Infant 0-1-2 Brain Atlases for MRI Segmentation and Normalization

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Introduction: Brain atlases, embedding knowledge of structural and functional properties of neuroanatomical sites, are widely used in computational neuroanatomy for pedagogical purposes, surgical planning, and image analysis. An atlas, in its different forms, can be used as a reference for normalization of a group of individuals, as a probability map for defining tissue prior distribution, or as a spatial map for brain parcellation. Although numerous human brain atlases have been produced, they are mostly developed for adults. Infant atlases, however, are not well studied. Recent studies suggested that using adult or even pediatric atlases may compromise accuracy in analyzing infant brain images. The degraded performance stems from the fact that dynamic and significant growth process occurs in the first years of life; thus, an atlas not created for infants simply fails to reflect their anatomy. In this paper, we construct brain atlases dedicated for infants at neonates, 1-year-olds, and 2-year-olds, referred to as the infant 0-1-2 brain atlases. Each atlas comprises a set of 3D images made up of the intensity model, tissue probability maps, and anatomical parcellation map.

Materials and Methods: Data were collected in one of our longitudinal studies, involving 95 infants (56 males and 39 females) scanned at 3 ages: neonates, 1-year-olds, and 2-year-olds. T1 and T2 MR images were collected using a 3T Siemens scanner. For T1 images, 160 sagittal slices were obtained with parameters: TR=1900ms, TE=4.38ms, Flip Angle=7°, and resolution=1x1x1mm^3. For T2 images, 70 transverse slices were acquired: TR=7380ms, TE=119ms, Flip Angle=150^0, and resolution=1.25x1.25x1.95mm^3. Before further operation, all images were preprocessed using a standard procedure including skull-stripping and bias correction. T2-weighted images were resampled to 1x1x1 mm^3. Note that one image modality with better tissue contrast was selected for each age group for delineation of anatomical patterns: T2 for neonates, and T1 for 1- and 2-year-olds.

To build the infant 0-1-2 atlases, the images need to be segmented, registered to a common space, and averaged to generate the atlas, which represents subject-independent population information. The key to construction of a good atlas involves performing reliable tissue segmentation to identify tissue structures and registration to determine the anatomical correspondences across age groups and subjects. Specifically, we perform the following steps for constructing the atlases: **Step 1: Longitudinal tissue segmentation.** The 2-year-old image was first segmented with a fuzzy segmentation algorithm. The result was then used as a subject-specific prior to guide tissue segmentation of the respective 1-year-old and neonate images [1]. Note that the longitudinal anatomical correspondences between age groups are also determined in this process. **Step 2: Anatomical labeling.** The Colin27 brain [2] was registered to all 2-year-old images to transfer the Automated Anatomical Labeling (AAL) map (90 cortical/subcortical brain regions). The warped AAL map was then propagated to the neonatal and 1-year-old images, using the longitudinal anatomical correspondences estimated in Step 1. By using the 2-year-old images as an intermediate template for registration, we avoid direct registration of Colin27 to the neonatal images, which can significantly improve the accuracy of the resulting anatomical correspondences. **Step 3: Unbiased groupwise atlas construction.** For each age group, we had, for each of the 95 subjects, the intensity images, segmented images (including probability maps for GM, WM, and CSF), and anatomical parcellation maps. Groupwise registration was performed in each age group to align all images into a common space. Warped to the common space, the intensity model, tissue probability maps, and anatomical parcellation map were then averaged (via majority voting) to generate the desired population atlases, respectively. By performing the above-mentioned steps, the dataset is reliably segmented and normalized, producing the infant 0-1-2 atlases.

