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Estimation of Cortical Thickness from T1- weighted MR Images using Tissue Fractions

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Abstract

- Thickness of the human cerebral cortex is an important phenotypical feature. Cortical thickness variations can be helpful in characterizing differences in cognitive performance, cortical changes associated with aging, and neurological disorders such as Alzheimer's and Parkinson's disease.
- Methods based on computing distances between crisp inner and outer cortical boundaries are sensitive to partial volume effects and selection of the threshold used to define transition between white matter, gray matter and CSF regions.
- We propose a novel method based on the anisotropic heat equation which exploits partial fraction tissue classification maps for accurate estimation.
- We compare our approach with other methods and histological findings reported in the literature. We also use our method to study left-right hemispherical thickness differences in a large population.
- Our results show a larger effect size than the other methods we tested, which is consistent with improved accuracy in detecting subtle differences in cortical thickness.

Methods

- We assume as input a T1-weighted MR image of the brain with inner and pial cortical surface representations as well as a partial tissue fraction image generated by BrainSuite [2].
- The proposed Anisotropic Laplace Equation (ALE) method is a modification of an earlier Isotropic Laplace Equation (LE) method [3]. We use tissue fractions to define anisotropies in the heat propagation.

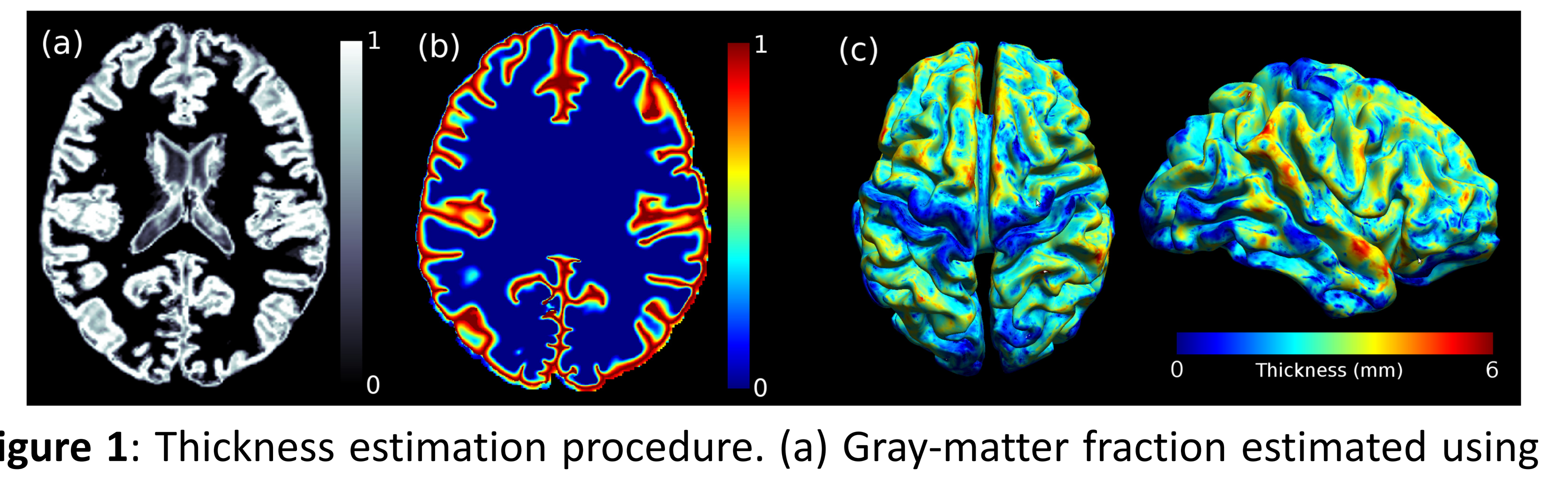

Figure 1: Thickness estimation procedure. (a) Gray-matter fraction estimated using a partial volume model; (b) Temperature map obtained using the proposed ALE method; and (c) Thickness estimate using the ALE method shown on the estimated mid-cortical surface.

