Diffusion Tensor MRI of the Thalamus: Differentiation of nuclei by their projections

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Introduction

While the correspondence between the principal eigenvector of the diffusion tensor and cerebral white matter orientation is well established, the possible significance of orientations in deep gray matter structures has not been addressed. We report diffusion tensor analysis of the thalamus, which show that the thalamic nuclei can be distinguished on the basis of their projections to the cortex. Diffusion tensor imaging offers a new way to analyze thalamus and its multiple nuclei non-invasively.

Methods

Diffusion tensor MRI: Using a Siemens Vision 1.5 T echo planar scanner, normal subjects underwent brain studies of 6 axial slices, 36 averages and 1.8x1.8x3 mm^3 resolution, which were completed in 20 minutes. Diffusion–unattenuated images had SNR > 15:1 giving a resulting SNR of 90:1 for the tensor images. Diffusion was encoded using a null gradient plus 6 encodings $\{(\pm1,1,0),\ (1,0,\ \pm1),\ (0,\ \pm1,1)\}$ with diffusion sensitivity b= 550 s/mm^2.

Diffusion tensor display: From each MRI data set images were computed of the diffusion tensor field **D**, its eigenvalues (λ_i) and eigenvectors (v_i). RGB-coded images [1] were constructed representing **1)** the leading eigenvector, i.e. the first eigenvector and **2)** the third eigenvector. The latter image shows the orientation of the 1-2 eigenplane of the diffusion tensor, as this is normal to v_3, and reflects the geometry of intra voxel dispersion of diffusion orientations [3]. Diffusion tensor fields were represented by 3D graphics (Figure 1) of unambiguous orientation (color application based on abs(v_i) are insensitive to the relative sign of the vector components).

Results

The thalamus was observed on 6 slices. It was possible to distinguish the following nuclei on the basis of their cortical projections. The anterior and medial dorsal nuclei was found to have anterior-posterior projections corresponding to their output to the limbic system (cingulate gyrus) and the frontal association cortex respectively. Both nuclei project through the anterior limb of the internal capsule. Of the ventral nuclei the ventral anterior, ventral lateral and ventral posterior nuclei could all be demarcated. Their projections (superior-inferior and lateral) occur all through the posterior limb of the internal capsule. The ventral anterior nucleus projects to the supplementary motor cortex and receives input from the basal ganglia via ansa lenticularis or the lenticular fascicle. The ventral lateral nucleus projects to the premotor and primary motor cortex and receives input from the cerebellum through the superior cerebellar peduncle. The ventral posterior nucleus is the primary sensory thalamic nucleus and projects to the primary somatic sensory cortex and receives input from the spinal cord via the spinothalamic tracts. The pulvinar nucleus has bidirectional connections to the parietal, temporal and occipital association cortex. The projections occur lateral to the optic radiation and spread out to the cortical areas from there.

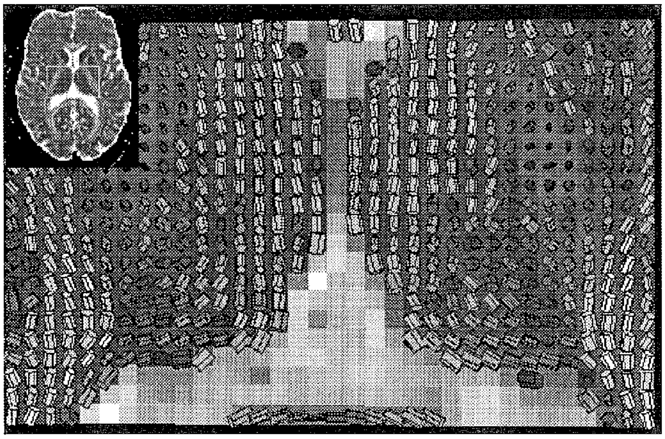

Figure 1. 3 Dimensional diffusion tensor field of the Thalamus. The longitudinal directions of the cylinders are directed along the first eigenvector.

Conclusions

Diffusion tensor imaging proves to show significant structure even in deep gray matter structures. This may have large implications in the evaluation of diseases of the thalamus. Since almost every sensory input relays through the thalamus (only exception is the olfactory sense) changes in those relay functions might be followed by diffusion tensor imaging – both by scalar measures and orientation analysis. The finding opens up for more intensive studies of the gray matter structures and their projections. Disordered diffusion orientation in pathology without mass effect is frequent and may reflect directional bias due to tract-specific fiber loss [4]. Diffusion anisotropy may change in areas remote from primary CNS lesions, also consistent with tract unmasking. Analysis of the complete geometry of the MRI diffusion tensor proves added insight into the organization of CNS white and gray matter architecture in health and disease.

References

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