White Matter Fiber Orientation from High Resolution Structural MRI scans and DTI in Fixed Brain Samples

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Introduction

- The ever increasing number of studies involving diffusion tensor tractography in the brain raises the need for better 'validation' of this technology.
- Ideally one would like to compare diffusion tensor (DTI) or high angular resolution diffusion imaging (HARDI) derived fiber orientation(s) directly with the axonal orientation(s) from histopathology (LFB, MBP, Silver stains etc..).
- Comparison of 3D tractography with multiple 2D stained tissue sections is difficult.
- Classical dissection studies have shown that WM fibers can be clearly visualized, at last in major structures.

Objectives

- Determine whether white matter fiber orientation can be obtained from high resolution structural MRI scans of brain tissue.

Methods

- Small blocks (2.5x5cm) from the corpus callosum/caudate and pons/brainstem were cut from a Formalin fixed cadaver brain.
- Tissue blocks were soaked in phosphate buffered saline containing MR contrast agent (poster 138).
- High resolution (200-225μm isotropic resolution) 3D DTI scans were acquired at 4.7T. ADC and anisotropy (FA) maps were constructed and fiber tracking performed (see poster 142).
- 3D FLASH structural scans were also acquired (50-100μm isotropic resolution) and registered to the DTI data volumes.

Fiber orientation

- Directional information was extracted from the high resolution structural scans by calculating the 2D or 3D autocorrelation function over small tissue regions.
- The autocorrelation function provides a measure of the 'coherence' of a function against linear shifts:

$$R_{xx}(t) = \int_{-\infty}^{\infty} f(t+\tau) f^*(\tau) d\tau$$

- Can be easily calculated in multiple dimensions using the Fourier transform

$$R_{xx}(t) = F_t^{-1}\left[F(\tau)F^*(\tau)\right]$$

Results

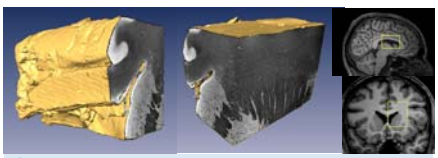

Figure 1. 3D views of the corpus callosum block and its original location in the brain.

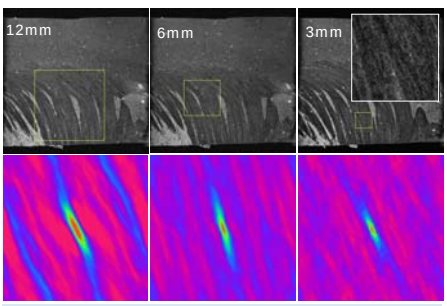

Figure 2: 2D autocorrelation maps (lower) from regions of various sizes (upper) in the ascending (SI) fiber bundles of the internal capsule. Autocorrelation maps show mean fiber bundle orientation in the sampling region: parallel smaller 'peaks' reflect the periodicity of structure perpendicular to the main bundle direction; their separation reflects the relative bundle spacing.

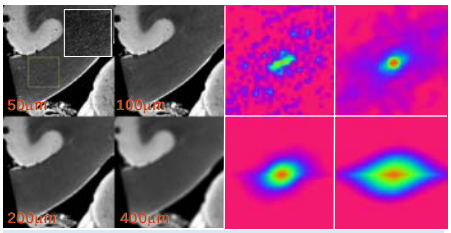

Figure 3. Effect of variable spatial resolution (by 3D smoothing of the original data) on the 2D autocorrelation function for detecting fine structure in the body of the corpus callosum. Orientation information seems to be lost for voxels greater than ~200μm in this case.

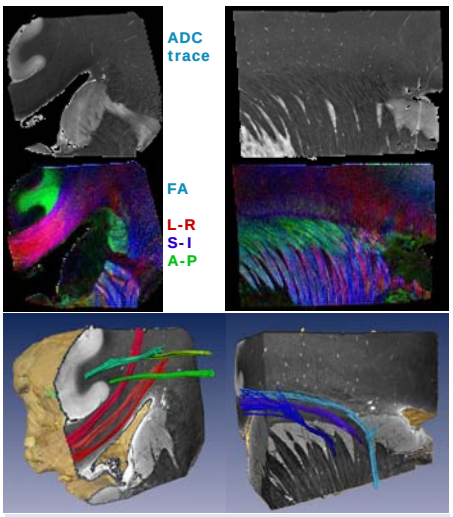

Figure 4. DTI data from the corpus callosum block. Top: Coronal and sagittal ADC maps. Middle: color direction encoded FA maps. Bottom: 3D view of DTI tractography results from selected seed regions placed in the body of the corpus callosum (red), the cingulum (green) and part of the internal capsule (blue).

