INTRODUCTION

The central surface (CS) of the brain cortex may have analytical advantages compared to boundary surfaces between the gray matter (GM) and either the white matter (WM) or cerebrospinal fluid (CSF) (Jones et al., 2001). This is based on CSF-GM-WM tissue segmentation and requires no explicit sulcal reconstruction. A test suite of phantoms with known thickness, resolution, and noise levels is used for validation.

METHODS

MRI images are first segmented into different tissue classes using toolboxes (http://dbm.neuro.uni-jena.de). The resulting segmentation is first manually separated into hemispheres and filled in the ventricular and subcortical regions. For each GM voxel, the distance from the CS boundary is projected through the GM using a standard graph-based distance method (Figures 3b2 & 3b3). The result is a GM distance map whose values at the GM-CSF boundary represent the GM thickness. These values at the GM-CSF boundary are then projected back to the GM-WM boundary (Figure 3b5). The voxels with the median GM thickness, found by examining the ratios of the forward- and reverse-projected maps, can then be used to locate the central surface. As a basis for comparison, we constructed another CS using a Laplace-based thickness measure on the original filled tissue segmentation map (Jones et al., 2001). This method requires an explicit sulcal reconstruction step (Bouix et al., 2000) and a correction step for underestimated measurements. The thickness map is generated by calculating the length of the CS surface lines that traverse the GM band. For validation, there were two types of spherical phantoms: a “gyral” case with WM/GM-CSF and a “sulcal” case WM/GM/CSF and a “sulcal” case WM/GM/CSF. Furthermore, a brain phantom with high convolution and uniform thickness is used to simulate different thickness, noise, and resolution levels (Figure 4). All phantoms were processed using the PBT method and Laplace method. Three different surfaces were identified in the volumetric data: the GM-WM boundary, the GM/CSF boundary, and the CS. Since the location of these surfaces in the volumetric data of the phantom is known, the two data sets could be directly compared.

RESULTS

The location of the CS in volumetric space is identified using the PBT method is exact and stable over a wide range of resolution, thickness, and noise levels, when compared with the original location of the CS in the phantoms (Figure 5 & 6). Figure 7 shows surface maps of the distance error for both the PBT and Laplace method. For most cases, the PBT method outperforms the Laplace method; however, for lower thickness values, there is a slight underestimation. Figure 7 shows the results of CS reconstruction. Figure 5 shows the mean distance error and standard deviation for the suite of phantoms. Lowering the resolution results in the same mean distance error but with higher standard deviation (i.e., more noise). The addition of Gaussian noise leads to both a higher standard deviation and an underestimation of mean values, if no noise correction during segmentation is used. Overall, the PBT method allows an accuracy comparable or better to the Laplace method for gyral regions, because the used distance measure overcomes grid restrictions of standard voxel-based distance measures. In sulcal regions, the PBT method produces more exact and stable results than the Laplace method, because it does not require the error-prone sulcus reconstruction step. Misdetections for thickness levels below sampling resolution are expected due to the sampling theorem. To get a correct topology for further analysis a topological correction (Yotter et al., 2010) is necessary.

CONCLUSIONS

We have presented a new method that allows an exact, stable and fast estimation of the CS within MRI volumetric data. As an additional benefit, the PBT method also delivers an accurate GM thickness measurement (Dahnke et. al., 2010). Future work involves developing an automatic method to fill the ventricular and subcortical regions. It may also be of interest to compare surface reconstructions directly using a metric such as the Hausdorff distance.

ACKNOWLEDGEMENTS

R.D. R.Y. and G.C. are supported by the German BMBF grants 01EV0709 & 01GW0740.

REFERENCES