LAPLACE BELTRAMI BASED QUANTIFICATION OF CORTICAL GYRIFICATION IN THE FETAL BRAIN

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TARGET AUDIENCE Researchers in the study of brain development using MRI

PURPOSE The gyrification pattern that is unique to each human cortex arises during development from a series of physiological and biomechanical factors that remain largely unknown, and the focus of on-going research[1]. A quantitative assessment of gyrification is necessary for a complete understanding of normal brain development and neuro-developmental disorders[2]. The most common approach for measuring the degree of cortical folding is the gyrification index (GI) of Zilles et al[3], computed from anatomical MRI scans. As GI is easily interpreted and implemented, it has found application in many studies of cortical folding[1]. The slice direction, however, is known to influence GI. In the present study, we present a modified GI, computed using the Laplace Beltrami (LB) operator. Our proposed method uses the intrinsic geometry of the cortex, rather than being constrained by the slice orientation. Futhermore, we quantify the degree of cortical folding using eigenvalues of the LB operator.

METHODS We studied a set of four ex-vivo fetal sheep brains at 60, 70, 80 and 90 days of gestation, which represents the critical period in sheep brain development during which cortical folding begins. Brains were perfusion fixed, extracted and subsequently scanned on a Brüker 4.7T MRI scanner. T2-weighted images were acquired (TE/TR=50/4000ms, resolution = 0.258 x 0.258 x 1mm^3). Images were manually segmented to provide 3D masks of the right hemispheres in each brain. Brain surfaces were smoothed using spherical harmonics[4]. The outer hull of each brain was computed using closing and dilation operators. **LB-GI Computation:** The first LB eigenfunction was computed for both the brain and its hull. Level sets of the LB eigenfunction were extracted as intrinsic features of brain shape[5]. Forty-nine level sets were computed to be comparable with the number of our MRI coronal slices. The ratio of the length of each level set curve to the length of the corresponding level set on the hull surface was computed, in contrast to the standard GI method which uses the coronal sections' perimeters of the pial and hull surfaces. A global GI metric is computed by averaging the LB-GIs. We propose a cortical complexity measurement based on the LB eigenvalues, λ, defined by $1/\lambda^{1/2}$, and denote this the Laplace Beltrami complexity measurement (LB-CM). Metrics were also evaluated on unit area surface normalized brains.

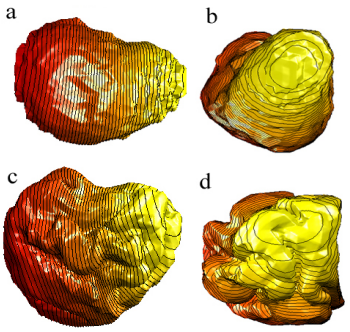

Fig.1 LB level sets of day 60 (a,b) and 90 (c,d) brains are represented with black curves in lateral (a,c) and anterior (b,d) view. Colour encodes the first LB eigenvalue.

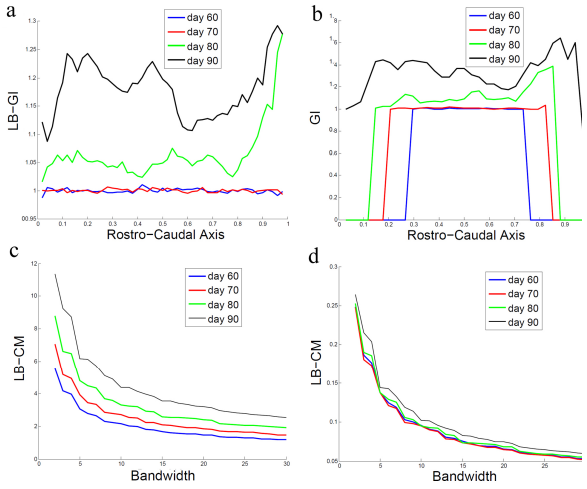

Fig.2 (a) Computed LB-GI, (b) standard GI, (c) LB-CM, (d) LB-CM of surface normalized data.

RESULTS The LB level sets track the developing sulci and gyri well (Fig.1 black curves, for 60 and 90 day brains). The LB-GI and standard GI values are depicted in Figs. 2a,b. As the acquired slice thickness was the same for all brains, earlier day brain volumes have less slices than more developed brains. A zero GI in the standard method indicates that there is no slice at that section. In contrast, LB-GI values are intrinsic features of the brain shape and are in correspondence between each brain. Thus they are applicable as a repeatable and local feature of cortical folding. The averaged GI of Laplace Beltrami based method and standard methods are compared in Table 1. Although these results are comparable, our proposed averaged GI is independent of brain orientation or slice directions and so it is repeatable in different experiments. Figs. 2c,d presents our proposed complexity measurement for 30 eigenvalues. The size differences are removed by surface normalization. Larger LB-CMs are measured for more developed brains. The effect, although more subtle, is also evidenced for surface area normalized brains (Fig. 2d).

Table 1. Comparison of global GI, proposed & standard methods.

	LB-GI	Standard GI
Day 60	1.0004	1.0046
Day 70	1.0009	1.0082
Day 80	1.0598	1.1210
Day 90	1.1808	1.3378

CONCLUSIONS We have presented a Laplace Beltrami based gyrification index that relies on intrinsic shape features and is isometry invariant. Unlike the standard GI method, the LB-GIs are in correspondence across the set of developing brains, and are applicable for local comparison of cortical folding pattern and statistical analyses of neuro-developmental disorders. We have also presented a global GI using the LB method. Both local and global LB-GIs demonstrate that the complexity of the brain at gestational day 60 and 70 is similar, while by day 80, a rapid increase in complexity has occurred in development that continues through day 90. Our LB-CM complexity measurement quantifies developing brain. In on-going work, we are extending the study to larger data sets, to statistically evaluate the discriminative capability of the proposed metrics.

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