84	92.7 ± 6	62.8 ± 6	0.34 ± 0.02	0.13 ± 0.01
dsi3(5000, 3.0x3.0)	27	98	169.2 ± 10	64.4 ± 5	0.36 ± 0.05	0.37 ± 0.10
dsi4(8000, 3.0x3.0)	27	113	127.5 ± 6	86.8 ± 9	0.37 ± 0.01	0.34 ± 0.02

Figure. Cingulum fibers of healthy human brain



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