Structure Tensor Informed Fiber Tractography

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VIP Brain Networks

Introduction

Structural connectivity research in the human brain in vivo relies heavily on fiber tractography in diffusion-weighted MRI (DWI). The accurate mapping of white matter (WM) pathways would gain from images with a higher resolution than the typical ~2 mm isotropic DWI voxel size. Recently, high field gradient echo MRI (GE) has attracted considerable attention for its detailed anatomical contrast even within the white and grey matter (GM). Susceptibility differences between various fiber bundles give a contrast that might provide a useful representation of white matter architecture complementary to that offered by DWI.

Structure Tensor Informed Fiber Tractography (STIFT) is proposed as a method to combine DWI and GE.

Methods

MR data acquisition:

- **GE** at 7T (Erwin L. Hahn Institute, Essen, Germany) — 0.5 mm
  3D FLASH; TR/TE=36/23 ms; flip angle=15º; BW 120 Hz/px; AF=3
- **DWI** at 3T (Donders Institute, Nijmegen, Netherlands) — 2.0 mm
  SE-EPI; TR/TE=8300/95 ms; 61 directions at b=1000 s/mm^2; AF=2
- **T1** at 3T (Donders Institute, Nijmegen, Netherlands) — 1.0 mm
  MPRAGE; TR/TE/TI=2300/3/1100 ms; AF=2

STIFT pipeline:

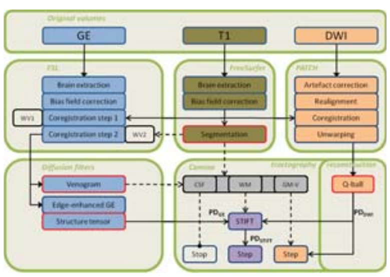

Figure 1. STIFT processing pipeline.

Structure tensor:

- Structure tensor (ST): describes GE image features in a local neighborhood through its intensity gradients
- ST's first eigenvector (Fig3) captures fiber sheet orientation
- Data-adaptive ST: edge-enhancing diffusion filter smooths small inhomogeneities, while enhancing fiber sheets (Fig2ab)

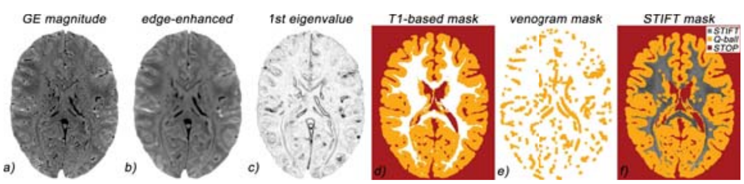

Figure 2. Structure tensor filtering and masking.

STIFT algorithm:

- Tractography algorithms (Camino) were adapted to incorporate the structure tensor by directly influencing the tracking direction
- The adapted tracking direction PD_{STIFT} is calculated as follows: the original Q-ball tracking direction PD_{DWI} is rotated towards the plane orthogonal to the ST's first eigenvector PD_{GE} and proportional to its first eigenvalue
- Masking of large veins and cortex (Fig2d-f; within the mask PD_{DWI} is used)

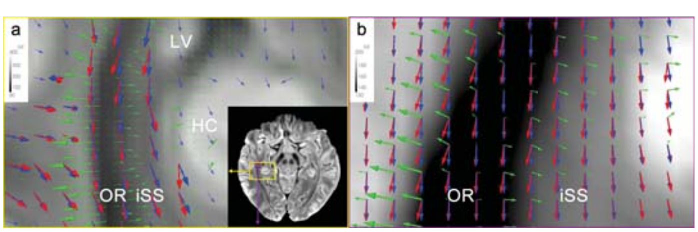

Figure 3. STIFT adaptation. Green arrows: structure tensor's 1st eigenvector (PD_{GE}). Blue arrows: Q-ball peak directions (PD_{DWI}). Red arrows: STIFT adaptation (PD_{STIFT}). a) STIFT adaptation performed at DWI voxel coordinates (Δ=2 mm). b) STIFT adaptation performed at GE voxel coordinates (Δ=0.5 mm); PD_{DWI} vectors are linearly interpolated. OR=optic radiation; iSS=internal sagittal stratum; HC=hippocampus; LV=lateral ventricle. Note that the STIFT vectors closely follow the structure of the optic radiation, whereas interpolated Q-ball vectors are not oriented along the tract.

