Estimation of Subplate Thickness by Surface Deformation

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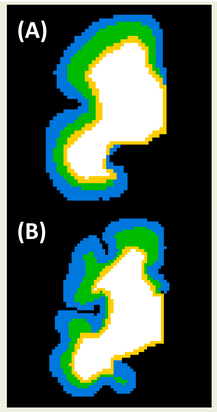
0.1 Abstract

The subplate zone's convoluted morphology during peak growth of the fetal brain is a unique challenge for MR image processing. Here we present modifications to the CIVET-2.1.0 pipeline to produce accurate surface mesh reconstructions of the subplate and intermediate zones from a segmented volumetric image. First the outer layer is extracted using a marching-cubes algorithm, then it is fit inwards to the inner layer. Subplate thickness can be calculated between corresponding vertexes on these two surfaces. This work advances the study of developmental human neuroanatomy by enabling new metrics for quantitative analysis of *in-utero* MRI.

0.2 Background

- Conventional MRI processing pipelines (e.g. FreeSurfer[1], CIVET[2]) use models specific to healthy adult brains.
- The developing cortical plate of the fetal brain is comprised of two transient compartments[3]:
  - Cortical plate
  - Subplate zone (SP)
- Gyrification occurs during brain development.

Fig. 1 (right): Fetal brain MRI image segmentation, coronal slice. Morphological comparison at age of **(A)** 27 and **(B)** 31 gestational weeks.



1.1 Surface Extraction

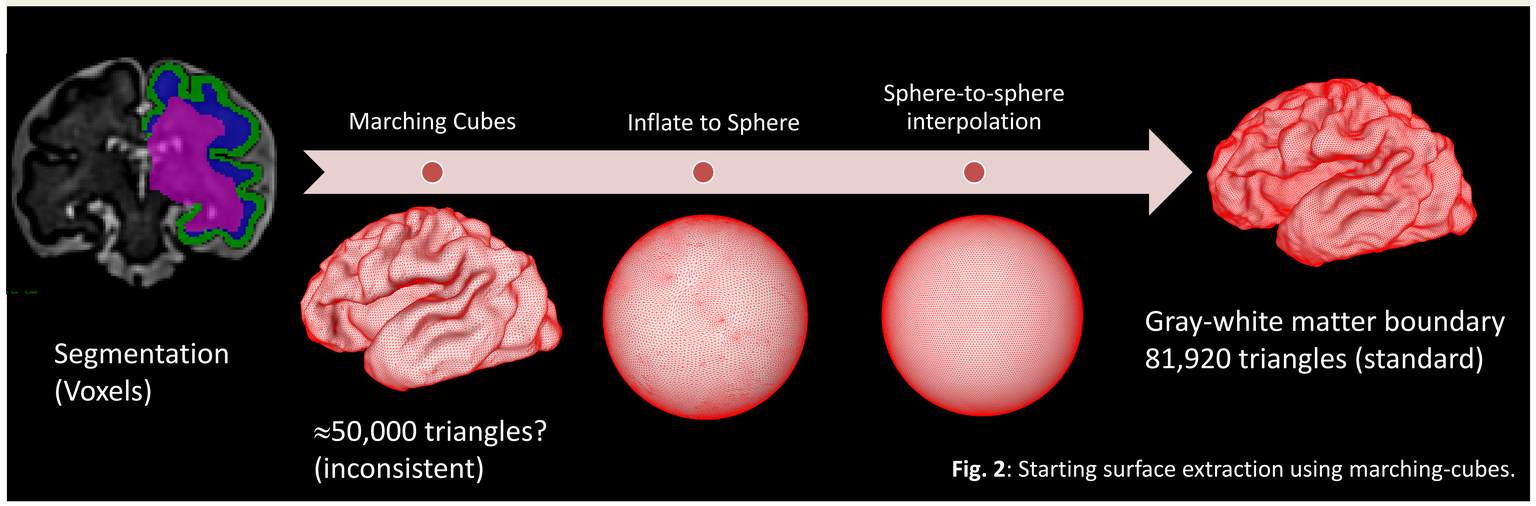


Fig. 2: Starting surface extraction using marching-cubes.

1.2 Deformation

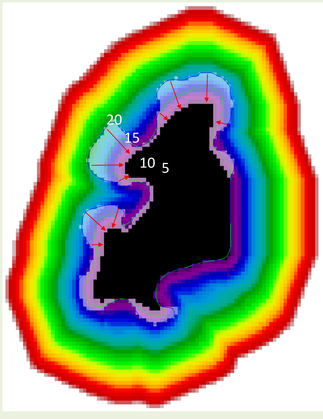


Fig. 3: Radial distance map as a gradient used to guide vertex movement to target.

The Anatomic Segmentation using Proximity (ASP) algorithm[4] is used to find an inner surface with vertex-to-vertex correspondence.

Outer surface (white-gray matter boundary) shrinks inwards to the intermediate zone.

The density of vertices must increase sharply on the inner surface under sulcal walls.

