

Investigating the role of choroid plexus in CSF pulsation by combining in-vivo and post-mortem MRI

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Introduction

Cerebrospinal fluid (CSF) pulsation is thought to play an important role in many neurological disorders, e.g. hydrocephalus. Mainly two theories on the transformation of the cardiac pulse pressure wave to the ventricular system were established in the past. The thalamic pump theory was introduced by du Boulay (1). Bering et al. (2) claimed the choroid plexus (CP) responsible for CSF pulsation. Due to many controversial findings in the past, current research still aims to identify the exact physiological origin of this pulsation. Recent MRI studies on phase shift between CSF flow in the foramina of Monro and the aqueduct suggest CP as the main pulsation source, with its volume variations in the lateral ventricles being mainly responsible for phase variations of the pulse wave between different subjects (3). To evaluate the capability of CP to drive CSF pulsation, the periodical volume change of CP necessary to produce CSF strokes in ranges measured in-vivo needs to be determined.

Segmentation of in-vivo MRI data is hampered by the blurring introduced by CP movements, and only in-situ imaging allows the determination of the CP such that the size of CP is equivalent to its actual in-vivo size. Additionally, sufficient contrast to noise ratio (CNR) between CP and adjacent CSF, grey and white matter is necessary. Therefore, we determined the size of CP in the lateral ventricles in deceased human subjects by segmenting magnetization transfer (MT) weighted balanced steady state free precession (bSSFP) in-situ MRI brain scans (4). Combining differently MT weighted bSSFP scans allowed for CNR enhancement with respect to tissue and CSF adjacent to the CP. To complement these, in-vivo phase contrast (PC) flow measurements were acquired to determine mean stroke volumes in the cerebral aqueduct to finally estimate expected CP variations.

Subjects and methods

Post mortem: Five deceased subjects without known neurological deficits (age range: 48 – 81ys) underwent MRI within 72 hours after death. All measurements were performed on a 3T Tim Trio (Siemens Healthcare, Erlangen, Germany) transversally covering the whole brain with a spatial resolution of 1.3x1.3x1.3 mm³. The MRI protocol consisted of two bSSFP sequences with a fixed flip angle of 30° and varying TR/T_{RF} ratios of 8.2 and 6.8 and two bSSFP sequences with TR/T_{RF} ratio of 5.8 and varying flip angles of 30° and 35°. For contrast enhancement, these four datasets were combined by multiplication.

The combined datasets were segmented using the 'Threshold segmentation' tool of Avizo (VSG Visual Sciences Group, Inc., MA). For optimized thresholding, two histograms with undersmoothed bin sizes for i) a region containing CSF, grey and white matter and ii) a region additionally including CP were compared. Partial volume effects were minimized by manual segmentation refinement (Figure 1). Following smoothing of the rough surfaces, the CP volume was derived with Avizo's 'Calculate volume' analysis tool. CP length L was calculated as the central arc length of a line following the curvature of the corresponding CP, as depicted in Figure 2c.

In-vivo: PC-MRI flow measurements were conducted in three healthy volunteers (age range 24-65 years) in the cerebral aqueduct (venc=15 cm/s, 26-28 heart phases, spatial res. 0.4x0.4x4 mm³) on a 3T Philips Achieva System (Philips Healthcare, Best, The Netherlands). CSF stroke volumes (5) were computed with Matlab (MathWorks, Inc., Natick, MA). Mean stroke volume was compared to CP volumes, and the volumetric deformation of CP necessary to produce the stroke was computed.

Results

Volumes of CP in the range of 4-5 ml were found (Table 1). A mean arc length of approximately 68 mm was derived. The mean stroke volume was 60 µl, which corresponds, under assumption of isotropic volumetric deformation of CP, to a mean CP volume variation of 1.27% (range 0.5-2.6%) necessary to drive the CSF stroke in the aqueduct.

Discussion and Conclusions

Geometric characterization of choroid plexus in humans based on postmortem MRI scans was carried out successfully. Variations of CP volume of 1.27% are shown here to be necessary for producing realistic stroke volumes. This is plausible, and therefore the CP cannot be excluded as a source of CSF pulsation.

Acknowledgement

Swiss National Science Foundation through SmartShunt – The Hydrocephalus Project, SNF K-32K1_120531/1

References

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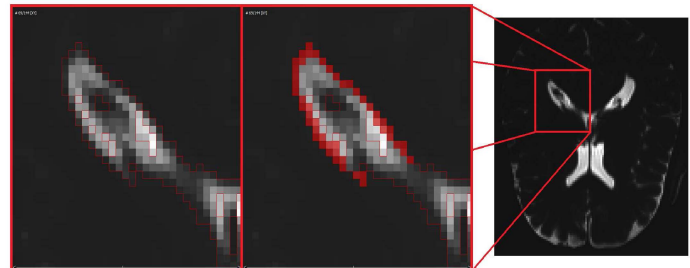


Figure 1: Manual threshold correction. Left: Automatic threshold line marked in dark red. Middle: Voxels to be removed are manually marked in bright red. Right: transversal MRI slice.

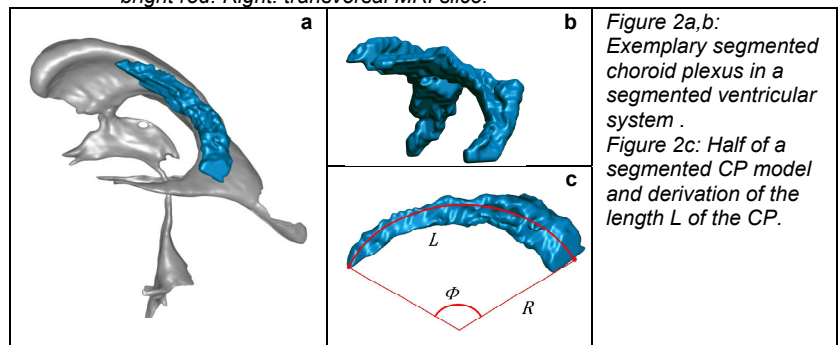


Figure 2a,b: Exemplary segmented choroid plexus in a segmented ventricular system. Figure 2c: Half of a segmented CP model and derivation of the length L of the CP.

Table 1: Obtained volumes and lengths from segmentation, their mean (μ) and standard deviation (σ).

No subject	of	Volume in mm ³	Length in mm
1		4596	78
2		5904	68
3		3449	65
4		4348	63
5		5708	65
$\mu \pm \sigma$		4801 ± 1014	68 ± 6