Results

Optic radiation (OR) and inferior longitudinal fasciculus (ILF):

- STIFT shows anatomically correct OR connectivity between thalamus and primary visual cortex (V1), whereas most Q-ball fibers connect V1 with temporal and frontal areas (Fig4ef)
- separation of tracts for seed pair on both sides of the border of the OR and ILF for STIFT, while Q-ball tracts are mixed (Fig4e)
- seed pairs in the interior of the tracts yield more similar (mixed) tracts as there is little contrast in the GE image (Fig4df)

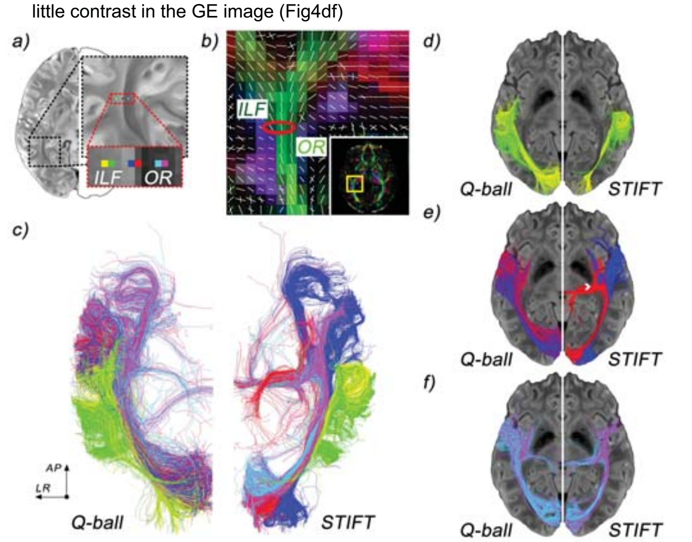

Figure 4. Optic radiation (OR) and inferior longitudinal fasciculus (ILF) fiber tracts. a) set of three seed pairs in the ILF (yellow/green) the OR (cyan/pink) and one pair on both sides of the border of these tracts (blue/red). b) Q-ball peak directions; red circle indicates the seed location. c) fiber tracts for Q-ball and STIFT: composite image for all six seed points (ventral view). d,e,f) fibers tracts for seeds pairs in the ILF, on the border and in the OR, respectively (ventral view).

Cingulum (CG) and corpus callosum (CC): 'kissing' tracts

- Multifiber voxels (with partial volume of CG and CC) lead to cross-over of fibers from CG to CC for standard Q-ball. For STIFT, this substantially reduced (Fig5f)
- The STIFT cingulum extends over the rostrum of the CC, while Q-ball shows more fibers fanning out into the frontal lobe (Fig5c)

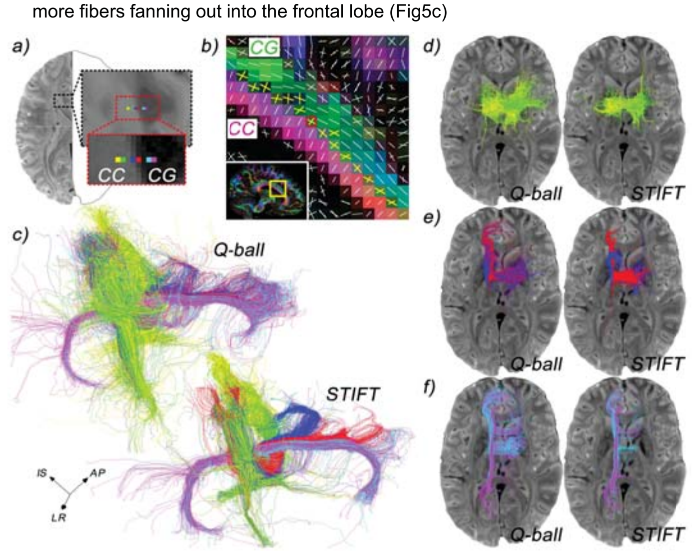

Figure 5. Cingulum (CG) and corpus callosum (CC) fiber tracts. Legend as in Fig4. Note the multifiber voxels (yellow crosses) at the border of the CG and CC that represent 'kissing' fibers

Discussion and conclusion

- STIFT improves tractography of fiber bundles with contrast in GE images
- STIFT can distinguish 'kissing' from crossing tracts, if they have different susceptibility
- Advances in anatomical gradient echo imaging, such as quantitative susceptibility mapping, are expected to further broaden the scope of STIFT to more fiber tracts

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