Fiber-Orientation can be Used for Sub-Clustering Anatomical Labels within the Human Thalamus

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Introduction: Segmentation of regions within the thalamus based on DTI data became popular because it allowed the evaluation of individual anatomy invivo. Different groups have used different algorithms to probe the substructure of the Thalamus; here we want to focus on the methods based on local diffusion orientation [1,2]. These previous publications assume that local diffusion orientation is specific to individual thalamic nuclei. Here we show that while segmentation of regions within the thalamus will help in the orientation within the individual brain, the segmented regions are not likely to correspond to segmentation based on cyto-architecture, because the information base is completely different.

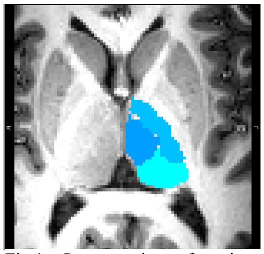

Fig.1: Segmentation of regions within the thalamus based on visually detectable contrast differences [3]. Anatomical labels (in blue) were drawn by an expert radiologist.

Methods: Data: The anatomical labels were manually defined on 1mm isotropic 3D MPRAGE (TE=3.4 ms, TR = 2300 ms) images that were optimized for the contrast within the Thalamus [3].. DTI images were acquired with a standard Siemens sequence, with a b-value of 800 ms, 3 repetitions and 20 diffusion weighted directions. The subjects gave written informed consent to be part in this study. DTI based segmentation: We did classify the local diffusion direction using a set of 21 reference directions [1,2]; so that each voxel is assigned the class whose reference direction has the least angular difference to the local diffusion direction. The individual classes are assigned unique colors corresponding to their reference directions as defined by Demiral et al [4]. Comparison: We used standard DTI data and did compare the segmentation results based on special MR contrasts [3] with segmentation based on local diffusion orientation. The contrast on the high resolution images was used to define anatomical labels by an expert radiologist (Fig.1). First we did analyze the diffusion orientation within these expert labels (Fig.2). Then, we compared the expert labels with our automatic segmentation based on local diffusion orientation (see Fig.3). The directions were characterized by their components in the three spatial directions (x,y,z).

Results: The comparison of the automatic segmentation with the expert labels did show that the labels often overlap with larger regions in the automatic segmentation but the label boundaries encompass voxels from a number of segmentation classes and the automatically segmented clusters will often also overlap with more than one label mask. The reason for this mismatch is clearly the non-uniform fiber orientation within the expert labels as is observable in Fig.2.

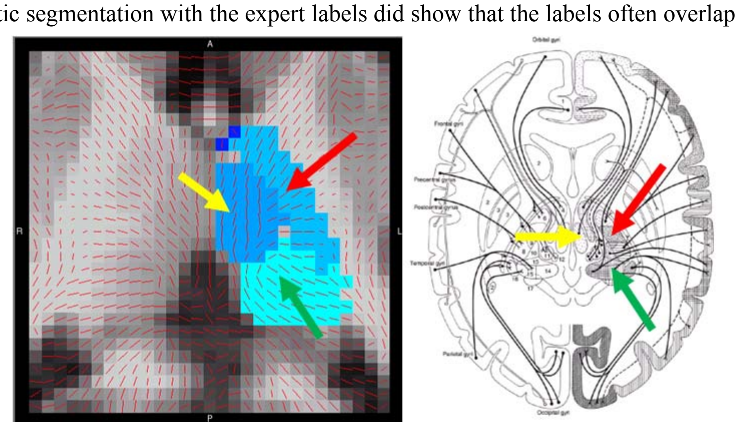

Fig.2: On the left, the principal eigenvector, which is associated with the dominant diffusion orientation is indicated by red lines and is overlayed on the expert labels in blue. The red arrow indicates the most problematic ventral label for automatic segmentation. The green arrow indicates the posterior label. On the right a schematic of the connectivity of the individual thalamic regions is given [5]. The colored arrows indicate the regions corresponding to the indicated labels on the left.

The ventral nuclear group indicated by the red arrow in Fig.2 (left) encompasses incoming fiber orientations that fan out in all directions, which is also known from anatomy to be true as indicated from the schematic on the right in Fig.2. This causes a number of DTI based segmentation clusters to be defined that can be used for orientation within the ventral label (see Fig.3). The posterior part of the ventral group shows a cluster of fibers that run in direction (0.7,0,0.7), which could indicate the position of the ventral posterior region opposed to the ventral lateral region above whose fibers are oriented more diagonally. Adjacent to the ventral anterior region, this might be associated with the cluster of fibers running in parallel to the y-axis. Also within the posterior label indicated by the green arrow in Fig.2, the diffusion orientation is non uniform. This leads to a number of sub-clusters from the DTI based segmentation within the labeled region. These might be used for further orientation within the labeled region. The largest DTI based segmentation cluster within this region corresponds to reference direction (1,0,0). This corresponds to the schematic, where a large part of the Pulvinar fiber connections are shown to be parallel to the x axis. The medial group, indicated by the yellow arrow in Fig.2, consists of a large body of fibers in parallel to the y axis, as indicated by the schematic. This region can be segmented well with diffusion orientation based classification.

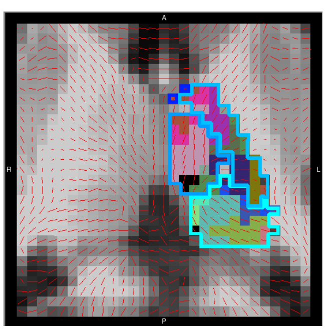

Fig.3: Segmentation results (color coded) in comparison with expert labels (blue outlines). The local diffusion orientation is indicated by red lines representing the principal eigenvector.

Discussion and Conclusion: In our investigation we could show that the evaluation of diffusion orientation within the Thalamus is complementary to the information gained from advanced imaging contrast. Even though it is not expected that the fiber orientation corresponds with known anatomy (see Fig.2) automatically segmented clusters correspond well to large regions in the expert labels. We therefore propose to use the segmentation based on the local diffusion direction for orientation within the thalamus. This might especially be helpful in patients with pathological changes of the thalamus. Previous studies did show that in a large population of normal subjects, DTI based segmentation shows good reproducibility [2].

References: [1] A. Unrath, U. Klose, W. Grodd, A. C. Ludolph, and J. Kassubek. Directional colour encoding of the human thalamus by diffusion tensor imaging. Neurosci Lett, 434(3):322–327, 2008. [2] S. Mang, A. Busza, S. Reiterer, W. Grodd, and U. Klose. Thalamus segmentation based on the local diffusion direction: A group study, MRM [epub: ahead of print]. [3] B.Bender, C. Mänz, A.Korn, T. Nägele, and U.Klose. Optimized 3D Magnetization-Prepared Rapid Acquisition of Gradient Echo: Identification of Thalamus Substructures at 3T, AJNR [epub: ahead of print]. [4] C. Demiralp, J. F Huges, and D. H. Laidlaw. in proceedings of IEEE TVCG, 2009. [5] Rudolf Nieuwenhuys, Jan Voogd, and Christiaan van Huijzen. The Human Central Nervous System: A Synopsis and Atlas. 4Ed. Steinkopff; 2007