LONGITUDINAL SHAPE ANALYSIS OF LATERAL VENTRICLES DURING THE FIRST YEAR OF HUMAN LIFE

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Introduction

Magnetic resonance imaging (MRI) has become the premier tool for quantitative and noninvasive study of children brain development. Previous MR studies [1] have shown that brain development in the first few years after birth is extremely dynamic and likely plays a role in neuro-developmental disorders including autism and schizophrenia. Thus, it is prominent to be able to determine the normal growth patterns of brain structures in healthy infants and young children. However, such information is lacking for the first year of human life. Most previous work only compares neonates and one year olds and/or even later age groups, but not within the first year during which the brain undergoes the most dramatic development. In this ongoing longitudinal study, subjects were scanned repeatedly every 3 months during the first year of age. We developed longitudinal shape statistical methods to study the growth pattern of the lateral ventricles of the brain, and obtained significant findings that the growth of lateral ventricles at different locations/regions is not uniform during the first year of life, with the frontal and caudal ends of the ventricle extend most rapidly towards the anterior and posterior directions respectively and the mid-body remains relatively constant.

Materials and Methods

Currently, a total of 24 healthy subjects were recruited and repeatedly imaged by a head-only 3T MR imaging scanner every 3 months (2 weeks, 3, 6, 9 and 12 months after birth), resulting in a total of 103 cases. Every subject included in this study has at least 4 scans over time (Figure 1). First, a longitudinal neonatal brain image segmentation algorithm [2] was applied for automatic tissue segmentation. Next, based on the cerebro-spinal fluid (CSF) segmentation, the lateral ventricle structures were carefully outlined and inspected by experts. Due to the young age of subjects, the segmentations of temporal and occipital horns were disconnected from the main body and thus were excluded from the analysis. Later, a densely sampled surface representation and surface correspondence were established using the framework of 3D Spherical Harmonics based Point Distribution Models (SPHARM-PDM) [3]. Such model has been successfully applied to study various brain structures including hippocampus, caudate, amygdala and lateral ventricles, etc.[3]. Each corresponding point represents a small corresponding surface patch among the population of lateral ventricles. To exclude the shape differences from rotation and translation, all lateral ventricles were rigidly aligned by rigid-body Procrustes alignment.

The study of the developmental growth patterns of lateral ventricles is broken down into two problems: what is the major growth direction at each corresponding local patch and what is the growth rate along that direction? First, the major growth direction at each corresponding point (Figure 2) was computed by performing singular value decomposition (SVD) on individual difference vectors from later time points to baseline locations. These individual difference vectors contain information of local growth trend, based on which SVD provides the optimal average local growth direction in a least square sense. Second, original corresponding points were projected onto the local growth directions (Figure 1). A longitudinal linear mixed-effects model [4] with a logarithmic population mean $y = a + b\log(t+1)$ was applied to the projected value to study the growth rates with regard to $\log(t+1)$ along these directions, where t is the number of days after birth. Normality tests were performed to validate the selection of the logarithmic mean model. A false discovery rate (FDR) of 0.001 was used to eliminate the effects of multiple comparisons on the statistical significance of growth rate coefficients.

Figure 1. Repeated measurements of the lateral ventricle shapes of 3 selected subjects. Each subject has at least 4 time points. The color map shows the projection value along the major growth direction at each corresponding locations.

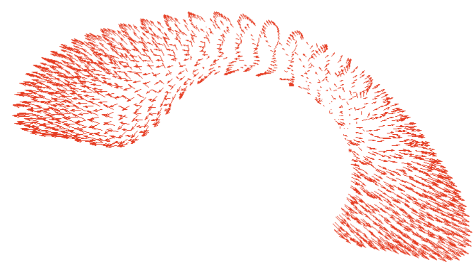

Figure 2. Densely sampled surface corresponding locations shown on the mean lateral ventricle. Local major growth directions, lengths of which are scaled by the corresponding growth rates, are displayed at each location.

Results

The local growth directions, combined with their corresponding growth rates, form a surfaced-based vector field (Figure 2). It provides us a clear image of the developmental pattern of lateral ventricles during the first year of human life: the frontal and caudal parts of the lateral ventricle body extend towards the anterior and posterior of the brain, respectively; while the mid-body of the lateral ventricle remains relatively constant over time. More specifically, the growth of the ventral part of the mid-body was tested to be statistically nonsignificant (Figure 3). The growth of the dorsal part of the mid-body was mostly significant, but its growth rate with regard to logarithmic of time $\log(t+1)$ is relatively small (colored green in Figure 3). Both the frontal and caudal ends of the ventricle are colored red in Figure 3, which means their growth is significant and the rates are the fastest. Based on these observations, we reach the conclusion that, during the first year of human life, the growth of lateral ventricles at different locations/regions is not uniform or congruent, with the frontal and caudal ends extend most rapidly towards the anterior and posterior of the brain respectively and the mid-body remains relatively constant over time. Such findings are consistent with previous studies [5] that the shape of human brain grows fastest in the anterior-posterior direction during early brain development.

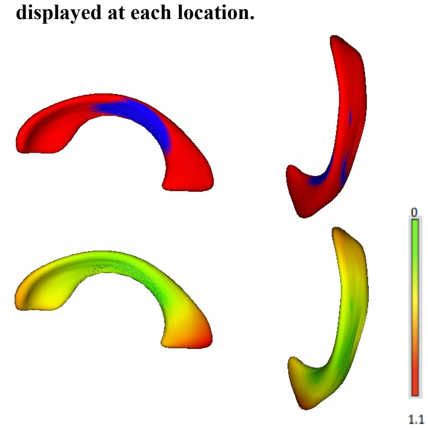

Figure 3. Top row: corrected P-value map (FDR at 0.001). Red regions indicate statistical significance. Bottom row: colormap of estimations of local growth rate with regard to Log(t) along the major growth directions.

Discussion

A longitudinal statistical shape analysis framework was proposed to study the developmental changes of lateral ventricle during the first year of age. Biologically meaningful significant growth patterns were found. This is an ongoing longitudinal study. With the increase of population size and time span, our future work includes comparing brain growth patterns between male and female and between the normal and diseased groups.

References

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