Development of partial volume segmentation of brain tissue based on diffusion tensor imaging (DTI)

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Introduction

To study the cortical/subcortical diffusivity quantified by the apparent diffusion coefficient (ADC) in neurological and neurodegenerative diseases, brain tissue segmentation methods for diffusion tensor magnetic resonance imaging (DT-MRI) data have been proposed, which utilize registration between segmented structural MRI and DT-MRI [1-3]. Recently, another method has been proposed, which can segment brain tissue in the DT-MRI space without the need for any registration [4]. However, in these methods, a partial volume (PV) effect and the imperfect registration between the images might complicate the segmentation of brain tissue and the analysis of the cortical/subcortical diffusivity. Our purpose was to develop a new brain tissue segmentation method based on DT-MRI without the need for any registration, taking the PV effect into account.

Materials and Methods

Our segmentation method: Based on the following five images derived from DT-MRI, i.e., images of the three eigenvalues, ADC and fractional anisotropy (FA), our method estimates the PV fractions of white matter (WM), gray matter (GM), and cerebrospinal fluid (CSF) in each voxel using a *maximum a posteriori* (MAP) probability principle. Assuming that the PV fraction M and the tissue class parameter set Φ are independent, the posterior distribution of M and Φ given the image Y is given by $P(M, \Phi|Y) \propto P(Y|M, \Phi)P(M)P(\Phi)$. By maximizing the posterior distribution $P(M, \Phi|Y)$, we obtained the PV fractions of tissue type within a voxel. In this study, we evaluated the performance of the proposed method quantitatively by using digital phantom data. Moreover, we applied our method to human DT-MRI data, and compared our results with those of a conventional segmentation method [4].

Digital DTI phantom data: The digital phantom used in this study was described in [5]. The DTI phantom data consisted of 6 diffusion-weighted image volumes ($b = 800$ s/mm^2) and an unweighted image volume ($b = 0$ s/mm^2) with a 128×128 in-plane resolution and 40 slices (FOV: 230×230 mm^2, 3 mm thick). The voxel size was 1.8×1.8×3 mm^3, which is the same as the voxels used in our clinical data. To compare with our method, we have implemented the conventional method [4], which does not take a PV effect into account. We evaluated the performance of the accuracy by use of an overlap measure given by $J(V_{seg}, V_{true}) = |V_{seg} \cap V_{true}|/|V_{seg} \cup V_{true}|$, where V_{seg} is a segmented volume and V_{true} is the ground truth, respectively.

Human DT-MRI data: The DT-MRI data of five healthy volunteers were acquired using a 1.5-tesla clinical scanner (Magnetom Symphony, Siemens) with an 8-channel phased-array coil. The data covering the whole brain were obtained using a single-shot echo-planar-imaging pulse sequence with TR = 8600 ms and TE = 119 ms. The DT-MRI data consisted of diffusion-weighted image volumes acquired using a six-directional diffusion encoding scheme at a b-value of 800 s/mm^2 and a diffusion-unweighted image volume obtained at $b = 0$ s/mm^2. The voxel size was the same as that of the voxels in DTI phantom data.

Results and discussion

Table 1 shows the volume overlap measure between the segmentation results and the ground truth data of the digital DTI phantom. In all three tissue types, the values of volume overlap with our method were more than 0.9 and were greater than those with the conventional method. In the conventional methods, it seems that the partial volume voxels complicate accurate segmentation in the case of lower image resolution, such as DT-MRI data. In visual comparisons as shown in Fig. 1, WM/GM/CSF regions estimated by our method were more similar to the corresponding regions depicted in the structural image than those estimated by the conventional method. For example, the external capsules were clearly depicted by our method, while these structures could not be identified in the results by the conventional segmentation method (yellow arrows).

Conclusions

We have presented a partial volume estimation and segmentation method for brain tissue based on DT-MRI data. The results of the digital phantom experiment and human DT-MRI data demonstrate that our method was able to perform a reasonable estimation and segmentation for brain tissue on DT-MRI data compared with the conventional segmentation method. Our method may be useful in evaluating the cortical and subcortical diffusivity in neurological diseases.

References

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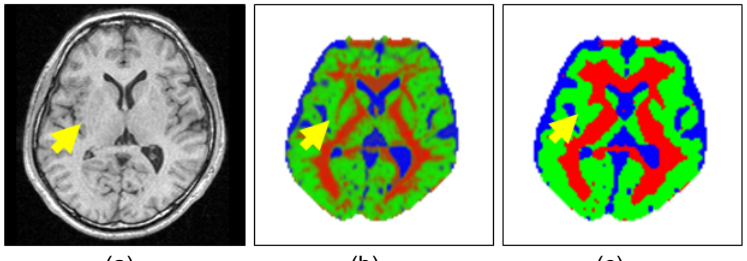
Table 1: Volume overlaps between segmentation results and ground truth of DTI phantom in each tissue type.

	WM	GM	CSF
Our method	0.910	0.970	0.921
Conventinal method	0.550	0.854	0.743



(a) (b) (c)

Fig.1 (a) The structural image (T_1-weighted image), (b) the estimated PV fraction maps obtained by our method, and (c) the conventional segmentation result.