A Novel Technique for Cerebral Cortical Thickness Estimation

M. Scott[1], N. Thacker[1], A. Jackson[1]

[1]Imaging Science and Biomedical Engineering, University of Manchester, Manchester, Greater Manchester, United Kingdom

Introduction

Clinically, the assessment of human cerebral cortical thickness has massive potential importance in the determination of pathology. Grey matter loss has been implicated in diseases such as Alzheimer's Disease, Huntington's Disease, Multiple Sclerosis and Schizophrenia, whereas increases in grey matter thickness have been shown in elderly depressed subjects. Two approaches are typically used to obtain measures of grey matter thickness from MR: Voxel-Based Morphometry (VBM) , which produces a GM density measure, and surface-deformation algorithms, which fit a surface to the GM/WM boundary. This abstract presents a novel method for true cortical thickness estimation, avoiding the statistical problems associated with VBM and the complexity of the surface-representation techniques.

Methods

T2 inversion-recovery MR scans (1.5T Philips ACS PT 6000 NT, TI/TR/TE = 300/6850/18ms, pixel size = 1.8x1.8mm) were taken of the entire cerebrum in 13 normal volunteers (9 male, mean age=36.9 years, range=19-46 years). 4 subjects had axial scans (3.0mm slice thickness), 9 had coronal scans (4.0mm thickness). The MR image volumes were initially pre-processed into a form suitable for cortical thickness estimation. The mean and standard deviation of the image grey-level values of the grey matter (GM), white matter (WM) and CSF were determined and used to up-interpolate the data to twice the resolution in the through-plane direction. This volume was then registered to the Talairach atlas in order to define the 31 sub-lobar regions for which cortical thickness was later obtained. Finally, the GM in the images was segmented to produce a volume of GM probability maps.

The general approach to estimating the GM thickness is to first determine the GM/WM boundary, then to estimate the surface normal of the boundary into the GM, and to search along this direction until a GM edge (with either WM or CSF) is found. The GM/WM boundary is detected using an iso-contour method applied to the up-interpolated images. Assuming that the boundary occurs at the average of the two pure tissue values, a z-score testing consistency with this midpoint can be constructed for each image pixel value. Z-score images are used by non-maximal suppression and hysteresis thresholding to produce localised connected edge strings of the boundary. The 3D surface normal at each edge string voxel is determined by performing 3D Gaussian smoothing (kernel of [½,5]) on the up-interpolated images to reduce the noise, then taking the spatial differentiation of the 6 adjacent voxels to the voxel of interest. In order to find the opposing GM edge, the GM probability maps are searched, starting at the GM/WM boundary edge voxel, in increments of 1mm in the direction of the surface normal into the GM. The detected edge may be with either WM or CSF. If it is a WM edge, it is assumed that two tightly opposing gyral banks, with on average equal width and no intervening CSF, have been traversed. A maximal search extent is employed to prevent spurious edge detection, and is 10mm for a CSF edge and 20mm for a WM edge, because of the possibility of traversing two gyral banks. A definite edge is where the GM probability drops below 50% , calculated as the linear interpolation between the values below 50% in the current voxel of interest and above 50% in the previous voxel. However, there may also be edges narrower than one voxel, hence partial voluming of the GM with either WM or CSF, and the voxel will show a lower GM probability than the surrounding tissue but will not dip below 50%. The greatest of these dips within the search extent is recorded, and its precise position is calculated as a linear approximtion to the quadratic formed by the value of the voxel of interest and those either side. A correction is also made to account for the fact that the actual 50% grey matter boundary is some fraction before the minimum of the dip. If the edge is a GM/WM edge, the thickness is halved. The first definite edge and the greatest dip within the search extent are recorded and the general order of preference in determining the length to use is: CSF edge>CSF dip>WM edge>WM dip.

31 cortical regions are defined according to the Talairach atlas, and the median and inter-quartile range of the GM thickness values in each region calculated. Whole-brain and individual left and right regional values are recorded. The reproducibility of the technique can be assessed by comparing the left-right symmetry of the measurements, which can be used to calibrate an equivalent of the standard error for the median, using the normalised inter-quartile range for the region. We compared our results in 10 regions (left and right, ie, 20 values) with data from a semi-automated manual mark-up method of Kabani et al. (2001) [1]. Results from a larger normative data set are presented in [2].

Results

Figure 1 shows a histogram of the “standard error” values of all 31 regions for one subject. Note that all statistical errors are under 1mm, with the majority less than 0.3mm, hence the median in most regions can be estimated to an accuracy of 0.3mm. Change greater than this, due to disease or ageing can therefore be detected. Figure 2 compares our results with Kabani's mark-up method. Note the good agreement between values for the ten regions, although half are considered significantly different.

Conclusions

We have presented a novel data-driven cortical thickness estimation method based on the determination of the GM/WM boundary and a search through the GM probability maps to find the opposing edge. We have illustrated that the technique has excellent statistical error, with a reproducibility of 0.3mm, and shown agreement between regional measurements made in this study and a semi-automated manual mark-up method.

References

[1] Kabani et al. Measurement of Cortical Thickness using an automated 3-D Algorithm: a Validation Study. NeuroImage 13:375-380 (2001)

[2] Scott et al. Determination of age-related loss of cerebral cortical thickness usign a novel technique. Submitted to ISMRM 2005.