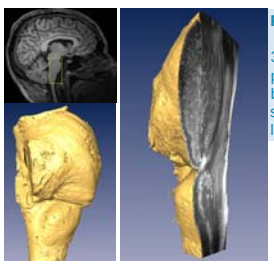

Figure 5.

3D renderings of the pons/brainstem tissue block, and sagittal MRI showing its original location in the brain.

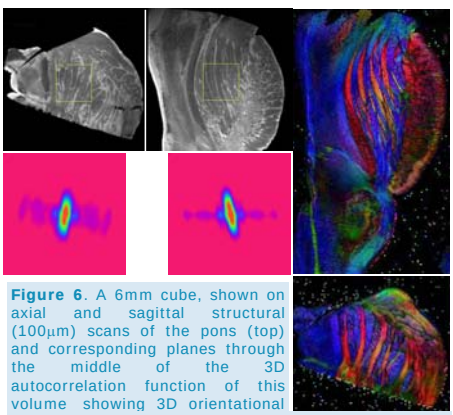

Figure 6. A 6mm cube, shown on axial and sagittal structural (100μm) scans of the pons (top) and corresponding planes through the middle of the 3D autocorrelation function of this volume showing 3D orientational structure. Color coded FA maps (right) show the interdigitated L-R and S-I fiber bundles.

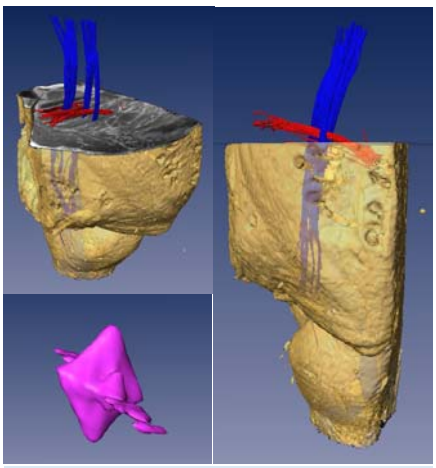

Figure 7. 3D Tractography reconstructions from seed regions drawn within selected L-R and S-I bundles in the box in Fig. 6. Lower left: 3D autocorrelation function showing two distinct orthogonal coherence directions with subsidiary 'peaks' indicating periodicity perpendicular to the 'crossing' plane of the fibers.

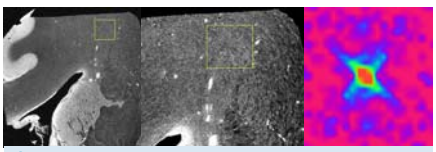

Figure 8. Crossing fiber structure at the intersection of the callosal fibers and ascending internal capsule.

Conclusions

- Local 2D autocorrelation functions in high resolution FLASH scans of fixed human white matter show orientational contrast both in large fiber bundles (*Fig. 2*) and in dense myelinated WM (*Fig. 3*) consistent with fiber orientation from DTI (*Fig. 4*).
- The 3D autocorrelation function, in regions where major fiber bundles cross such as in the pons, shows 2 orthogonal directions of high coherence, in agreement with the DTI data (*Figs. 6, 7*). Orthogonal structure is also seen in dense WM areas of known fiber crossings (*Fig 8*).
- This approach may be useful in 'validating' DTI fiber orientations against underlying WM structure.

but...

- Orientational contrast in structural images of WM may not always be parallel to the fibers (*Fig. 9*).

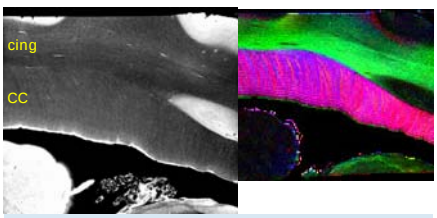

Figure 9. 'Parcellation' of callosal fibers. Left: 50μm sagittal structural scan shows A-P fibers in the cingulum (at the top), and seems to show S-I fiber orientation in the corpus callosum (below it). Right: Color coded FA map confirms A-P fiber orientation in the cingulum, but indicates that the apparent vertical orientation in the CC is in fact alternating 'flat' bundles of L-R (more red) and S-I (more blue) curving fibers.

References

1. WS Krieg, Connections to the Cerebral Cortex (1963)

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