- The inner and outer surfaces are set to temperatures 0 and 1, respectively, where the boundaries enclose both full and partial volume cortical gray matter voxels.
- In our model, the heat flux is inversely proportional to the fraction of gray matter in each voxel, denoted as $f(x,y,z)$. The temperature $\phi(x,y,z,t)$ as a function of spatial locations x,y,z and time t is given by the anisotropic heat equation:

$$\frac{\partial \phi(x,y,z,t)}{\partial t} = div\left(\frac{1}{f(x,y,z)} \nabla \phi(x,y,z,t)\right)$$

- The steady state equilibrium solution, $\phi_\infty(x,y,z)$ is given by the anisotropic Laplace equation:

$$div\left(\frac{1}{f(x,y,z)} \nabla \phi_\infty(x,y,z)\right) = 0$$

- We define cortical thickness T as:

$$T(x,y,z) = f(x,y,z)\frac{1}{||\nabla \phi_\infty(x,y,z)||}$$

- We solve the above equations using a finite difference method on the voxel grid.
- The cortical thickness is computed for all points on the mid-cortical surface, which is defined to be the isosurface having a temperature value of 0.5.
- The method is implemented in MATLAB and has an approximate computation time of 10 minutes.

BrainSuite Software: http://brainsuite.org

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Results

- We computed the vertex-wise cortical thickness measure using three approaches: Linked Distance (LD) [2], Isotropic Laplace Equation (LE) [3], and the proposed Anisotropic Laplace Equation (ALE).
- Our dataset consisted of a population of 480 normal right-handed subjects of age 22 to 26 years.
- All subjects were registered to a single-subject anatomical atlas using BrainSuite and SVReg software [1,2].
- Using a point-to-point correspondence between subject and atlas, these measures were transferred to the common atlas space. Then, we computed the vertex-wise average of these measures.
- From Figure 2, it can be seen that the thickness patterns that we find using the ALE method have closer resemblance to those found in literature [4].