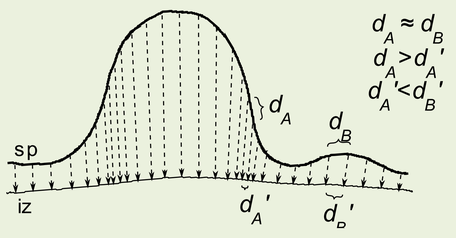
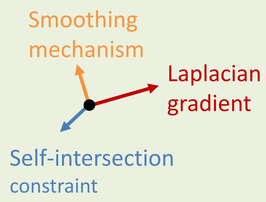


Fig. 4: Illustration depicting trajectory from outer (sp) to inner (iz) surface.

2.1 Algorithm Weights

Fitting accuracy is at a trade-off with surface quality. Parameters are optimized for the dataset.

Parameter schedule is multi-staged: first, aggressive values are used to flatten gyrification. The last stage uses a large Laplacian weight and small steps for improved accuracy.



2.2 Downsizing

1. Crowding causes self-intersection.
2. Merge adjacent polygons (20,480 triangles) and converge to target.
3. Subdivide polygons to restore original count (81,920 triangles).

2.3 Mesh Quality

Python scripts were used to quantify differential measurements of quality.

- Smoothness
- Distortion angles
- Triangle aspect ratio

These measurements were considered by a loss-function for parameter adjustment.

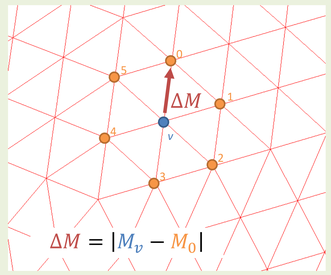


Fig. 5: Function to collect local change in a metric of quality.

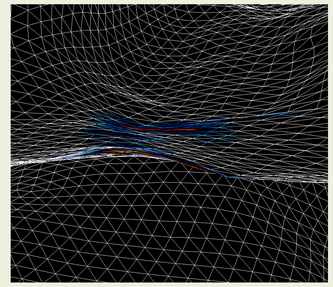
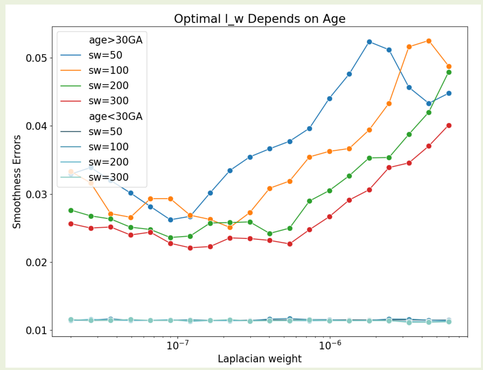
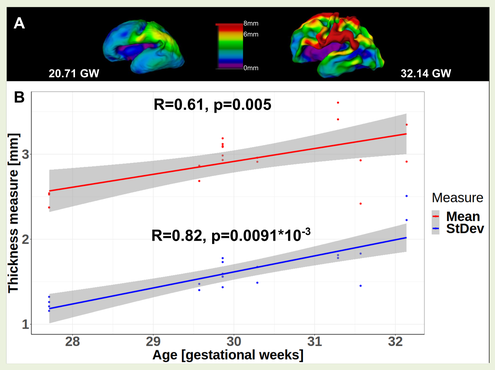


Fig. 6: Visualization of poor-quality area on a bad fit.

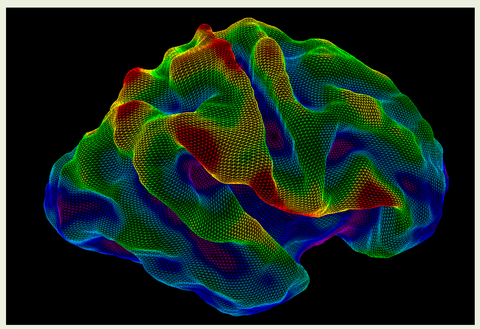
3.1 Results





3.2 Conclusion

- New methodology for calibrating a neuroimaging pipeline against unique data.
- Accurate surface reconstruction for fetal MRI before 32 gestational weeks of age.
- Measurement of subplate thickness from *in-vivo* MRI of human fetus.
- Record of normal rate of relative subplate growth for humans[5], potential relevance as a biomarker for healthy development.



4.1 Data

In-vivo brain MRIs of 14 healthy fetuses, 8 of which were between 29 to 32 GA.

Image sequences were preprocessed[6], then automatic segmentations were corrected by hand.

4.1 Software

All software are free and open source.
https://gitlab.com/jennydaman/subplate

4.3 References

1. Fischl B. (2012), "FreeSurfer." *Neuroimage*, 62(2):774–81
2. Lepage C. (2017), "Human MR Evaluation of Cortical Thickness Using CIVET v2.1", *OBHM*. http://mcin.ca/wp-content/uploads/2017/08/HBM2017_civet.png
3. Bystron I. (2008), "Development of the human cerebral cortex," *Nat. Rev. Neuroscience*. 9(2):110–22.
4. Kim et. al, (2005). "Automated 3-D extraction and evaluation of the inner and outer cortical surfaces using a Laplacian map and partial volume effect classification". *NeuroImage* 27, pp. 210–221.
5. Vasung et. al, (2019). "Spatiotemporal Differences in the Regional Cortical Plate and Subplate Volume Growth during Fetal Development." *Cerebral Cortex*.
6. Gholipour (2017). "A normative spatiotemporal MRI atlas of the fetal brain for automatic segmentation and analysis of early brain growth." Scientific Reports.