Hybrid Atlas based Tissue Segmentation for Neonatal Brain MRI Acquired Using a Dedicated Phased Array Coil

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Introduction: The image quality of neonatal brain MR is largely hampered by the small head size and low tissue contrast. As a result, it often hinders the subsequent steps of image processing and analysis, especially for brain tissue segmentation. To this end, a dedicated phased array neonatal head coil was devised to improve the MR image quality without lengthening data acquisition time. In addition, a hybrid-atlas-based tissue segmentation algorithm was developed for segmentation of fine structures in the acquired neonatal brain images using the newly devised neonatal phased array coil.

Methods: A total of 43 neonates, with postnatal age range of 2.0-8.3 weeks, participated in this study. All MR images were acquired using a 3T head-only MR scanner. The overall shape of the dedicated neonatal phased array coil was devised based on the brain surface of a probabilistic brain atlas established from ~60 normal pediatric subjects. The phased array coil consisted of 8 receiving channels (Fig 1). T1-weighted images were acquired using a MP-RAGE sequence and the imaging parameters were as follows: TR=1820ms, TE=4.38ms, Flip Angle=7, resolution=0.79×0.79×0.8 mm^3, 2 average and acceleration factor (AF=2). T2 image were also acquired with parameters, TR=9280ms, TE=119ms, Flip Angle=150, resolution=1×1×1.3 mm^3, and AF=2. In addition, a low resolution spin density weighted 3D FLASH sequence was employed to obtain eight coil sensitivity profiles. By combining eight coil sensitivity profiles with eight images of each modality (T1 or T2) using a sum of squares metric [1], high-quality images can be reconstructed for each modality. Fig. 2 shows the results for T1 and T2 images, where the skull and cerebellum have been removed for subsequent tissue segmentation. The fine cortical structures with high tissue contrast and clear cortical convolutions can be observed in T1 and T2 images.

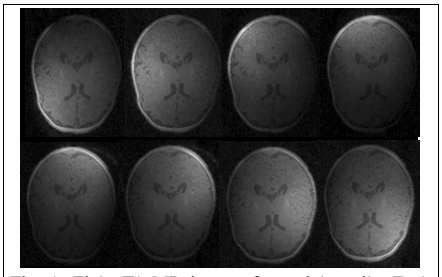

Fig. 1. Eight T1 MR images from eight coils. Each image has different coil sensitivity, corresponding to the eight locations of coils placed.

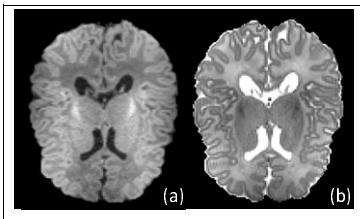

Fig. 2. The reconstructed neonatal brain MR images with new imaging protocol. (a) T1 image; (b) T2 image.

In order to segment the brain tissues into gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF) using the acquired images, a hybrid atlas based segmentation method was developed. Specifically, this approach consists of the following steps. 10 presegmented neonatal images were used independently as atlas to guide tissue segmentation of the same subject [2], and then the 10 sets of tissue probability maps corresponding to 10 different segmentation results were averaged to obtain three population atlases for GM, WM and CSF, respectively (Fig 3a-c). These obtained population atlases preserved the main spatial patterns of GM and WM; however, they were too fuzzy to provide good guidance for cortical segmentation. To address this problem, the cortical GM in T1 MR images were enhanced with a modified Hessian filter (popularly used in vessel tracking) [3]. The enhanced cortical GM map (Fig. 3d) was combined with the population GM atlas, and further normalized with WM and CSF atlases, to finally generate three new hybrid atlases for GM, WM, and CSF, respectively (Fig 3e-g). Based on these hybrid atlases, the T1 and T2 images of neonate were segmented with a unified segmentation approach [4].

Results: The final segmentation result with our hybrid atlas based segmentation method is provided in Fig 3h, where cortex is well segmented. Based on our dataset, neonatal total brain volume is obtained as $(4.05\pm0.52)\times10^5$ mm^3, in which cerebral gray matter and white matter account for 60% and 33%, respectively. This high-quality segmentation also allows for cortical surface reconstruction and cortical thickness measurement from the neonate images (Fig. 4).

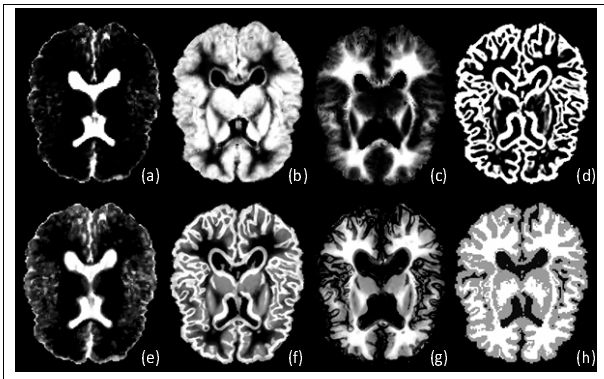

Fig. 3. Generation of population atlases and hybrid atlases for tissue segmentation. (a-c) Population atlases for CSF, GM, and WM; (d) Enhanced cortical GM map from the reconstructed T1 image (Fig 2(left)); (e-g) Hybrid atlases for CSF, GM, and WM; (h) Tissue segmentation result.

Discussion: Detailed segmentation of different brain tissue types in neonates has been a daunting task owing largely to the poor spatial resolution and low signal-to-noise ratio (SNR). With a dedicated phased array neonatal head coil, it enables the improvement of spatial resolution without lengthening data acquisition time via parallel imaging methods. In addition, the small head size of the neonates maximizes the SNR benefit of using surface coils. Together, a substantial improvement in the image quality as well as spatial resolution can be obtained with the dedicated neonatal phased array coil. The improved image quality further improves our ability to accurate segment different brain tissue types. A novel hybrid atlas based MRI segmentation was developed and results demonstrated that this approach is capable of segmenting different tissue types with high quality, facilitating the investigation of neonatal brain development.

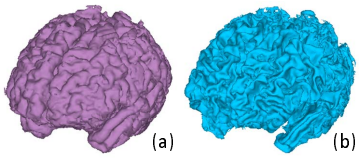

Fig. 4. Surface rendering of tissue segmentation results. (a) Gray matter surface; (b) White matter surface.

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