Robust Tissue Segmentation of Human Brain Images Acquired with a Surface Coil at Ultrahigh Field

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INTRODUCTION Surface coil is commonly employed in human brain MRI/MRS study for achieving high signal-to-noise ratio (SNR) in an interested brain region. Despite its merit, the presence of strong B_1 field inhomogeneity leads to large variations in both imaging signal intensity and tissue contrast across the brain regions, thus, quantitative tissue segmentation for differentiating the grey matter (GM), white matter (WM) and cerebral spinal fluid (CSF) becomes very challenging. However, tissue segmentation including partial volume estimation (PVE) and correction (PVC) are of great importance for *in vivo* MRI/MRS or MRSI study, particularly for absolute metabolites quantification in different brain tissues. So far, segmentation for PVC has been carried out via manual contouring based on annotations, which is a highly subjective and time-consuming approach with large variability. Therefore, the goal of this study was to develop a robust and reliable automatic segmentation method for partial brain volume estimation based on anatomic images of human brain acquired at ultrahigh field using a surface coil. To evaluate the segmentation algorithm, we selected occipital lobe as the region of interest, and compared the segmentation results with that of whole brain images acquired with a volume coil.

METHODS Six healthy subjects participated in this study and provided written informed consent approved by the University of Minnesota IRB committee. All MRI data were acquired on a 7T/90cm human scanner (Magnex/Siemens) using a quadrature surface coil covering occipital/parietal lobe and/or a 32-channel transmit-receive head coil (Nova/Medical). 3D-MPRAGE T_1-weighted (TR/TE/TI= 3000ms/2.42ms/1500ms, FA= 7°, isotropic pixel size: 1 mm^3) and 3D PD (proton density, TR/TE=3000ms/2.42ms, FA= 7°) images were acquired.

Preprocessing Steps: Correction of B_1 and MRI intensity inhomogeneity: First**,** the T_1/PD ratio image proposed by Moortele *et al* [1] was used to correct global biased signal variation, and the inter-scan head motion was corrected using SPM8 [2]. Second, to simplify tissue segmentation, we identified and extracted the brain region after removal of exterior skull using BET in FSL. Third, a nonparametric MRI intensity inhomogeneity correction method was applied for further removing artefactual signal inhomogeneity [3].

Partial Tissue Probability Maps (pTPMs): The pTPMs mainly covering the occipital and parietal lobes and cerebellum consisting of 3 brain tissue types were generated via a full TPM model in MNI space. Finally, the bias-corrected T_1/PD ratio image was used as an input for segmentation processing with VBM8 [4] as described below.

Initial Atlas-Based Segmentation: Atlas-based segmentation method was done for estimation of three tissue classes of GM, WM and CSF after registering the pTPMs' image to the T_1/PD ratio image. Importantly, two different Markov Random Field (MRF) parameters that determine the number of neighboring voxels for estimating single pixel's probability were carefully optimized for WM and CSF, respectively.

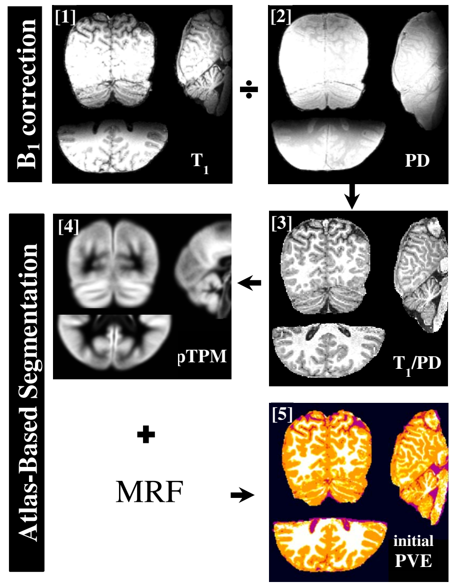
Estimation of Model parameters: From the initial segmentation, spatial distribution of both mean values and variances of signal intensities of each tissue type were calibrated by applying p thresholds of tissue probability.

