Neonatal MRI Brain Tissue Segmentation and Morphological Analysis

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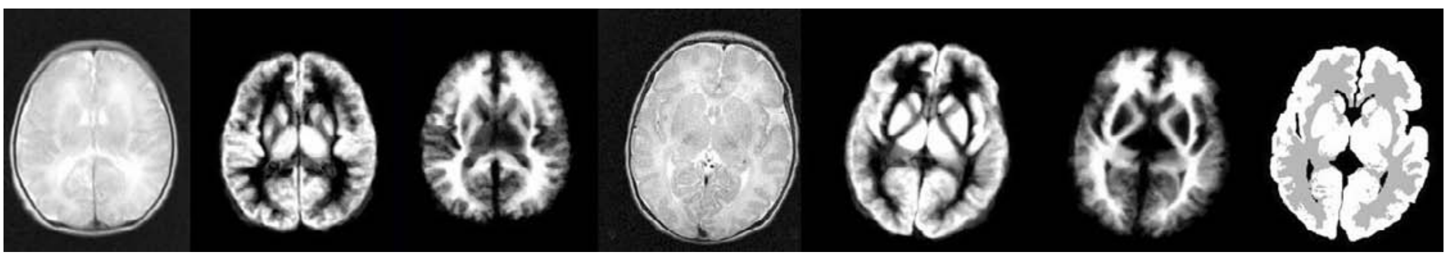
Introduction MRI provides a non-invasive imaging technique to study normal brain development and neurodevelopmental disorders. The challenges in neonatal brain tissue segmentation reside in both intrinsic biological properties and neonatal MR imaging techniques. Due to the inherent brain tissue composition, when compared to adult brain MRIs, neonatal brain MR images have low contrast-to-noise ratio (CNR), large tissue non-uniformity, and large shape variance. Infants born with severe forms of congenital heart defects (CHD) have been shown to have acquired brain injury to the white matter in the form of periventricular leukomalacia (PVL). The ability to quantify gray and white matter volumes changes over time in patients with and without PVL will allow physicians to better understand the developmental consequences of heart surgery, and open up an opportunity to design and monitor neuroprotective strategies. For this purpose, we applied a fully automatic graph-cut based segmentation method, which incorporates adaptive MRI inhomogeneity correction and probabilistic atlases to address the challenges in neonatal MR brain tissue segmentation. The total volumes of gray and white matter were then calculated for each subject in the dataset. When compared to normal neonates reported in the literature [1], the statistical results show significantly smaller volume size of both total gray and white matter.

Method Graph cuts guarantee global or near-global minima of energy functions associated with Markov Random Field (MRF) [2]. Based on this efficient combinatorial optimization method, we incorporate a priori information derived from registered brain atlases as well as the features derived directly from the images. The algorithm adaptively alternates segmentation and inhomogeneity correction in an adaptive scheme. In the first step, to obtain tissue priors, an unbiased population template was constructed by averaging the shape and appearance of the MRIs in the dataset [3]. In the second step, a probability atlas for each tissue type was created by averaging manual segmentations after registering to the template image space. The probabilistic atlases were warped to the subject image space prior to image segmentation. The adaptive component of the segmentation combines inhomogeneity correction and segmentation in an iterative mode. MRI inhomogeneity is characterized by a low frequency field, and is assumed to be multiplicative and uniform for any tissue type. A cubic B-spline approximation method was applied to estimate the inhomogeneity field in each iteration.

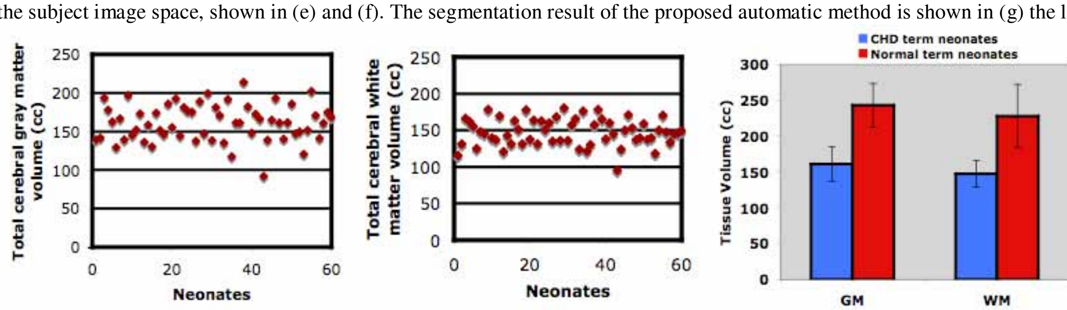
Dataset 60 term neonates (post conceptual age of 36 to 43 weeks at the time of study) with various forms of severe congenital heart defects (CHD) were studied. The MRI scans were performed on a Siemens 1.5T Sonata scanner. Axial T2 weighted images were scanned by using spin echo pulse sequence. The image voxel size was $0.35*0.35*3\ mm^3$. The segmentation was performed for only gray and white matter, while other brain tissue and skull were removed manually from the images.

Results and Discussion 10 MRIs in the dataset were manually segmented. The resulting segmentations were used to create tissue probabilistic atlas. The template, the probabilistic atlases, and the segmentation result are illustrated in Figure 1. The validation of the method has been done in our earlier work [2]. After the segmentation of the 60 T2 weighted images in the study, we measured the total volume size of gray and white matters respectively, the results of which are shown in Figure 2. The average volumes are 161.04±23.72cc for gray matter, and 147.30±18.32cc for white matter. Inder et al. [1] reported the total tissue volumes of normal term neonates are 243±30.4cc for gray matter, and 227.9±43.7cc for white matter. Thus the total tissue volumes of both gray and white matter in these CHD term neonates are significantly smaller than the normal term neonates.



(a) (b) (c) (d) (e) (f) (g)

Fig.1. The tissue priors for a subject image are obtained by registering the probabilistic atlases from the template space to the subject image space. The 10 manually segmented images were registered to (a) the template image space, the average of which are probabilistic atlases for (b) gray matter and (c) white matter. The pixel value in the probabilistic atlases were normalized to the range of [0, 1]. In segmentation of (d) a subject image, the probabilistic atlases of gray and white matters were registered to the subject image space, shown in (e) and (f). The segmentation result of the proposed automatic method is shown in (g) the labeled image.



(a) (b) (c)

Fig.2. Scatter plots were drawn to demonstrate the distribution of the total volumes of (a) gray and (b) white matters. In (c), the average volumes are compared to those data of normal term neonates reported in [1].

Reference

1. Inder T.E. et al., Ann Neurol. 1999 Nov;46(5):755-60.
2. Song Z., Tustison N.J., Avants B.B., Gee J.C., MICCAI (2) 2006: 831-838
3. Avants B.B. and Gee J. C., Neuroimage. 2004;23 Suppl 1:S139-50.