Development of an Algorithm for Segmentation of Cerebral Cortex in T2 Weighted Neonatal Brain MRIs and Its Use to Construct Prototype Age Specific Surface Atlases

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Introduction. Extensive brain development and cortical folding occurs in the third trimester of pregnancy. A developmentally plausible theory of cortical growth and maturation proposes that neural connectivity directly leads to cortical folding by exerting mechanical tension along long-distance cortico-cortical pathways[1]. Perturbations to this connectivity are not uncommon in premature birth and could affect cortical folding in a number of ways. We are studying the pattern of cortical development at various gestational ages by generating cortical surface reconstructions from T2-weighted MRI volumes. Specifically, we have developed an algorithm for cortical segmentation of preterm brain MRIs that can be used to generate cortical surfaces and build age specific atlases.

Methods. Our segmentation algorithm, known as the Local Intensity Gradient And Seed Expansion (LIGASE) algorithm, runs in MATLAB. In LIGASE segmentation volume grows in three dimensions from a user specified seed voxel placed in the white matter, segmenting each white matter voxel it contacts and stopping at the gray/white boundary. Growth of the segmentation volume is constrained probabilistically using parameters derived from the voxel intensity histogram. We model the white matter intensity with a Gaussian function, assigning each voxel a white matter probability. For each voxel we also calculate a gradient, defined as the magnitude of a vector whose components are the difference in intensity between the voxel and its adjacent neighbors in three dimensions, as well as a pairwise difference, defined as the difference in intensity between the voxel being tested for segmentation and the last voxel segmented. As the segmentation volume grows the white matter probability value is used to determine the allowable ranges of the gradient and pairwise difference for a voxel to be identified as white matter. After the initial white matter segmentation is generated we dilate the segmentation to achieve a boundary that more closely approximates a mid cortical thickness. The final segmentation is loaded into Caret v5.5 software and a fiducial (3D) surface is generated. Using the small number of hemispheres processed to date we generated a prototype atlas (proto-atlas) for two age ranges. Each fiducial surface was mapped to a minimally distorted sphere using existing algorithms in Caret. Landmarks shown to have little interindividual variability in adults[2] were drawn on each hemisphere, projected onto the minimally distorted standard sphere and then averaged to create a population averaged proto-atlas that can serve as a target for registering individuals to a common space.

Results and Discussion. Figure 1 shows representative coronal MRI slices demonstrating the accuracy of the segmentation algorithm in capturing the mid-cortical thickness on a 30 week gestation infant scanned at birth and a preterm infant scanned at term equivalent (38 weeks). Figure 2 shows the fiducial and inflated surface for each of the individuals in figure 1 along with three lateral registration boundaries drawn on the surfaces (central suclus, Sylvian fissure, superior temporal gyrus). The inflated surfaces are color coded according to sulcal depth. Projecting landmarks drawn on three individual surfaces to a standard sphere shows similar trajectories across individuals in both the 30 week gestation and the term equivalent infants. The high degree of correspondence in these landmarks allows us to average them together and create a proto-atlas for the corresponding gestational age. The proto-atlases in turn allow us to register individuals to a common space and create average surfaces. Figure 4 shows a fiducial and inflated surface for the average of three individual infants for each of the two gestational ages. The inflated maps are colored according to average sulcal depth for each gestational age. Differences between the 30-week and term atlases as well as between the term atlas and an adult human atlas (PALS-B12, data not shown) underscore the importance of developing postconceptional age-specific atlases for evaluation of prematurely-born infants. This approach holds promise for defining the alterations in macroscopic cortical architecture associated with both normal brain development and injury in prematurely-born infants.

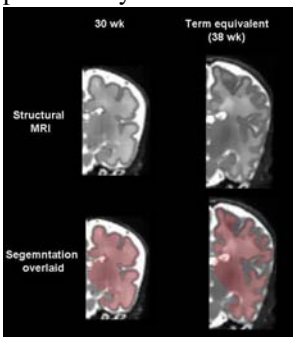

Figure 1

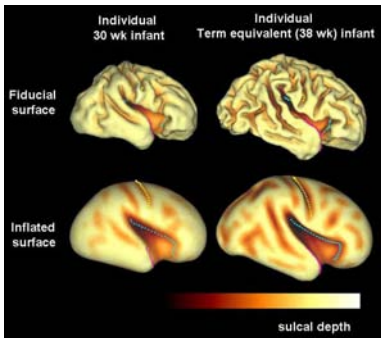

Figure 2

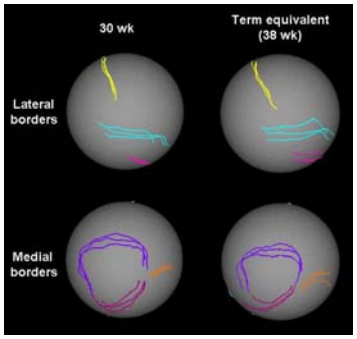

Figure 3

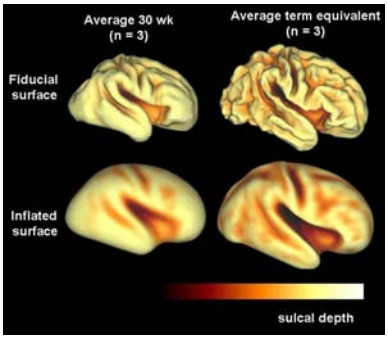

Figure 4

1. Van Essen, DC (1997) A tension-based theory of morphogenesis and compact wiring in the central nervous system. Nature 385:313-318
2. Van Essen, DC (2005) A Population-Average, Landmark-and Surface-based (PALS) atlas of the human cerebral cortex. NeuroImage 635 – 662