Cortical Surface Segmentation in Infants by Coupled Surfaces Deformation across Feature Field

François Leroy [1 2], Jean-François Mangin [2], François Rousseau [3], Hervé Glasel [1 2], L. Hertz-Pannier [2,], Jessica Dubois [4], Ghislaine Dehaene-Lambertz [1 2]

[1] INSERM, U562; [2] CEA/I2BM/NeuroSpin, Gif/Yvette, France
francois.leroy@cea.fr
[3] LSIIT, UMR CNRS-ULP 7005, Illkirch, France
[4] INSERM, U663, Hôpital Necker-Enfants malades, Paris, France

Summary

Understanding the development of the human brain is challenging because imaging an immature brain encounters several difficulties. First, partial volume effects due to the small size of the brain associated with an already complex pattern of gyrification (Fig. 1) hamper cortex edges detection. Second, the GM-WM contrast is weak due to unmyelinated white matter. Finally, the human brain undergoes big and fast changes during the first months of post-natal life (e.g., the cranial perimeter increases by 0.5cm per week). However, these changes are not homogeneous across the brain, some areas showing intense myelination and synaptogenesis (e.g., visual and motor areas) while others have a more protracted development (e.g., frontal areas) [1]. This maturation inhomogeneity produces important variation in tissue intensity on T2 Magnetic Resonance (MR) images. As shown in Figure 1, WM is much darker in myelinated areas than in non-myelinated ones.

These specific characteristics of the infant brain explain why segmentation methods designed for T1 MR images of the adult brain are not optimal. To our knowledge, none of the well-known brain softwares, such as FreeSurfer, Caret, BrainSuite and BrainVisa, have produced as yet automatic reconstruction of the infant's cortical surface.

As for T2-specific methods, atlas-based segmentations of the cortex [2, 3] require accurate and robust brain templates. However, variations of tissue contrast are rapid and asynchronous during the first months of life. We have not used brain atlas because we believe that multiple atlases would be required to capture the anatomical variability of infant brains.

Xue and colleagues [4] have recently developed the only, to our knowledge, atlas-free automatic method for use in preterms and newborns. Their approach is mainly based on local estimates of tissue intensity to deal with intensity fluctuations across the brain. However, the GM-WM contrast quickly decreases in areas being myelinated during the first months of life. Thus, the GM-WM interface would not be properly detected in those regions using tissue intensity alone. Here we propose features to ameliorate this problem.

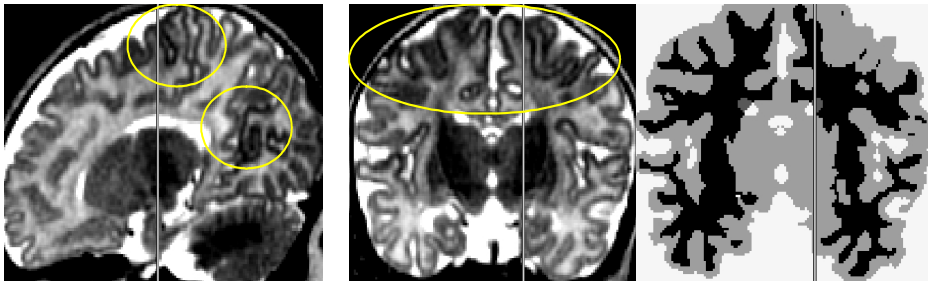

Fig. 1. Myelination in a 9-week-old infant in T2 MRI and segmentation results. *Left*: sagittal slice. *Middle:* coronal slice; the myelinated central and occipital areas are shown in *yellow circles*. *Right*: WM segmentation in *black* (and brain mask in *gray*). V*ertical lines* show the intersection between the sagittal and the coronal planes.

On the one hand, we propose using some of the geometrical properties of brain tissue to produce a more robust detection. First, we extracted ridge segments which are present in WM at every level of myelination. Second, we applied morphological top hats to detect cortex based on both its relatively constant thickness and its low intensity values. We have combined these two features within a feature field.

On the other hand, we have applied a coupled surface deformation method which preserves topology. Such deformation approach has produced faithful detections of the folding patterns in T1 MR images of adult brains [5]. However, we had to adapt it to T2 MR images, because the contrast between corticospinal fluid (CSF) and GM is similar to the WM-GM contrast. Thus, the deformation process would not discriminate the GM-WM interface from the CSF-GM interface where partial volume effects are strong. Therefore, we have applied deformation to two converging surfaces, initialized on each side of the GM-WM interface to reduce localization errors.

An evaluation of this method has been conducted with 11 infants from one to four months of age. Mesh results, which have been built from the segmented GM-WM interface, are shown in Figure 2.

We have evaluated the detection of the GM-WM interface using sulcal landmarks. These landmarks were drawn manually and were validated by an expert neuroanatomist. We have measured the distance between these landmarks and the GM-WM interface. The distance matches estimates of cortex thickness to a very large extent (over 80% of sulcal voxels). Segmentation errors due to overlay, i.e., when the distance between segmentation and landmarks falls below cortex thickness, happen for only 2% of all landmark voxels.

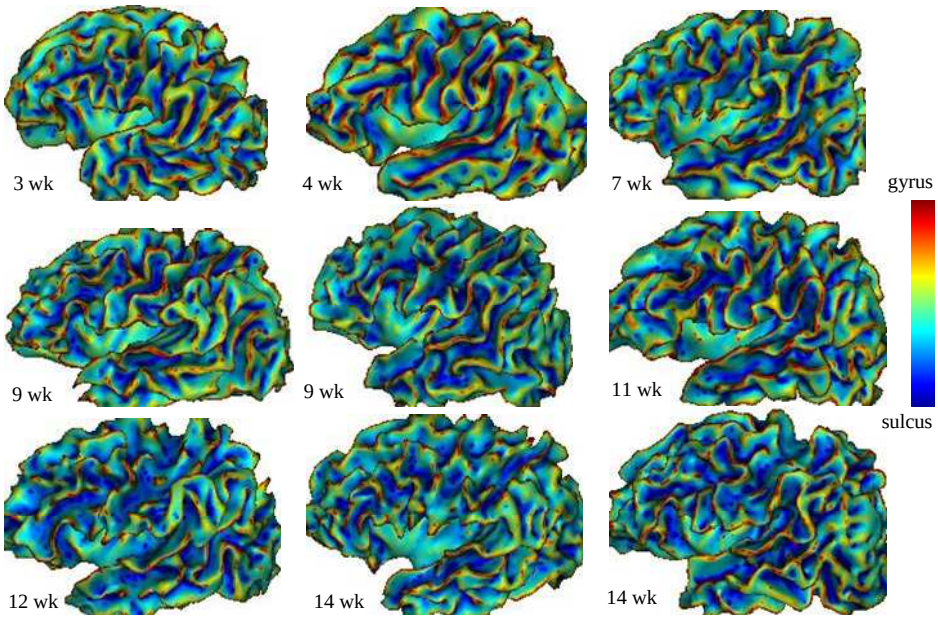

Fig. 2. White matter meshes of the left hemisphere for 9 infants; *wk*: weeks.

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