Validation of the Laplacian Approach for Cortical Thickness Measurement

Haissam Haidar[1], Janet S. Soul[1]
[1] Department of Neurology, Children's Hospital and Harvard Medical School, Boston, MA.
Haissam.Haidar@childrens.harvard.edu
Janet.Soul@childrens.harvard.edu

Abstract. We present a validation study of the Laplacian method for tissue thickness measurement. In particular, we compared the variability of this method to others due to factors such slice thickness, head repositioning and interchange of boundaries. Our results show the advantage of the Laplacian approach.

1 Introduction

The use of advanced image post-processing techniques of three-dimensional magnetic resonance imaging (3D MRI) to analyze structural changes in neurological populations is becoming increasingly popular. Among the newest of such analyses is the in vivo measurement of cortical thickness of the human brain. Cerebral cortical thickness has been shown to be relevant both to normal development and to a wide variety of neurodegenerative and psychiatric disorders. Cortical thickness is also important for understanding the process of cerebral development in children. Hence a reliable method for cortical thickness measurement represents an important objective in medical imaging. Various methods based on different mathematical definitions of thickness are currently in use in clinical studies. The accuracy of some of these methods was assessed in published studies [1,2]. Tools from mathematical physics were used to introduce a Laplacian approach for measuring tissue thickness [3,4]. This promising approach is based on solving the Laplace equation between the two boundaries. The length of the streamlines which follow the gradient defines the thickness. The proprieties of this method provide a significant theoretical advantage compared to other existing methods. However, the reliability of the Laplacian approach has not been the subject of any reported study. Moreover, validation studies of thickness methods that employ voxel based tissue classifiers as segmentation algorithm are lacking. It is the goal of this paper to validate the Laplacian approach for cortical thickness measurement and to evaluate its performance compared to other thickness methods initially designed to analyze brain tissue classifiers.

2 Methods

In this section, we describe the experiments for validation of the Laplacian approach for cortical thickness compared to other methods when applied on medical data. Ten healthy adults were enrolled in this study. MR images of the whole brain were acquired on a GE Signa 1.5-T MR system (GE Medical Systems, Milwaukee, WI). All scans were acquired using coronal SPGR (Spoiled Gradient Recalled acquisition in the steady state). To estimate the effect of slice thickness on the measurement of thickness we scanned each participant two times with the same position of the head inside the scanner. The first scan was acquired using a voxel size of 1x1x1 mm^3 and for the second scan we used voxel size 1x1x2 mm^3. Each participant in this study was scanned a third time using the same sequence and a voxel size of 1x1x2 mm^3 after repositioning the subject's head inside the scanner. An implementation of the adaptive Expectation Maximization (EM) segmentation algorithm, which uses spatial information provided by a probabilistic atlas [5] was applied to all MR images. An expert manually corrected the cortical gray matter (GM)- cerebrospinal fluid (CSF) boundary to overcome the partial volume effect and extracted the basal ganglia and the cerebellum. To achieve high accuracy the manual steps described above were performed four times for each scan. The resulting cortical gray matter volumes were considered independent for statistical purposes in the following calculations. We implemented and applied the following three methods to all scans: the "Laplacian" [3,4], the "nearest distance", defined at each point on one boundary as the shortest distance to the other boundary, and the "orthogonal projection" which represents the length of the orthogonal projection of each point from one boundary to the other. From here on, these methods will be referred to as M1, M2 and M3, respectively.

3 Results

3.1 Symmetry and reciprocity

To estimate the variability of the three different measurement methods due to the interchange of boundaries, we performed the following experiment. Cortical thickness was first determined using the white matter (WM)-gray matter (GM) surface as the inner boundary, while the gray matter (GM)-cerebrospinal fluid (CSF) surface served as the outer boundary. Next, we calculated the thickness after interchanging the surfaces. One-way analysis of variance (ANOVA) was performed to compare the results of different methods. M1 showed no statistically significant difference ($p<0.11$) between the values of mean thickness when the boundaries are interchanged. However, we found a statistically significant difference ($p<0.003$) between the mean thickness determined using M2 when the boundaries were interchanged. Moreover, we found an even greater difference ($p< 0.0001$) between the outputs of M3 when the same experiment was performed.

3.2 Slice thickness

The variability of different algorithms due to the change in slice thickness was determined by applying these algorithms to the segmented data obtained from the scans with different slice thickness (1 and 2mm) with fixed head position in the scanner. Using one-way analysis of variance (ANOVA), we found no statistically significant difference ($p<0.06$) between the values of mean thickness for M1 due to this slice thickness change. However, we found statistically significant differences between the outputs of M2 ($p<0.003$) as well as for M3 ($p<0.0001$).

3.3 Repositioning of the head

The variability of different algorithms due to repositioning of the participant's head in the scanner was determined by applying these algorithms to the segmented data obtained before and after repositioning. We performed one-way analysis of variance (ANOVA) on the output of these algorithms. We found no statistically significant difference ($p<0,08$) between the thickness values for M1 due to repositioning. We found statistically significant differences between the outputs of M2 as well as M3 ($p<0.033$ and $p<0.015$ respectively).

4 Conclusions

In this paper, we validated the Laplacian method for thickness measurement by comparing it to different methods that employ brain tissue classifiers for segmentation. Our results confirmed the mathematical hypothesis of the accuray of the Laplacian method over other methods described previously [3,4]. The results on medical data show minimum variability of the results obtained by this method with regard to interchange of boundaries, slice thickness and repositioning of the head inside the scanner. Moreover, these results demonstrate that the thickness algorithm that defines thickness as the nearest distance between points (M2) clearly underestimates the value of cortical thickness when compared with the other two methods. We also conclude that slice thickness, i.e. the resolution of the original MRI data, has the highest impact on the variability of the results compared with the other factors tested. To our knowledge, this is the first study that validates the Laplacian method for cortical thickness measurement using medical data.

Acknowledgments

This work was supported by a research grant from the William Randolph Hearst foundation (HH) and the United Cerebral Palsy Foundation (JSS).

References

1. Fischl, B. and A. M. Dale (2000). "Measuring the thickness of the human cerebral cortex from magnetic resonance images." Proc Natl Acad Sci U S A **97**(20): 11050-5.
2. Kabani, N., G. Le Goualher, et al. (2001). "Measurement of cortical thickness using an automated 3-D algorithm: a validation study." Neuroimage **13**(2): 375-80..
3. Jones, S. E., B. R. Buchbinder, et al. (2000). "Three-dimensional mapping of cortical thickness using Laplace's equation." Hum Brain Mapp **11**(1): 12-32.
4. Yezzi, A. J., Jr. and J. L. Prince (2003). "An Eulerian PDE approach for computing tissue thickness." IEEE Trans Med Imaging **22**(10): 1332-9.
5. Pohl, K. M., W. M. Wells, et al. (2002). Incorporating non-rigid registration into expectation maximization algorithm to segment MR images. MICCAI 2002.