INTRODUCTION

A strong relation between cortical convolution and cognitive development is known to exist between species (Hoffmann et al., 1989). However, a relevant problem is how to quantify brain convolution accurately. To describe brain convolution, Zilles et al. defined the gyrification index (GI) as the relation between the inner and outer contour within a slice of a brain (Zilles et al., 1988). Most previous approaches to measure the GI or other metrics related to convolution have some sort of drawback, for instance, requiring manual interaction which reduces measurement repeatability, using only coronal slices which may introduce an acquisition bias, etc. Here, we present a fully automatic method that overcomes these limitations. Furthermore, this method introduces a local estimation of the GI that can be used to analyze brain subregions selectively.

METHODS

The algorithm uses a novel approach that relies on solving the Laplace equation. First, the MRI data is segmented using VBM8 into three different tissue classes: white matter (WM), grey matter (GM), and cerebrospinal fluid (CSF). Although any boundary can be used to measure GI, we chose to use the central surface (CS). The tissue segmentation maps are used to locate the CS within the GM using a projection-based thickness method (Dahnke et al., 2010). A hull volume is then created from the CS using a morphometric closing operation (Figure 1).

Using the CS and hull volume maps, the Laplace equation is solved for the spaces between the two surfaces in volumetric space (Jones et al., 2001), such that a one-to-one vertex mapping between the CS and the hull surfaces is created. Figure 1 illustrates the method for a 2D slice. Calculation of the GI takes advantage of the fact that the Laplace equation field lines increase in density in regions of high convolution. To calculate the GI, these vertices are transformed into mesh representations of the two surfaces. For each vertex, an area value is assigned based on the average area of neighboring polygons. Finally, the local GI is calculated by calculating the area ratio of corresponding vertices. When calculated directly, this GI measure contains large values due to the inclusion of high-frequency folding patterns. These large values distort the GI estimation such that it no longer provides valid information. Gaussian smoothing of sulcal/gyral areas reduces the effect of the high-frequency contributions and provides a more representative GI measure.

For validation, the global GI is calculated using the ratio of total surface areas of the CS mesh and an iso-surface. The iso-surface is found by first calculating the average MRI intensity value from the volumetric hull surface, then creating a new surface at that intensity value. The global GI is then compared to the local vertex-specific GI values.

RESULTS

Global GI is around 2.25, whereas local values strongly depend on the regional folding pattern. The Laplace field forces all streamlines to the center of the sulci, which leads to highly nonlinear increases in GI values. Gaussian smoothing of the areas reduces the nonlinearity, thus improving the results. Figure 3 shows different test surfaces after Gaussian smoothing with 50, 200, and 800 iterations.

CONCLUSIONS

We have presented a new method that allows the estimation of the gyrification index on a local level for 3D surfaces to describe brain convolution. In comparison to other local curvature measures, this method allows a one-to-one connection between the cortical surface and the hull. Previous measures often did not have a direct correspondence between the cortical surface and the hull (Schaer et al., 2008), while others relied on other shapes such as sphere or triangles (Toro et al., 2008). As a side note, although the hull was generated using a morphometric closing operation, it is possible to generate a hull using the skull or by using another approach such as spherical harmonics (Yotter et al., 2010). In conclusion, these initial results suggest that it may be possible to extract meaningful convolution information within highly specific brain subregions.

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REFERENCES