Changes in CSF Pulsatile Flow Distributions with Age

M. E. Wagshul[1,2], M. R. Egnor[2], S. Fiore[3], S. L. Hochberg[4], E. J. Kelly[5], C. J. Perkins[3], and Z. Yan[1]

[1]Radiology, Stony Brook University, Stony Brook, NY, United States, [2]Neurosurgery, Stony Brook University, Stony Brook, NY, United States, [3]Neurology, Stony Brook University, Stony Brook, NY, United States, [4]Plainview, NY, [5]Toshiba Medical Systems, Irvine, CA, United States

Introduction

Hyperdynamic pulsations of CSF flow in the cerebral aqueduct have often been used as a marker of abnormal CSF dynamics in hydrocephalus. A number of investigators have attempted to establish criteria for predicting successful shunt surgery based on the aqueductal pulse stroke volume [1]. However, a number of more recent large-scale studies have shown that this measure is not a reliable predictor [2]. In general, these studies show that only severely elevated aqueductal stroke volume reliably predicts shunt success, while prediction is very variable in patients with normal to mildly-elevated levels. Furthermore, most of the prior literature has studied CSF flow in normal pressure hydrocephalus, while studies in pediatric hydrocephalus are very limited. In previous publications, we have hypothesized that a more reliable predictor of shunt success may involve the relative aqueduct pulsation as compared to the subarachnoid space (SAS) pulsations [3], measured either in the cervical spine (C2) or within the prepontine (PPC) or basal cisterns. As a first step, we investigated the flow distribution with age in healthy controls. We find marked changes in the distribution of CSF flow pulsations with age.

Methods

Eight pediatric (mean age, 13.1 ± 3.1yo) and five elderly (mean age, 72.4 ± 3.8yo) healthy volunteers participated in the study. All had no known neurological disease, and the elderly subjects had no deterioration in mental status (mini mental state exam score > 25). Three phase contrast, balanced steady state free precession flow images [4] were acquired on a 3T Philips Achieva scanner: 1) aqueduct (Venc 7 cm/s), 2) cervical SAS at level of C2 (Venc 5 cm/s), 3) PPC at mid-pons (Venc 5 cm/s); vascular flow images were also taken, but were not analyzed for the current study.

Data Analysis: All images were analyzed using custom-designed software to extract flow net waveforms from the CSF or vascular region-of-interest only. FFT analysis was used to exclude non-CSF flow regions [3], such as the epidural veins outside of the cervical SAS. Stroke volume calculated from the net flow waveform represents the net CSF volume flowing in one direction over the cardiac cycle. Flow distributions were extracted as the aqueduct/C2, aqueduct/PPC and PPC/C2 stroke volume ratios. These ratios represent the distribution of CSF flow pulsation between the ventricular vs. spinal subarachnoid, ventricular vs. cranial subarachnoid and cranial vs. spinal subarachnoid spaces, respectively. In a number of cases, two valid images of prepontine flow were obtained, at the level of the mid-pons and just above the pons (in the aqueduct image). In the case of a significant difference (> 10 %) between the results for the two sequences, the higher value was taken as the final value, using the assumption that signal loss in the prepontine space due to irregular flow can in certain situations cause an underestimation of flow. Flow differences between the two groups were analyzed using an unpaired Student's t-test, with significance at the $p < 0.05$ level.

Results

Table 1 shows the results for the two groups in all three CSF flow regions. While none of these comparisons reached statistical significance, there was a trend toward lower aqueductal pulsations and higher cervical pulsations in the pediatric group. In fact, the cervical stroke volume in one of the elderly subjects was close to double that of the others, and may have skewed this comparison significantly. We are analyzing the data further (e.g. differences in vascular pulsations) to try to understand this outlier data.

Comparisons of pulsation distributions, on the other hand, resulted in very significant differences between the populations, as shown in Table 2. This illustrates a very different distribution of CSF pulsations along the craniospinal axis with age. The aqueduct/cervical ratio was consistent with previous measurement in a middle-age population (32 yo) with a 4.4% stroke volume ratio [4].

	Kids	Seniors	p-value
Aqueduct	30.7 ± 13.7 µl	43.6 ± 6.6 µl	0.077
Cervical	919.8 ± 264.9 µl	610.2 ± 313.8 µl	0.088
Prepontine	438.3 ± 163.6 µl	463.6 ± 190.0 µl	0.98

Table 1: Comparison of CSF flow measurements

	Kids	Seniors	p-value
Aq/Cervical	3.1 ± 1.3 %	8.8 ± 3.3 %	0.004
Aq/Prepon	5.7 ± 2.3 %	10.5 ± 3.8 %	0.044
Prepont/Cervical	47.2 ± 6.0 %	88.4 ± 27.2 %	0.012

Table 2: Comparison of CSF flow distributions

Discussion

To understand these results, we propose the following model of intracranial pulsations, schematically shown in Figure 1:

- Arterial pulsations entering the brain are dissipated throughout the cranium, primarily into the subarachnoid CSF spaces. Pulsations are then transferred out of the brain, either into the spinal CSF space or through the intracranial veins, effectively preventing these pulsations from being transmitted into the cerebral capillary beds.
- A small fraction of the pulsations do enter the capillaries, which leads to overall pulsatile brain motion. This in turn causes pulsatile compression of the ventricular walls and pulsatile CSF outflow through the cerebral aqueduct.

In this model, the aqueduct/cervical ratio thus represents the efficiency of the cranium in shunting arterial pulsations into the spinal CSF as opposed to into the capillary beds. Our results indicate, as one might expect, that the elderly brain is much less effective in this dissipation. Similarly, the large prepontine/cervical ratio in seniors may be indicative of the reduced spinal compliance with age, requiring the majority of dissipation to occur intracranially (prepontine) as opposed to into the spinal spaces (cervical). These results have important implications for studying changes in CSF pulsation in neurological diseases which affect intracranial flow dynamics, such as hydrocephalus.

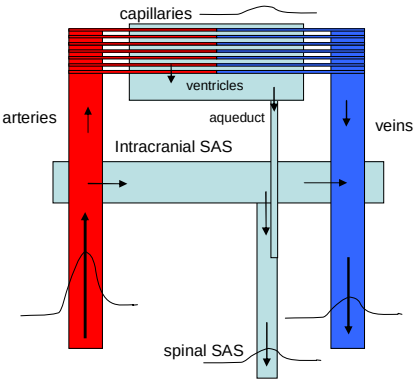

Figure 1: Schematic model of distribution of intracranial pulsations, showing the relationship between pulsations in the capillary beds and aqueductal pulse flow.

References

1. Bradley *et al. Radiology* 198:523-529 (1996).
2. Kahlon *et al. Neurosurg,* 60:124-130 (2007).
3. Wagshul *et al. J Neurourg,* 104:810:819 (2006).
4. McCormack *et al, MRI,* 25:172-182 (2007).

We would like to acknowledge the Brain Child Foundation for support of this work.