Modification of the CIVET Pipeline for Estimation of Subplate Thickness

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Abstract Submission

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Introduction:

Fetal magnetic resonance (MR) imaging presents challenges for conventional neuroimaging processing pipelines, which need substantial modification in order to measure surface area and thickness of the developing cerebral cortex (Ad-Dab'bagh et al. 2006; Fischl 2012).
To measure the cortical thickness its inner surface needs to be obtained with preservation of vertex-to-vertex correspondence to the outer surface. In the adult brain, a method called Constrained Laplacian Anatomic Segmentation using Proximity (CLASP) has been proposed to find the outer surface of the cortex by expanding its inner surface outwards (MacDonald et al. 2000; Kim et al. 2005).
Unlike the adult cortex, the fetal cortex is comprised of two compartments that are visible on MRI: cortical plate (CP) and subplate (SP) (Bystron et al. 2008). The CLASP algorithm can be applied for the CP. However, it gives poor results when applied to SP because SP inner and outer surfaces are morphologically distinct-vertices fail to converge to gyri. The aim of our work was to develop an algorithm that can reliably measure SP thickness during its peak growth.

Methods:

MRI processing

In-vivo brain MRIs of 8 fetuses (age range 29-32 gestational weeks (GW)) were acquired on a 3T Siemens Skyra MRI scanner using multiple T2-weighted Half-Fourier Single Shot Turbo Spin Echo scans

(TR=1400-2000ms, TE=100-120ms, voxels size=0.9×1.1×2mm^3). MRIs were pre-processed and segmented with an in-house built pipeline described previously (Gholipour et al. 2017; Vasung et al. 2019).

Extraction of the inner and outer surface of SP

First, from a segmented volume, a polygonal mesh of 81,920 triangles and 40,962 vertices representing the outer SP surface was extracted using a marching-cubes algorithm provided by CIVET-2.1.0 (Lepage et al. 2017).
A radial distance map was generated from the SP inner surface to provide the directional guides for deformation. Different from the CLASP approach, the outer, convoluted SP surface was fit inwards to the inner SP surface, which is relatively flat in shape.
Next, we calibrated the ASP algorithm parameters to account for the smaller fetal brain. Vertex distribution over gyri sharply increases on the inner SP surface, amplifying the risk of self-intersection. Thus, we used a "stretch" mechanism to regulate the mesh quality of the inner SP surface. It works by considering the average position of its neighbours in determining each vertex's new location per step, resulting in both smoothing and shrinking. The effect of stretch is that edge length is held to be more consistent. Moreover, mesh size was downsized from 81,920 to 20,480 triangles. This was doable because of the simple inner SP surface morphology. With these modifications, we prevented self-intersection and improved our software's runtime per brain hemisphere (from 20 minutes to less than 2).
Finally, using inner and outer SP surfaces, we calculated SP thickness between corresponding vertices (Lerch and Evans 2005) (Figure 1A). We used linear regression to estimate the association between gestational age, mean SP thickness and the variation of SP thickness (standard deviation of the mean) using the R software.

Results:

The mean SP thickness of each hemisphere showed a significant positive correlation with age (linear relationship, $R=0.61$, $p<0.05$, Figure 1B). The standard deviation of the mean SP thickness of each hemisphere also showed a significant positive correlation with age (linear relationship, $R=0.82$, $p<0.05$, Figure 1B). These results are in agreement with histological and postmortem MRI studies (Kostovic and Rakic 1990; Vasung et al. 2016).

Conclusions:

To our knowledge, this is the first pipeline able to asses the thickness of the CP and SP of the human fetal brain during its peak growth, which might be a useful biomarker of normal and abnormal in-utero brain development (Rossi 2019).

Modeling and Analysis Methods:

Image Registration and Computational Anatomy [1]

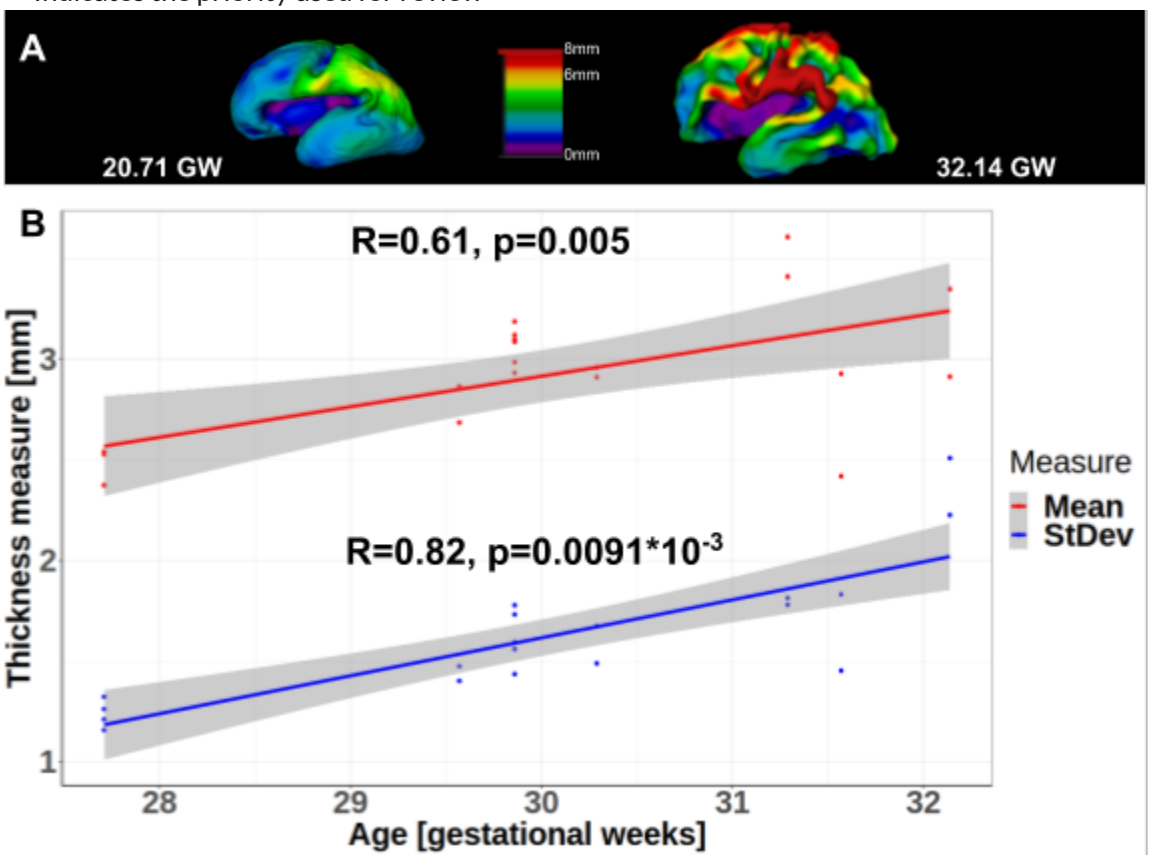
Neuroanatomy, Physiology, Metabolism and Neurotransmission:

Cortical Anatomy and Brain Mapping [2]
Normal Development

Keywords:

Computational Neuroscience
Data Registration
Informatics
MRI
PEDIATRIC
Segmentation

[1|2]Indicates the priority used for review



My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Resting state

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Are you Internal Review Board (IRB) certified? Please note: Failure to have IRB, if applicable will lead to automatic rejection of abstract.

Yes

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Yes

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Structural MRI
Computational modeling

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

Other, Please list - CIVET

Provide references using author date format

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