There are three major applications for the proposed atlases. Specifically, they can be used as references for normalizing a group of infant images, as tissue priors for atlas-based segmentation, or as templates for brain parcellation. The concept of using age-matched atlas as reference for spatial normalization is widely accepted. In the following, we evaluate the performance of the proposed atlases on guiding segmentation and brain parcellation for new neonatal images. For segmentation evaluation, 10 neonatal images (6 males and 4 females, not included in atlas construction) were selected and manually segmented to serve as the ground truth. Atlas-based segmentation is performed with the segmentation module distributed in SPM5 software [3] by replacing the default tissue probability maps with that of the proposed infant atlas. Segmentation accuracy is evaluated based on the overlap rate, measured by Dice Ratio: $DR = 2|A \cap M|/(|A| + |M|)$, where A and M are the automated and manual segmented regions, respectively. For brain parcellation evaluation, the proposed atlas is registered to 20 new test subjects with longitudinal 0, 1, and 2 year old images. The brain parcellation map is then propagated to all images of each subject. By using their longitudinal correspondence, the label maps in different ages of the same subject can be compared for overlap rate. A 1-year-old infant atlas (constructed from images of 76 infants with age ranging from 6 to 15 months) is used as a comparison baseline in the above evaluation.

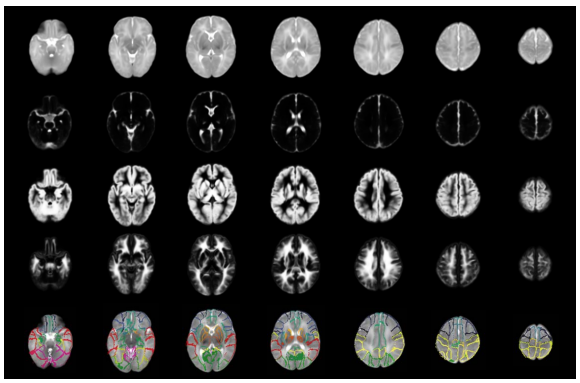

Figure 1. The resulting neonatal atlas.

Results: Fig. 1 shows the neonatal atlas. From top to bottom are the intensity model, probability maps (for CSF, GM, and WM), and anatomical parcellation map, respectively. In atlas-based segmentation evaluation, the overlap rate between manual results and the proposed atlas is 0.84 for GM, 0.79 for WM, and 0.77 for CSF; whereas for the control atlas the overlap rate is 0.81 for GM, 0.75 for WM, and 0.76 for CSF. Significant better segmentation is found in both GM and WM by using the proposed atlas. For brain parcellation evaluation, we compared the overlap rate for each pair of the three warped parcellation maps at three different age groups of each subject, i.e., 0 vs 1, 0 vs 2, and 1 vs 2 (Fig. 2). Our proposed atlases achieve significantly better brain parcellation consistency ($p < 0.05$) than the comparison method in all pairs.

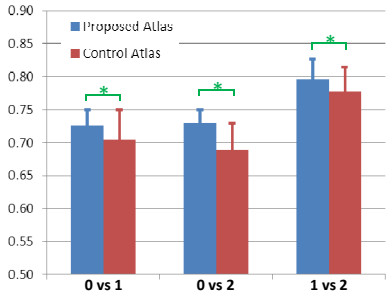

Figure 2. Anatomical parcellation consistency. "*" represents the significant difference between groups under comparison ($p<0.05$).

Discussion: In this paper, we have constructed the Infant 0-1-2 atlases. State-of-the-art segmentation and registration techniques were employed for atlas construction. The proposed Infant 0-1-2 atlases were shown effective for spatial normalization of a population of infant images, as well as their anatomical labeling and tissue segmentation. It is not difficult to foresee that the proposed infant 0-1-2 brain atlases will be significantly conducive to structural and functional studies of the infant brain. These atlases are publicly available on our website, http://bric.unc.edu/ideagroup/free-softwares/.

References: [1]. Shi, F., et al., NeuroImage, 51(2):684-693, 2010. [2]. Holmes, C.J., et al, Journal of Computer Assisted Tomography 22, 324-333, 1998. [3]. Ashburner, J., Friston, K.J., Human Brain Mapping 7, 254-266, 1999.