Intracranial compliance study by phase contrast magnetic resonance imaging in newborns and children

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INTRODUCTION: Intraventricular hemorrhage and fetal distress are the main causes of perinatal neurological pathologies. They generate an increase in intracranial pressure (ICP) due to a decreased craniospinal compliance. Intracranial compliance is defined as the quotient of intracranial volume variation over ICP response. Intracranial volume variation during a cardiac cycle (cc) is mainly caused by vascular volume variation (ΔVasc). To date, invasive sensors are the only available techniques to measure ICP. Based on *Marmarou*'s knowledge [1], we hypothesized that ICP could be extracted from the cerebrospinal fluid (CSF) volume flushing from intracranial compartment to cervical subarachnoidal spaces (ΔVcsf). Then a compliance index can be proposed as the ratio ΔVvasc/ΔVcsf. Phase-contrast MRI (PCMRI) is sensitive to CSF and arterial blood flows as it was demonstrated in adult [2] and pediatric populations [3].The aim of this study was to define craniospinal compliance index in control children during brain maturation.

METHOD: Twenty-nine infants (age range: 5 days – 9 years and 10 months) underwent 3T MRI scan for clinical indications (minor and transient delayed of development, feverishness convulsion, subcutaneous malformations). They presented normal MRI findings and good clinical outcome at 12 months. Three different coils were used for this study based on patient's age and weight: knee coil (under one month of age), 8-channel head coil (weight < 10 kg), and phased-array head coil for the others. MRI parameters were: TR/TE = 10–18/4–8, ms; FOV=14 x 14 cm^2, 256^2 matrix; 5 mm slice thickness; 2 excitations and 2 views per segment. Cardiac Synchronization was achieved with peripheral gating. Velocity encoding (VENC) was set to 80cm/sec for blood and 10 cm/sec for CSF. The slice acquisition planes were perpendicular to the presumed direction of flow and were selected below the magnum foramen crossing the second cervical vertebra. Semi-automatic flow measurements were performed using dedicated and validated software (www.tidam.fr) that combines region growing and thresholding of the velocity map. We bilaterally selected the internal carotid artery and vertebral artery to reconstruct arterial input flow. The jugular blood flow was normalized with mean cerebral arterial input flows to calculate total cerebral venous outflow. After extraction of the arteriovenous flow difference through the cardiac-cycle we generated ΔVvasc by the area of the negative (filling) part of the blood flow (figure 1). ΔVcsf was obtained by the area of the positive (flushing) part of the CSF flows curve (figure 1). The compliance index was defined as ΔVvasc over ΔVcsf.

RESULTS: We observed increases of ΔVvasc and ΔVcsf with age (figure 2) whereas the compliance index (figure 3) first decreased until approximately 24 months of age and increased during growth.

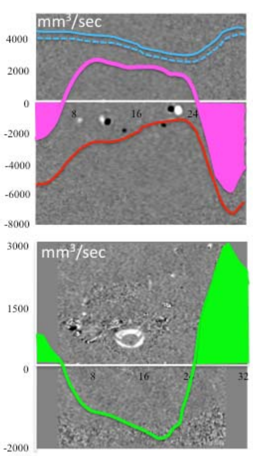

Figure 1: Top image shows the jugular blood (blue) and arterial (red) flow curves overlaid on a phase image. The pink curve shows the area under the curve at the filling period. Bottom image shows the area under the curve during CSF flush.

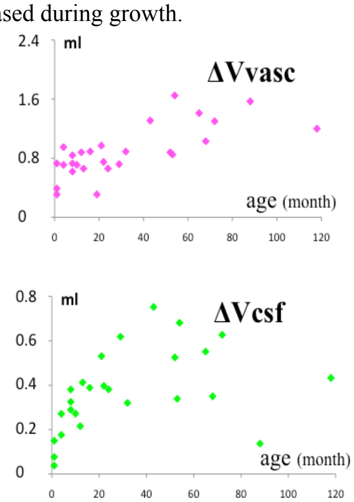

Figure 2: Top graph represents the vascular volume variation (ΔVvasc) versus age and the lower graph shows the cerebrospinal fluid (CSF) volume variation (ΔVcsf) versus age.

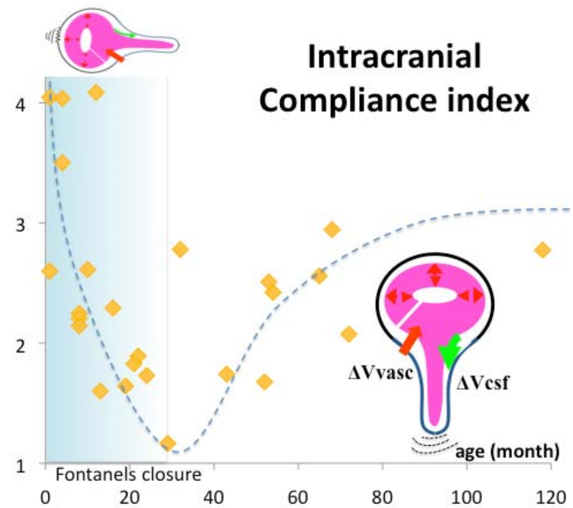

Figure 3: Curve fitting of the resulting intra-cranial compliance index showing the cut-off at 24 months of age. The sketches show the vascular (ΔVvasc) and CSF (ΔVcsf) volume variations through the cardiac cycle.

DISCUSSION: PC-MRI is a reproducible non-invasive technique of choice to measure CSF and blood oscillations during cardiac cycle providing hemodynamic views of the main cerebral arteries and veins. Although it was challenging to study small vessels in neonates and to select a 2D high resolution image with enough signal to noise ratio to reconstruct accurate flow curves, our work showed that PC-MRI is able to quantify CSF oscillations and cerebral blood flows in small vessels such as vertebral and internal carotid arteries in neonates. We also demonstrated that the compliance index decreases until nearly 24 months, probably due to progressive fontanels closure, followed by an increase likely related to posture changes leading to spinal compliance increase as gravity assists CSF flush toward the dural sac. Understanding normal hemo- and hydro-dynamic physiology during brain maturation should help to better investigate brain alterations and could be used to evaluate hydrodynamic disorders in intra-ventricular hemorrhage, fetal distress or hydrocephalus. In conclusion, we pointed out that within few months both hydro- and hemo-dynamic change dramatically and we suggested an intracranial compliance index as a new quantitative parameter that can be measured by PC-MRI. Higher sample size and more homogeneous population will definitely prove that this index might be used as a biomarker of intracranial compliance changes during brain maturation.

REFERENCES: 1. Marmarou A. J. et al Neurosurg (1975) 2. Enzmann D.R. et al. Radiology (1991) 3. Balédent O. et al ISMRM #4376 (2010)