Impacts of Prematurity on Neonatal Deep Gray Matter Using Diffusion Basis Spectrum Imaging

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Introduction

MRI has been used to understand the impact of prematurity on brain development in the last 30 years. Diffusion tensor imaging (DTI) allows the characterization of brain microstructure. However, most studies have focused primarily on major fiber bundles. Yet, evidence showed very preterm infants at term equivalent age had risk of having reduced deep gray matter volumes compared to term controls [2]. Diffusion basis spectrum imaging (DBSI) model allows for a more comprehensive understanding of microstructural development in the brain by decomposing diffusion signals into fiber fraction, hindered diffusivity (extracellular), restricted diffusivity (intracellular) and water fraction. It has been applied on neonatal white matter injury [3] but not yet on neonatal deep gray matter.

Objectives

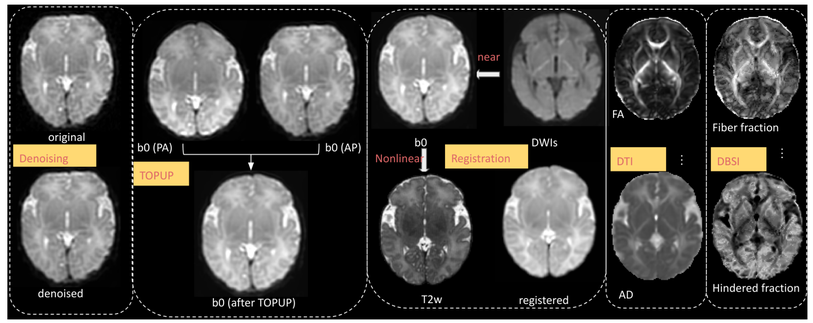
Our goal is to characterize deep gray matter integrity in preterm infants using DBSI to gain a deeper understanding of the complex processes in the developing brain following prematurity. More specifically to: 1) Detect intracellular and extracellular fraction in preterm deep gray matter; 2) Assess potential differences with term controls.

Methods

Data acquisition ($3T$ *GE Discovery™ MR750* scanner at CHU Sainte-Justine Hospital)

DWIs: resolution $2 \times 2 \times 2mm^3$, 2 b0 and an array of 25 b values ($0 < b \leq 800s/mm^2$).

Processing pipeline



Notes: Templates for 34 weeks and 40 weeks were built using DTI-TK. ROIs: caudate nucleus, lentiform nucleus and thalamus (on color-coded FA template maps).

Subjects

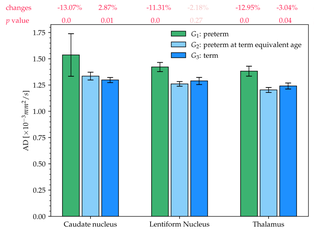
	Group 1 Preterm Scan 1	Group 2 Preterm Scan 2	Group3 Term control
Age at born (weeks)	32.00 ± 1.49	32.30 ± 1.49	39.51 ± 1.38
Ages at scan (weeks)	34.14 ± 1.19	40.18 ± 0.90	39.51 ± 1.38
Number	15	11	5

Statistics

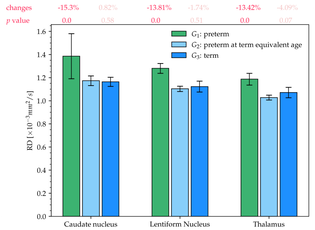
Comparisons (G1 vs G2, G2 vs G3) were made in each ROI using masked metrics from DBSI and DTI. Mann-whiteney test ($p < 0.05$) was used for the statistics.

Results

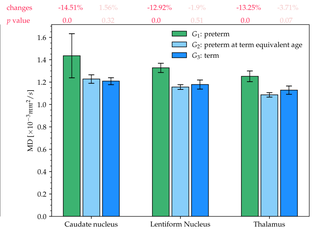
DTI results in ROIs



(a) Axial Diffusivity

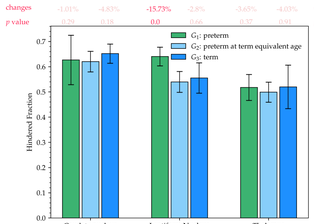


(b) Radial Diffusivity

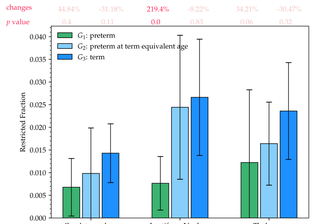


(c) Mean Diffusivity

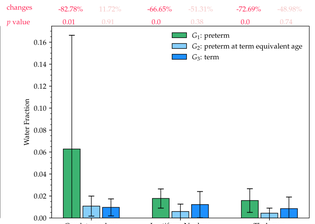
DBSI results in ROIs



(a) Hindered Fraction



(b) Restricted Fraction



(c) Water Fraction

Notes: Mann-Whitney tests with $p < 0.05$, (red color for $p < 0.05$, pink color for $p \geq 0.05$).

Preterm at term vs Term controls:

1. The caudate nucleus was the only structure to retain differences in preterms at term equivalent age with higher axial diffusivity (2.87% higher, $p = 0.01$) compared to term controls.

Preterm at 34 weeks vs Preterm at term equivalent age:

1. Diffusivity values (AD, RD, MD) extracted from DTI showed significant decrease (more than 11%) in all three ROIs with most significant changes in the caudate nucleus.
2. DBSI model showed that water fraction in all three regions were dramatically decreasing (-82.78% ($p = 0.01$), -66.65% ($p = 0.004$) and -72.69% ($p = 0.003$) in caudate, lentiform and thalamus respectively).
3. In the lentiform nucleus, extracellular diffusion fraction decreased significantly ($+219.4\%$, $p = 0.003$) and intracellular diffusion fraction decreased ($-15,73\%$, $p = 0.004$) significantly. This probably reveals that the lentiform nucleus experienced cell enlargement more than volume increase.

Conclusion

Our data revealed an increased vulnerability of the microstructural maturation of the caudate nucleus in a rather healthy preterm born at 32 weeks of gestational age. This resonates with data in preterm children born under 32 weeks of gestation found to have smaller caudate and putamen volumes when scanned at term equivalent age [4]. These changes may have a profound impact as when persisting at age 7, a strong correlation was found with IQ [1].

References

[1] Laurence J Abernethy and et al. Caudate and hippocampal volumes, intelligence, and motor impairment in children born preterm. *Pediatr. Res.*, 55(5):884–893, May 2004.

[2] James P Boardman and et al. Abnormal deep grey matter development following preterm birth detected using deformation-based morphometry. *Neuroimage*, 32(1):70–78, August 2006.

[3] Albert M Isaacs and et al. Microstructural periventricular white matter injury in Post-Hemorrhagic ventricular dilatation. *Neurology*, 98(4):e364–75, November 2021.

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