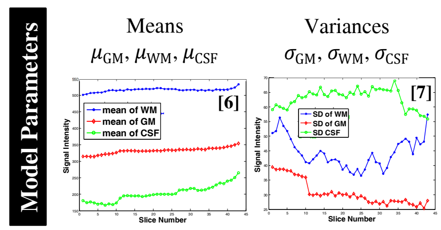
Partial Volume Estimation (PVE): As the last processing step, PVE strategy was implemented to quantify the CSF within a voxel using the provided model parameters. The mixed model of two tissue types in a voxel such as CSF/GM or CSF/WM was assumed. Based on the mixed model, the probability of CSF content was readjusted using a constrained clustering method which estimates the likelihood of belonging of CSF by measuring difference between voxel's intensity and mean values of different tissue types.

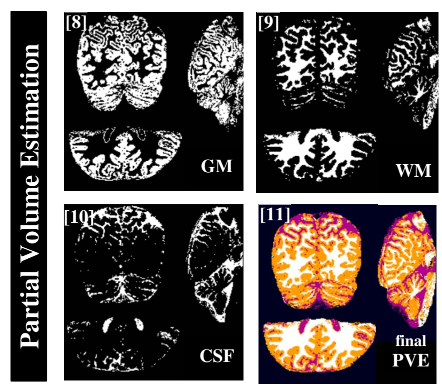
For the volumetric comparison, the whole brain images were co-registered into partial brain volume using entropy correlation coefficient method of SPM8. Tissue contents within 18 identified voxels (8 ml voxel size) of interest adjacent to the surface coil were quantified and compared.

RESUTLS & DISCUSSION Figs.1-2 displays the large intensity/contrast variations in T_1 and PD images of a representative human brain acquired with a surface coil. Such bias intensity variations can be partially corrected by using the T_1/PD ratio images, thus, a relatively uniform intensity profile and much better imaging contrast can be obtained as shown in Figure 3. Direct segmentation on T_1-weighted image with simple B_1 correction failed to provide satisfactory outcome (data not shown herein). Proper control of MRF weighting parameters with incorporation of pTPM model was able to help initial tissue segmentation with Maximum a posteriori (MAP) of each tissue classes (see Fig. 4). For example, MRF weighting of 0.10 provided a good estimation of the WM/GM tissue volumes, while CSF volume was underestimated due to weighting effects on small CSF regions such as sulcus (Fig. 5). Thus, the introduction of PVE with mixed model overcome the underestimation of CSF contents by readjusting probability of CSF voxels using a constrained clustering method with prior information of means and variances of each tissue class (Figs. 6-7). As shown in Figs. 8-12, the robust tissue segmentation was achievable (Figs. 8-11), and the CSF content was more reliably estimated as compared to the segmentation without PVE (Fig. 12). Furthermore, a strong correlation of the GM/WM tissue contents between the partial brain volume segmentation results vs. that of whole brain volume analysis was observed (Fig. 13), which had clearly proven the robustness of the algorithm. In contrast, the relatively low correlation in CSF content is due to the different B_1 field variation induced intensity differences between the surface and volume RF coils.

CONCLUSION In this study, we successfully demonstrate a robust automatic segmentation method for partial brain volume estimation and correction of human brain images acquired using a surface coil at 7T. This advanced method will provide a valuable imaging processing tool for many quantitative brain MRI/MRS studied, and it is particularly critical for ultrahigh-field applications using either a surface coil or trans-receive array coil or even head volume coil, which are all characterized by inhomogeneous B_1 distribution in the human head owing to the complication of RF wave behavior at higher field.







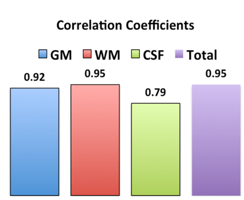


Figure 13. Correlation analysis of tissue contents between volume and surface coil

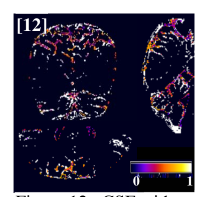


Figure 12. CSF with PVE – CSF without PVE

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