Whole Brain Fractal Analysis of the Cerebral Cortex Across the Adult Lifespan
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INTRODUCTION
Neuroimaging studies in recent years have highlighted the numerous important properties of the human cerebral cortex. One of the more interesting characteristics of the cortex is that it displays fractal properties (i.e. statistical similarity in shape) over a range of spatial scales. The complexity of the fractal brain can be quantified by a numerical value known as fractal dimension. Previous work has demonstrated that subjects with Alzheimer’s disease have a significantly lower cortical fractal dimension than age-matched controls. The effects of age itself on fractal dimension have not yet been determined.

The current standard of care regarding interpretation of structural imaging data is qualitative (e.g. “mild” vs. “moderate”) and highly subjective. Fractal dimension quantifies this current subjective and qualitative metric of cortical shape change. The resulting complexity value would replace the current subjective evaluation of cortical shape with a quantitative statistical measure.

The purpose of this project is to evaluate fractal dimension (a measure of complexity) as an objective biomarker for changes in the shape of the cerebral cortex. We can compute the degree of similarity between images by calculating the deformation energy required to morph images together (in this case we are using vector energy).

HYPOTHESES
- Fractal dimension (FD) is a consistent and replicable metric which can quantitatively characterize cortical shape change better than the qualitative assessment of “age-appropriateness”.
- FD-weighted atlases will be a superior tool, in capturing the trend and variability in shape changes in the cerebral cortex, than age-weighted atlases.

METHODS

Atlas Construction

Age-FD Frequency Distribution

RESULTS

Fractal Analysis

Source Data: Magnetic resonance images (MP-RAGE sequence) came from an existing, de-identified image database of cognitively normal subjects in the Dallas Lifespan Brain study (DLBS); N=322; ages 20-90.

Image Segmentation: 3D surfaces were generated from the MR images through a semi-automated segmentation software suite called FreeSurfer (Martinos Imaging Center, Massachusetts General Hospital, Boston). 3D tessellated triangle surfaces of the cerebral cortex were computed using custom software, Cortical Complexity Calculator. A(Alzheimer’s Image Analysis Laboratory, Salt Lake City, UT).

Computing Fractal Dimension: The fractal dimension (FD) of the 3D tessellated triangle models of the cortical ribbons were computed using custom software, Cortical Complexity Calculator. B(Alzheimer’s Image Analysis Laboratory, Salt Lake City, UT). This is a cube counting algorithm which uses the following formula:

\[ FD = \log \left( \frac{\text{cube count}}{\text{cube size}} \right) \]

Figure 1. Creating cube-tiled brains to calculate global fractal dimension from FreeSurfer generated brain surfaces.

CONCLUSIONS
- There is a significant negative correlation between aging and cortical fractal dimension (r=-0.636, p<0.001). Fractal dimension (FD) is a consistent and replicable metric which can quantitatively characterize cortical shape change better than the qualitative assessment of “age-appropriateness”.
- FD-weighted atlases will be a superior tool, in capturing the trend and variability in shape changes in the cerebral cortex, than age-weighted atlases.
- Variability in cortical structure is highest in brains of higher age or lower FD. Atlases based upon FD capture more of the variance in cortical shape than atlases based upon age (R2=0.6245 and R2=0.3274 respectively). Energy of warping via the LDMM framework suggests brains of equivalent fractal dimension (irrespective of age) are much closer in structure than brains of equivalent age.
- Cortical fractal dimension is a better predictor of cerebral shape than age. Cortical FD is used as a novel imaging biomarker that quantifies age-related brain shape changes.

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