

Characterizing spatial-temporal patterns of neonatal brain development using volume-surface analysis

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Target audience: Clinical researchers who are interested in neonatal brain growth patterns seen on MRI and their associated regions with functional and pathological abnormalities.

Purpose: We aim at providing a volume-surface analysis (VSA) tool to quantify longitudinal developmental change of the human brain. The variation of brain development is often associated with neurological diseases and functional deficits. Previous studies provided local morphological changes related to cortical development, but there have been little attempt to investigate the spatial-temporal patterns of the entire brain development and the intra- and inter-individual variability. We introduced diffeomorphic mapping tools to quantify the growth patterns for whole brain.

Methods: Longitudinal T1-weighted MR images were acquired from five normal term-born babies (2 boys, 3 girls; 38.4-41.1 weeks post-menstrual age (PMA) at birth) at 3 Tesla (matrix size: 160x176x256, 1mm³ isotropic). Each subject was scanned at ~1 week after birth, followed by two scans at ~5 weeks and ~10 weeks after birth. Within each subject, images were rigidly aligned using 6 anatomical landmarks. Experiment 1: To quantify the combined effect of both morphometric and photometric changes related to brain development, each image was mapped to its corresponding image from the next time point. The diffeomorphic registration tool (LDDMM [1]) was used for the volume mapping, and the log of Jacobian determinant was calculated from the diffeomorphic transformation. Experiment 2: To quantify changes in the cortical surface between two time points, the diffeomorphic surface mapping technique [2] was used. The JHU-neonate-SS atlas [3] was used to normalize and report the volume and surface analysis results in a common coordinate.

Results and Discussion: Shown in Fig.1, the total brain volume (TBV) had a higher growth rate ($20.7 \pm 4.1\%$) during the 1st to the 5th week after birth than that during the stage of the 5th to the 10th week ($12.9 \pm 4.7\%$). Fig.2 (Exp.1) shows the change in the two developing stages quantified by log-Jacobian. The cerebellum was detected as a rapidly growing structure in both stages (white arrows). The effects of brain development, such as gyrification, myelination and other factors that might affect T1-weighted contrast, were also visualized as high log-Jacobian area (warm color) seen in the cortico-spinal tract (green arrows), and low log-Jacobian areas seen in the basal ganglia and the frontal white matter (yellow arrows). Fig.3 (Exp.2) shows the growth pattern of cortex, using the measurement of the displacement on the norm direction. Although the average pattern shows a faster growth in the parietal lobe between 1 to 5 weeks, and in the temporal lobe between 5 to 10 weeks (red arrows), the most striking finding is the high inter-subject variability. The standard deviation (STD) map shows greater variation in the parieto-temporal area (yellow arrows). We observed three different brain growth patterns (black arrows): 1) the “widening pattern”, in which the brain grows faster in the left-right direction (sub1); 2) the “elongating pattern”, in which the brain grows faster in the anterior-posterior direction (subs2 and 4); and 3) the “isotropic growth pattern”.

Conclusion: The VSA tool can quantify patterns of the brain growth and cortical development. Brain growth pattern shows great spatial and temporal variability, both within an infant and across infants. Clinical significance of the developmental variability needs to be elucidated.

References: 1. M.F. Beg., et al. Computing large deformation metric mappings via geodesic flows of diffeomorphisms. *Int. J. Comp. Vis.* 61 (20):139-157. 2. M. Vaillant, et al., Surface Matching via Currents. *Info.Proc.Med. Imag.*, 2005. 3. K. Oishi, et al. Multi-contrast human neonatal brain atlas: Application to normal neonate development analysis. *Neuroimage* 2011; 56 (1); 8-20. **Grant support:** R01HD065955; U54NS/DA056883; K24DA16170.

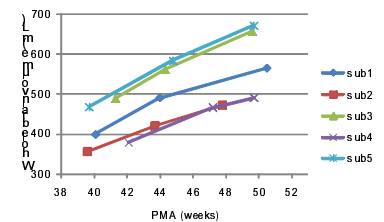


Fig.1. Total brain volume for longitudinal data.

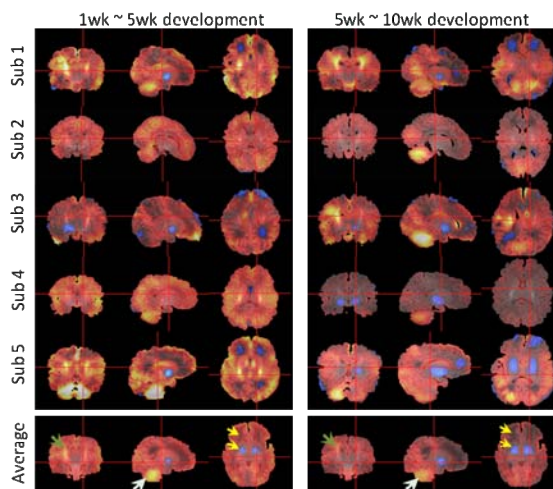


Fig.2. The individual and the average log-Jacobian during the developmental stage of 1st -5th week and 5th -10th week.

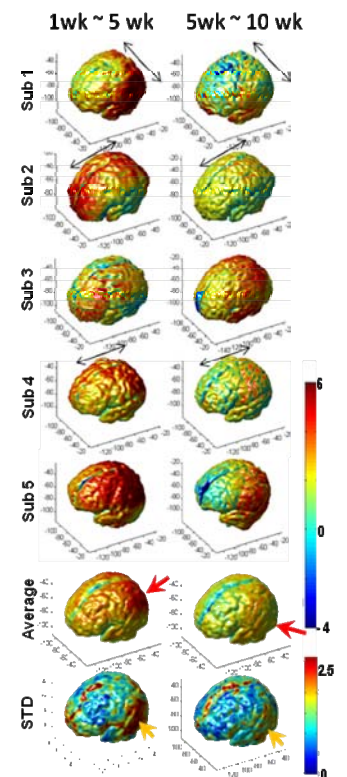


Fig.3. Surface displacement on norm direction for the two developing stages.