Separation of Fiber Tracts Within the Human Cingulum Bundle Using Single-shot STEAM DTI With Partial Fourier Encoding and Parallel Imaging

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Introduction: The cingulum bundle is a complex white matter fiber tract of the human brain that comprises long association fibers, commissural fibers, and various U-fibers. It is located above the corpus callosum and interconnects limbic structures. In this work a separation of the bi-hemispheric lateral longitudinal stria and selected U-fibers was achieved by fiber tractography of the cingulum bundle based on diffusion tensor imaging at 1.8 mm isotropic spatial resolution. Anatomic accuracy without susceptibility-induced distortions was ensured by diffusion-weighted single-shot STEAM MRI with 24 gradient directions and *b* values of 0 and 1000 s mm^{-2}.

Single-shot STEAM DTI: MRI studies were conducted at 2.9 T using a 32-channel phased-array head coil. T1-weighted anatomic images were obtained with an RF-spoiled 3D FLASH MRI sequence. DTI acquisitions were performed at 1.8 mm isotropic resolution using diffusion-weighted single-shot STEAM MRI. A schematic drawing of the sequence is shown in Fig. 1a to identify specific timings and repetition cycles. Briefly, a leading spin-echo (SE) diffusion module gives rise to a diffusion-weighted SE signal at echo time TE_{SE} which replaces the initial 90° RF pulse of a single-shot STEAM sequence. The last interval in square brackets is repeated with a repetition time TR_{STE}. Pre-dephasing of the read gradient also serves to fulfill the stimulated echo condition. The outermost repetition cycle includes the desired diffusion directions, the image acquisition without diffusion weighting, and the acquisition of the external reference lines required for parallel imaging.

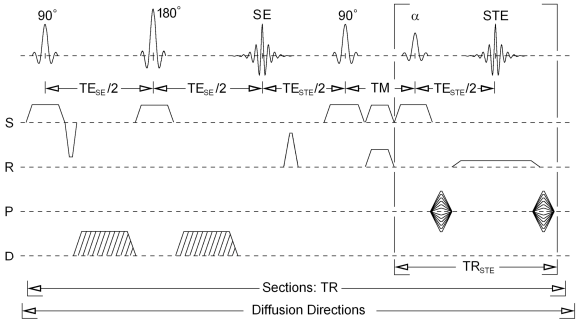

Figure 1a

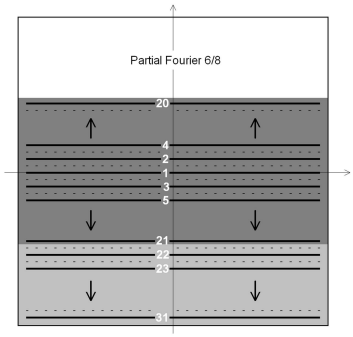

Figure 1b

Method: The SNR performance of a single-shot STEAM sequence largely depends on the number of STEs required for covering k-space. Variable flip angles for the low-flip angle readout pulses were recursively calculated according to $\alpha_i = \arctan [\sin \alpha_{i+1} \cdot \exp (-TR/T1)]$ which generates equal intensities for the individual STE signals. The echo train length depends on the choice of a rectangular field-of-view (FOV) , the use of 6/8 partial Fourier encoding, and the application of parallel imaging based on the GRAPPA technique. Fig. 1b illustrates the resulting coverage of k-space as chosen for the present experimental conditions. For DTI of the cingulum bundle, the head was covered by a 191 mm (read) × 151 mm (phase) FOV and a 106 × 84 matrix yielding 1.8 mm in-plane resolution. The use of partial Fourier encoding and the additional implementation of GRAPPA with an acceleration factor of 2 and a separate acquisition of 24 reference lines reduce the number of lines from 84 to 31. The echo time for the diffusion module was TE_{SE} = 51.5 ms which together with the aforementioned experimental parameters led to a total measurement time of about 290 ms for the acquisition of an individual diffusion-weighted single-shot image. The total measurement time for 3 and 5 accumulations was 15 and 25 min, respectively.

Fiber tractography results: Fig. 2 shows fractional anisotropy (FA) maps of a selected section with contributions from both the cingulum bundle and callosal fibers. While the FA map based on a single acquisition precludes an unambiguous separation of the cingulum bundle (arrows) from neighboring white matter tracks of the corpus callosum, marked improvements are obtained for 3 and 5 accumulations. Although the longest acquisition obviously offers the best SNR, all subsequent fiber tracks were derived from 3 accumulations acquired within a measuring time of 15 min because of the similarity between 3 and 5 accumulations. Fig. 3 - 4 demonstrate the results obtained for the human cingulum bundle (green) in different views and orientations as well as relative to the fibers of the corpus callosum (yellow). In Fig. 3, the lateral longitudinal stria (red) as one of the longest fiber bundles runs from the frontal lobe to the parahippocampal gyrus in both hemispheres. The much shorter U-fibers (blue) that connect directly neighboring structures, enter and leave the cingulum bundle along its entire extension bilaterally. Fig. 4 shows the lateral longitudinal stria.
In summary, our results provide the first in vivo demonstration of the heterogeneous fiber composition of the human cingulum bundle.

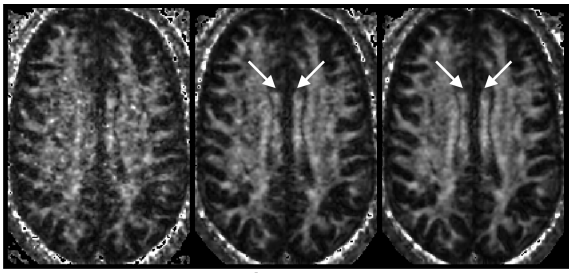

Figure 2

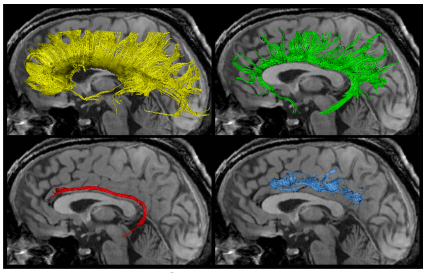

Figure 3

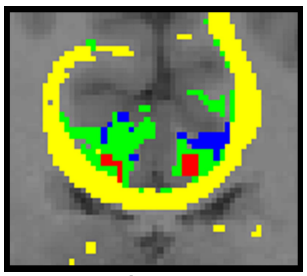

Figure 4

Reference: Separation of Fiber Tracts Within the Human Cingulum Bundle Using Single-shot STEAM DTI With Partial Fourier Encoding and Parallel Imaging (Submitted to MRM)