# Cortical surface Reconstructions for Developing Neonates

**H. Xue[1,2], S. Jiang[1], L. Srinivasan[1], S. J. Counsell[1], M. A. Rutherford[1], D. Edwards[3], D. Rueckert[2], and J. Hajnal[1]**

[1]Robert Steiner MRI Unit Imaging Sciences Department, MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, London, United Kingdom, [2]Visual Information Processing, Department of Computing, Imperial College London, London, London, United Kingdom, [3]Department of Paediatrics, MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, London, United Kingdom

**Introduction** Automatic segmentation and reconstruction of neonatal cortex is much more challenging than in adults mainly due to immature tissues displaying different contrast patterns and often a higher level of intra-tissue signal heterogeneity. We have developed a fully automatic algorithm that provides an accurate segmentation of both cortical gray matter and white matter [1]. To perform quantitative analysis of the cortex in neonates a final step of cortical reconstruction is required. There are established methods for doing this developed for adult data, but because of the large range of cortical geometries with gestational age (GA) their application is not guaranteed in this subject group. In this work we have implemented a suitable reconstruction based on a level set approach, adapted it and tested it on a cohort of infants with a wide range of GA

**Surface reconstruction** Starting from a probabilistic tissue classification determined using an automated segmentation algorithm we developed specifically for use on neonates [1] the inner, central and outer cortical surfaces are reconstructed. We adopt the reconstruction workflow proposed in [2]. Specifically, the cortical surfaces are implicitly represented by the zero level-set and surface evolution is driven by resolving the standard level-set partial differential equation. The signed pressure function for evolving the inner surface is defined by $R_{in}(\vec{x}) = 2P_{WM}(\vec{x}) - 1$ which approximates the 0.5-isosurface of white matter posterior probability produced by the segmentation step. A small curvature force proportional to the mean curvature of the surface is added to keep the surface smooth. The outer cortical surface is obtained by evolving the level-set function initialized by the inner cortical surface with the signed pressure function $R_{out}(\vec{x}) = 2(P_{WM}(\vec{x}) + P_{GM}(\vec{x})) - 1$ and the small curvature force. Unlike the method in [2], we exploit a simple approach to compute the level-set function corresponding to the central surface: given that the level-set functions $\phi_{inner}$ and $\phi_{outer}$ for the inner and outer surfaces remain signed distance functions, a central surface is defined to be equidistant from the inner and outer surfaces; thus, the level set function for central surface $\phi_{central}$ can be computed by $\phi_{inner} + \phi_{outer}$ because the level-set functions used are negative inside and positive outside. The central surface can be explicitly generated as the 0-isosurface of $\phi_{central}$. As $\phi_{inner}$ and $\phi_{outer}$ may deviate from signed distance functions, either the reinitialization equation or fast marching algorithm [3] needs to use before computing the central surface. Because the level-set evolution may not conserve the surface topology, a topology preserving level-set algorithm [2] is used for both inner and outer surfaces, which favors the recovery of very thin sulci.

**Results** The method has been applied to 67 subjects with the GA from ~27 to 45 weeks. This period includes most of the current GA range for preterm neonates. All MR images were acquired on a 3T Philips Intera system (Best, The Netherlands) using a standard 6 channel head array coil. The preterm infants were sedated with chloral hydrate and a trained neonatologist was present throughout scanning. The MR sequence parameters were as follows: T2w fast spin echo pseudo volumes: TR 1712 /TE 160ms, FOV 220, matrix $224 \times 224$, flip angle 90°, voxel size of $0.86 \times 0.86 \times 1$mm with the 50% slice overlapping. T1-weighted images were also acquired for all neonates. However, we did not find T1w images helpful for cortical segmentation either on their own or in combination with the T2w images due to very limited gray-and-white matter contrast. Only the T2 channel of MR dataset is therefore used. We visually inspected the surface reconstructed by rendering the intersection contours on 2D slices as well as 3D surfaces and verified that the method performs well for all subjects. Fig. 1 shows the 2D intersection contours of inner, central and outer surfaces for neonates over a representative range of GA. The corresponding 3D surfaces are presented in Fig. 2 where the mean curvature is used for color-coding.

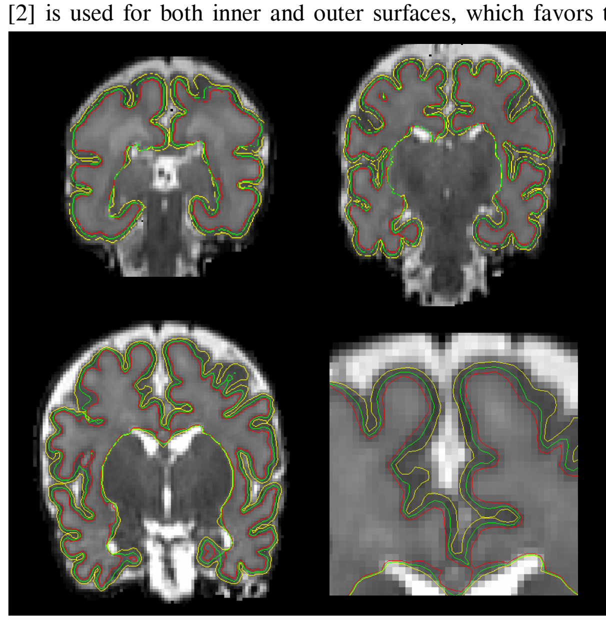

**Fig. 1.** Three reconstructed surfaces displayed on coronal slices of T2w MRIs of neonates of varying GA. Top left 29.86w, top right 34.39 w, bottom left 39.86w, bottom right detail of 39.68w.

**Conclusion** Based on the improved segmentation of cortical gray matter, we present an effective reconstruction procedure for the inner, central and outer surfaces of the cortex in developing neonates. The method employs implicit level-set surface evolution with a topology conserving constraint to preserve sulcal formations. The method has been tested on 67 neonates from very premature to term equivalent age and satisfactory results are obtained for all subjects. The method was effective over the whole GA range tested paving the way to quantitative studies of this critical aspect of neonatal brain development.

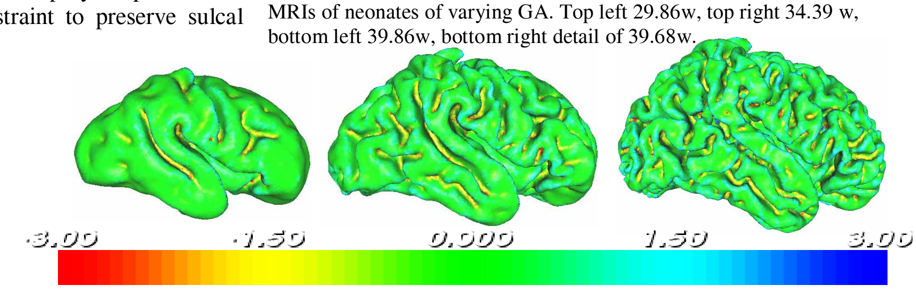


**Fig. 2.** 3D rendering of reconstructed central cortex surfaces for neonates in Fig. 1.

**References** [1] H. Xue, et al., submitted to ISMRM 2007. [2] X. Han, et al., NeuroImage 23: 997–1012, 2004. [3] S. J. Osher, et al., ISBN 0387954821, Springer, 2002.

**Acknowledgment** We thank the KC Wong Education Foundation for Fellowship support to HX and Philips Medical Systems for research grant support.