Longitudinal Cortical Atrophy Detection Using Geometric Active Contours: a Validation Study

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Background: Although multiple sclerosis (MS) is typically considered a white matter (WM) disease, gray matter (GM) pathology is commonly found in MS brains and may contribute significantly to disability.[1] Since GM lesions are undetectable in conventional MRI, GM atrophy is a common measure of GM pathology. Most GM atrophy measurements have used cross-sectional algorithms, where each measurement is done independently from other time points, each with its own independent measurement error. [2] In order to detect small changes over short time intervals, a GM atrophy detection tool is needed that uses information from all available MR images acquired over time.

Objective: The objective of this study was to develop a new cortical longitudinal atrophy detection algorithm (CLADA) using a dual surface active contour model of the cortex and to investigate its accuracy and reproducibility.

Methods: We used T1-weighted spin echo images (TR/TE = 600/20ms, slice thickness = 5mm, pixel size = 0.94x0.94mm) from MS patients and healthy controls (HC) participating in a longitudinal atrophy study. MRIs were acquired either semi-annually (for MS) or annually (for controls) over the course of 4 years. For each subject, we registered and averaged all images. We then applied a geometric active contour model to create a subject specific cortical model consisting of 2 surfaces bordering the inner WM surface and outer pial surface. To identify the locations of the inner and outer surfaces at each time-point, the cortical model was deformed along the surface normal using a parametric warp. Cortical GM volumes (CGMV) were measured to quantify the longitudinal GM morphometric changes. We performed 3 validation studies: 1) a test of the accuracy of the cortical model, 2) a comparison of CLADA to manual segmentation, and 3) a scan-rescan test to determine reproducibility. To test the accuracy of the cortical model, we used 5 IBSR image data sets (Center for Morphometric Analysis, Massachusetts General Hospital). For each one, we measured the CGMV and created binary GM masks, which were compared with the 'true' segmentation in terms of volumetric error, similarity index (SI), and the correlation of 2 measurements. For the second validation, we manually segmented MR images from 2 MS patients and 3 HC acquired at 2 different time-points and compared with the results of CLADA to determine longitudinal accuracy. For the scan-rescan test, we used MRI's from 8 MS patients acquired weekly over 4 weeks and measured coefficient of variation in CGMV measurements.

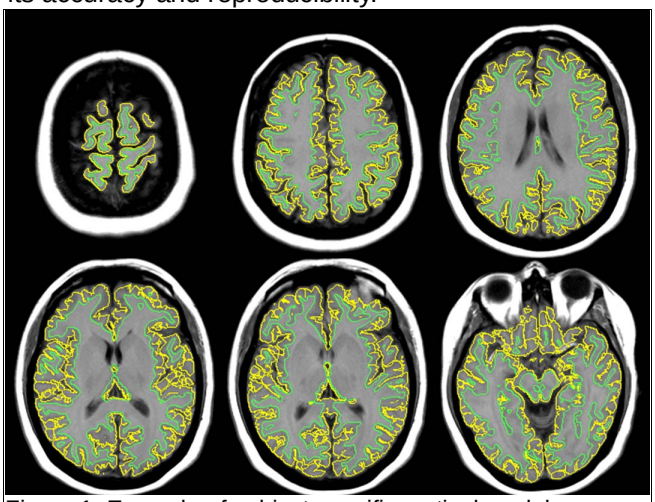

Figure 1: Example of subject specific cortical model (Green=inner, Yellow=outer surfaces)

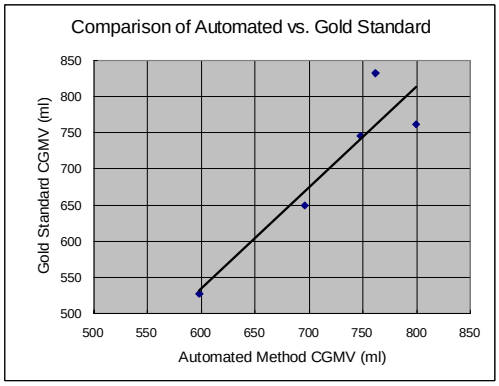

Figure 2: IBSR comparison of cortex model

Results: An example of the cortical model is shown in Figure 1. 1) Accuracy of cortical model: Comparisons of cortical GM using 5 IBSR data sets showed an average SI of 0.88 (indicating excellent agreement), an average volumetric error of 6.8%, and CGMV correlation of r=0.924 (Figure 2). 2) Accuracy of CLADA: The average SI from comparison with manual segmentation was 0.77, the volumetric error was 6.4%, and the CGMV correlation was r=0.914 (Figure 3). 3) Scan-rescan test: The coefficient of variation from 8 MS patients imaged weekly was 0.42%.

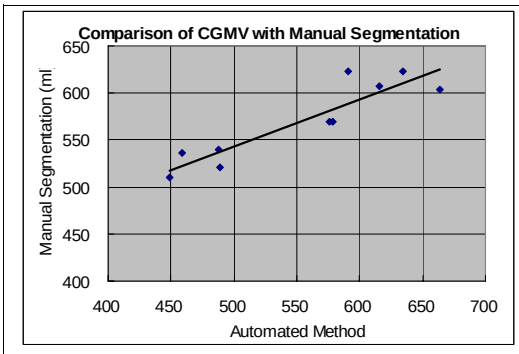

Figure 3: Comparison of CLADA with manual segmentation

Conclusion: These validation experiments showed that the new CLADA method is applicable for measurement of cortical GM atrophy in MS patients. Future studies will aim at determining the relevance of CGM atrophy in clinical settings.

Reference:

1. Bo L. et al. Multiple Sclerosis. 9(4) 2003. 323-331.
2. Chard DT. et al. Multiple Sclerosis. 10(4) 2004. 387-391.