Stability of Diffusion Direction Based Thalamus Segmentation

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Introduction: The segmentation of sub-structures in deep gray matter regions, for example the thalamus, is not possible on standard T1 or T2 weighted MR images, because there, these regions have homogeneous signal intensity. In contrast diffusion tensor MR-imaging (DTI) data provides strong variations, especially within the thalamus. These variations can be used for segmentation of different thalamic sub-structures (see for example [1-3]). The methods proposed by Wiegell et al [1] and Behrens et al [2] require considerable prior knowledge, processing time, and/or manual segmentation. The method proposed by Unrath et al [3] relies solely on the evaluation of the principal diffusion direction. Even though this last method is very simple in comparison with the two other approaches the segmentation results can clearly identify several thalamic sub-structures. We evaluated this diffusion direction based method in a group study on 53 healthy volunteers to show the quality and reproducibility of the results of this simple and fast segmentation method.

Methods: Segmentation: In the segmentation we did classify each voxel according to the orientation of the principal diffusion direction, which is the eigenvector corresponding to the largest eigenvalue of the diffusion tensor. Nine segmentation classes were defined to correspond with color regions that were placed symmetrically in eight quadrants on the unit sphere as shown in Figure 1 [3]. The principal diffusion direction is projected onto this color-sphere to determine the segmentation class and the corresponding coloring.

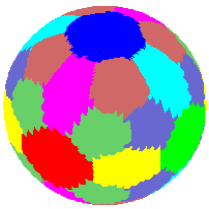

Figure 1: *Color-sphere that is used to determine the segmentation class for the principal diffusion directions*

Data: DTI data and T1 weighted images were acquired for 53 healthy volunteers (27 male and 26 female) between 20 and 43 years old (mean 26.49 years +/- 5.36; females: mean 25.31 years +/- 4.47) on a 1.5T MR-Scanner (Sonata, Siemens, Erlangen, Germany) after written informed consent. Each DTI data set did consist of twelve diffusion weighted images and an unweighted image with a b-value of 800s/mm^2. The resolution of the DTI data was 2x2mm in plane with a slice thickness of 2.5mm.

Group Study: Prior to segmentation the data was interpolated to a 1mm^3 isotropic resolution. The data sets were normalized to NMI-space with the SPM software to allow automatic comparison. The principal diffusion directions were computed in each normalized DTI data set before the segmentation was performed on all voxels with FA higher than 0.1 and lower than 0.5. The FA threshold was introduced to exclude CSF and fiber bundles that border on the thalamus from the segmentation (see Figures 2c-f). To evaluate the stability of the results the segmentation was computed first for all individual subjects. Then we did compute the distribution of the classes that were assigned during the segmentation process in each individual voxel for all subjects. Based on this distribution the `dominant segmentation class´ of a voxel was defined as the class that was most often the result of the segmentation in the evaluated population (see Figures 2c-d). The stability of the segmentation was assessed by applying a threshold to the number of classifications for the dominant segmentation class to determine which percentage of the investigated population was assigned the dominant class (see for example Figures 2e-f).

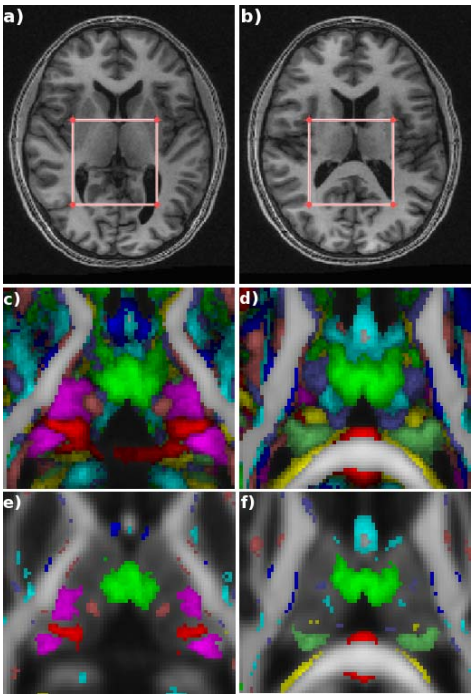

Figure 2: *Segmentation results: a-b show the regions the segmentation was evaluated in; c-d show the dominant segmentation classes (occur most in the evaluated subjects); e-f show clusters that are common to at least 60% of the subjects.*

Results: Segmentation results are presented for two exemplary slices; the regions for which the segmentation is shown in Figures 2c-f are indicated by red boxes on the T1 weighted images in Figures 2a-b. Figures 2c-d show the dominant segmentation classes. Figures 2e-f display the segmentation clusters that are common to more than 60% of the subjects. These segmented clusters are considered stable because they occur in exactly the same position for the majority of the evaluated population. Large dominant regions can be identified in Figure 2e (magenta, red, brown and light green) and Figure 2f (light and dark green). Figure 2f also shows smaller clusters (cyan, violet and yellow).

Discussion: The results show that a stable segmentation of thalamic sub-structures is possible using only the principal diffusion direction. The red, light green and magenta regions correspond to the lateral, frontal and parietal thalamic sub-structures that were defined by Unrath et al [3]. These segmented sub-structures show a correspondence to the segmentation results of the method proposed by Behrens et al [2]. We could also segment other stable sub-structures (brown, dark green, cyan and violet) whose anatomical correlations need to be further investigated.

Conclusion: Our preliminary results show that it is possible to segment major thalamic sub-structures accurately with simple means in a large population of subjects.

References: [1] M. R. Wiegell, D. S. Tuch, H. B. W. Larsson, and V. J. Wedeen. Automatic segmentation of thalamic nuclei from diffusion tensor magnetic resonance imaging Neuroimage, 19:391–401, 2003. [2] T. E. J. Behrens, M. W. Woolrich, M. Jenkinson, H. Johansen-Berg, R. G. Nunes, S. Clare, P. M. Matthews, J. M. Brandy, and S. M. Smith. Characterization and Propagation of Uncertainty in Diffusion-Weighted MR Imaging. Magn Reson Med, 50(5):1077–1088, 2003. [3] 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.