

Influence of a partial volume effect in the segmentation of brain tissue based on diffusion tensor imaging (DTI) data: a digital DTI phantom study

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Introduction

A few methods for brain tissue segmentation based on diffusion tensor imaging (DTI) data have been proposed. These methods are utilized for studying the diffusivity of gray matter (GM) or subcortical white matter (WM) in neurodegenerative and neurological diseases [1, 2]. Although the accuracy of the segmentation performance might have significant influence on the diffusivity measurements, to the best of our knowledge, it has not been evaluated by use of the digital DTI phantoms. Moreover, due to a low spatial resolution of the DTI voxel, a partial volume effect (PVE) might complicate the segmentation of brain tissue and the analysis of the diffusivity of GM or subcortical WM. In order to investigate the influence of a PVE in the brain tissue segmentation based on DTI data, we have implemented a reported segmentation method and evaluated the performance by use of the digital DTI phantom with a PVE model.

Materials and Methods

Digital DTI phantom data: The digital phantom used in this study (Fig. 1) was modified the model described in [3], and extended to the partial volume description of diffusion measurements by using the model of [4]. Three eigenvalues ($\lambda_1, \lambda_2, \lambda_3$) [10^{-6} mm²/s] in each tissue object of the phantom were set as follows: GM: (800±20, 800±20, 800±20), WM: (1700±150, 250±40, 250±40), and CSF (cerebrospinal fluid): (3200±100, 3200±100, 3200±100). The simulated signal at a voxel is modeled by $S = S_0 \sum \alpha_i \exp(-b \mathbf{g} \mathbf{D}_i \mathbf{g})$, where b is the b-value, S_0 is the signal intensity with $b=0$, \mathbf{g} is the unit vector of the diffusion encoding gradient, α is weighting factor, and i is a site within a voxel. In this study, DTI phantom data consisted of 6 diffusion-weighted image volumes ($b = 800$ s/mm²) and an unweighted image volume ($b = 0$ s/mm²) with a 128×128 in-plane resolution and 40 slices (FOV: 230×230 mm², 3 mm thick). The voxel size was 1.8×1.8×3 mm³, which is the same as the voxels used in our clinical data. In order to generate the ground truth, each voxel was assigned a membership of only one tissue object, which has the largest mixture percentage among all the objects contained within the voxel.

Segmentation method and the evaluation: We have implemented the brain tissue segmentation method [5], which is based on a Hidden Markov Random Field model and the Expectation-Maximization algorithm, and does not take a PVE into account. We evaluated the performance of the accuracy by use of an overlap measure given by $J(V_{\text{seg}}, V_{\text{true}}) = |V_{\text{seg}} \cap V_{\text{true}}| / |V_{\text{seg}} \cup V_{\text{true}}|$, where V_{seg} is a segmented volume and V_{true} is the ground truth, respectively.

Results and discussion

Table 1 shows the results of the overlap measure between segmentation using the method [5] and ground truth on digital DTI phantom data with/without a PVE. Especially, in the GM and WM with a PVE, the values of overlap measure are lower than those without a PVE. In this case, these were due to overestimation of the WM region. Because the spatial resolution of DTI voxel is a generally low, a PVE would have a significant influence on the accuracy of the segmentation performance on the clinical DTI data.

Conclusions

We extended the previous DTI phantom model to the partial volume description of diffusion measurements, and investigated the performance of segmentation using the conventional method on the DTI phantom with a PVE model. These results indicate that a method taking a PVE into account can improve the segmentation performance on DTI data.

References

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- [2] Yoshiura T, et al., Magn Reson Med 2005; 54:455-459.
- [3] Alexander DC, et al., Proc. SPIE, 2000; 3979: 470-481.
- [4] Alexander AL, et al., Magn Reson Med 2001; 45:770-780.
- [5] Liu T, et al., NeuroImage 2007; 38:114-123.

Table 1: Overlap measure between segmentation and ground truth on our digital DTI phantom data with/without a PVE.

No PVE			PVE		
WM	GM	CSF	WM	GM	CSF
0.821	0.857	0.694	0.502	0.716	0.620

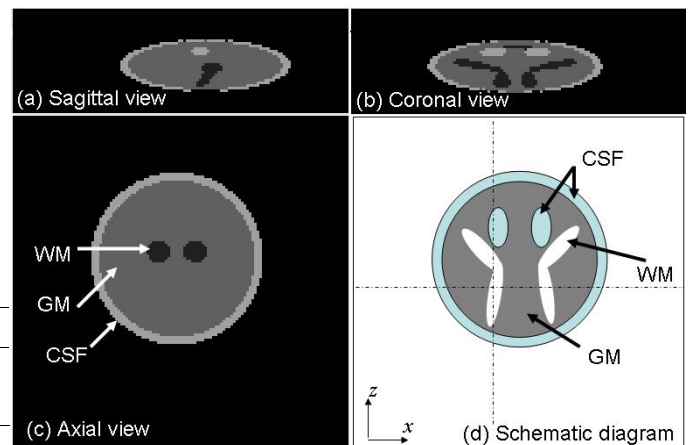


Figure 1. Digital DTI phantom images and the schematic diagram of the phantom objects.