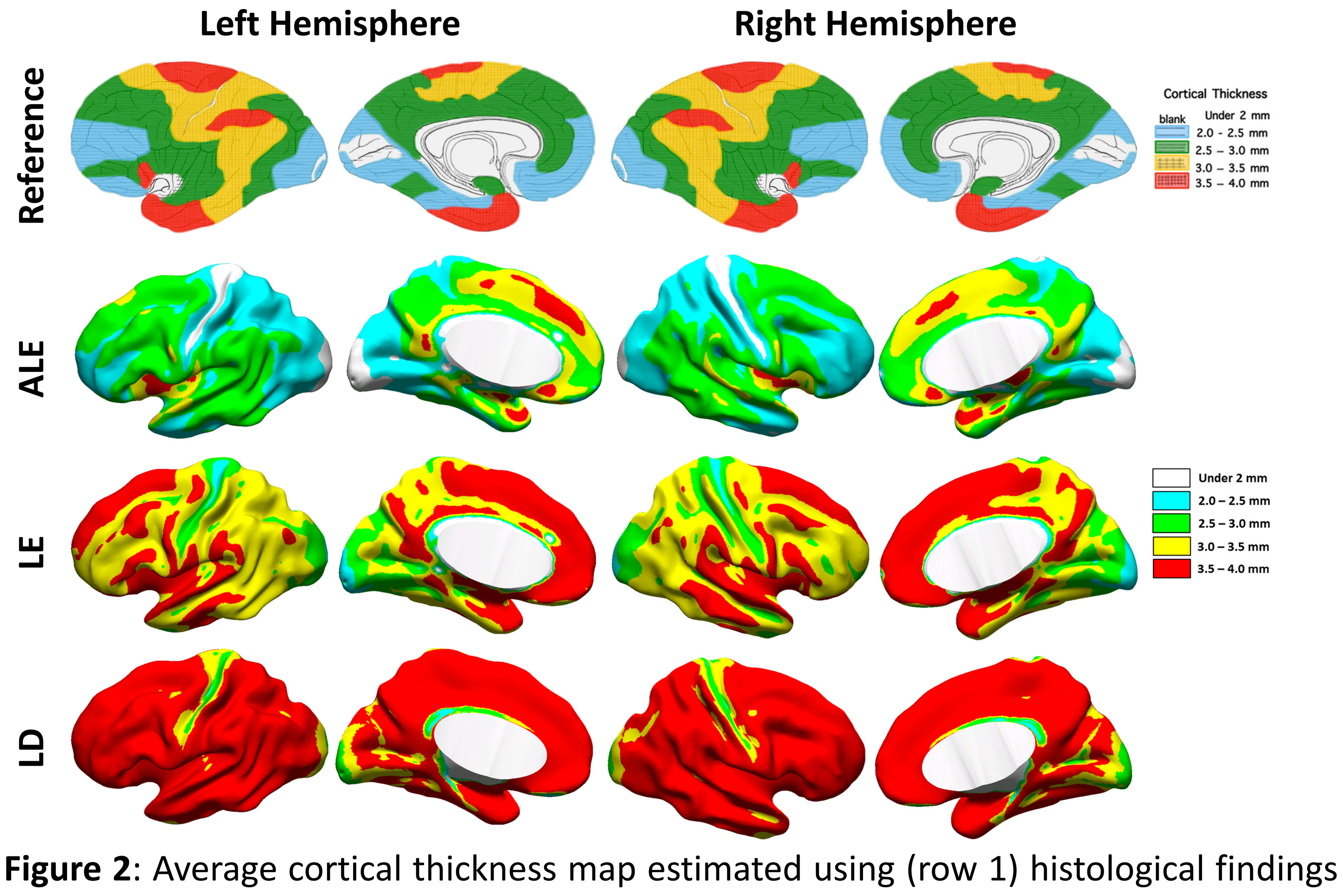

Figure 2: Average cortical thickness map estimated using (row 1) histological findings from literature [4]*; (row 2) proposed Anisotropic Laplace Equation (ALE) method; (row 3) Isotropic Laplace Equation (LE) method; and (row 4) Linked Distance (LD) method.

- For further validation, we performed a study of hemispheric thickness differences using the three approaches.
- We coregistered the left and right hemisphere of the atlas brain and computed pointwise thickness differences for each subject.
- We performed a Mann–Whitney U test with a null hypothesis of zero interhemispheric differences. The p-values were corrected for multiple comparisons using FDR at $\alpha = 0.05$.
- Maps of p-values are shown in Figure 3 for the three methods.
- It can be seen that the proposed ALE method yielded the largest significance in the hemispheric differences.

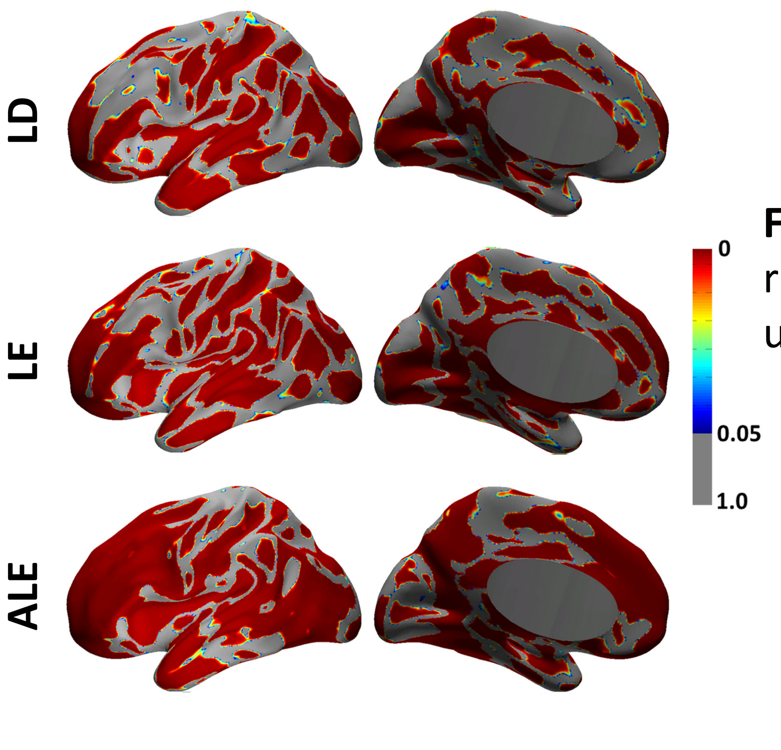

Figure 3: The p-value map of significant left-to-right cortical thickness differences estimated using the three different methods (LD, LE, ALE).

Discussion and Conclusion

- One issue that can affect the accuracy of the thickness computation is the bias field in the MR images, which can affect the tissue classification algorithm. This problem is mitigated by including bias correction as a preprocessing step in the MR processing sequence.
- Another issue of interest is the computation time. LD was the fastest method of the three, while ALE and LE required longer computation times.
- Of the three methods, the ALE method is seen to be most consistent with the literature [4] in terms of thickness profiles and also showed larger significance in the validation study.

References

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