A novel framework for the local extraction of extra-axial cerebrospinal fluid from brain MRI

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What is CSF?

- CSF = Cerebro-spinal fluid
- Protection, Ischemia prevention
- Plumbing system of brain
- 0.5L generated per day
- Pulsatile flow
- MRI:
  - Dark in T1w
  - Bright in T2w

What is Extra-Axial CSF?

• CSF between outer cortical surface and dura mater
  – Subarachnoid space
  – Does not include ventricles, foramen, choroid plexus

• Radiology observation (anecdotal):
  – Can be increased early in postnatal phase
  – Can be increased in aging, Alzheimer’s

Why are we interested in EA-CSF?

- EA-CSF findings in Autism by Shen et al

BRAIN
A JOURNAL OF NEUROLOGY

Early brain enlargement and elevated extra-axial fluid in infants who develop autism spectrum disorder

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- However, small UCD sample (2013): N=55 (HR-ASD=10, HR-Neg =45)
- Confirmation separate IBIS sample (2017): N = 221 (47 HR-ASD, 174 HR-Neg)
Extra-Axial CSF 6-24 Mo

Low-Risk Infant with Normal MRI; **ASD-negative**

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<th>6M</th>
<th>12M</th>
<th>24M</th>
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High-Risk Infant with Increased Extra-Axial CSF; **Diagnosed with ASD**

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Increased EA-CSF Pronounced in Greatest Severity


Adjusted for covariates: Age, Sex, Site, Total Cerebral Tissue Volume

*p<0.05 vs. all other groups. Mixed effects model w/ repeated measures
Prediction of ASD?

• Can we predict which kids will develop ASD before behavioral diagnosis possible?
  – In high risk population

• Potential for early interventions
  – Improve long-term outcome
  – Reduce ASD severity

• Single volume measured at 6 month

• Balance boosted trees ensemble

• IBIS data: **Accu: 69%**, Sens: 0.66, Spec: 0.68

• UCD data: **Accu: 72%**, Sens: 0.80, Spec: 0.67
Local EA-CSF Measure

• Local patterns to EA-CSF enlargement in ASD?
  – 2 open problems

• **1. No method to compute local EA-CSF**
  – Aim to quantify EA-CSF from GM to outer CSF
  – Our approach: Use cortical and outer surface

• **2. No knowledge of EA-CSF trajectory in typical brain development**
Local EA-CSF Scheme

- Tissue segmentation
  - CSF posterior probability map
  - Cortical surface reconstruction
Local Extra-Axial CSF

- How much EA-CSF is between GM and dura?
- Laplacian PDE for correspondence GM to dura
- Fourth-order Runge-Kutta (RK4) streamlines
Local Extra-Axial CSF

- Integration of CSF probabilities along the streamlines
  - Uniform steps along streamlines
- No a true volume measure
Prelim: Developmental Trajectory of EA-CSF

- IBIS data – only low-risk, typically developing
  – 51 kids, scanned at 6, 12 and 24 months
- Consistent pattern of EA-CSF (r > 0.98)
- Overall decrease from 6-12, particularly in frontal regions
Change in EA-CSF

- Actually large changes, overall pattern preserved
- More changes from 6 to 12 month than in the next 12
- Largest relative changes in frontal lobes
- Increased EA-CSF in posterior lobes and in deep sulci
Regional Analysis (new)

• AAL, 78 cortical regions (out of 90)
  – Monthly EA-CSF monthly change
• 6=>12: 54 regions significant decreases
• 12=>24: 33 regions significant decreases
• 30 regions common in both analyses
  – L & R inferior occipital gyrus
  – L & R fusiform gyrus
  – L & R middle occipital gyrus.
• Next: Potential biomarker of Autism prediction
• Next: longitudinal modeling
• Next: Baby Connectome for actual trajectories
Take Home

• Extra-axial CSF is an important measure of brain development
• Novel automatic method for local, cortical surface based quantification of EA-CSF
• EA-CSF important in Autism & potentially other neurodevelopmental diseases
  • Possible predictive biomarker for Autism
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Infant Brain Imaging Study

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