Independence of Compliance and CSF Hydrodynamics as an Explanation for Volume Preservation in the Neural Axis

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Introduction

Historically, investigations of CSF hydrodynamics preceded studies of pressure volume relationships within the neural axis. As techniques were developed to describe the two concomitantly, a greater understanding of the interaction between CSF hydrodynamics and neural axis pressure volume relationships has been achieved, but has been limited to acute studies.

Earlier studies from this laboratory demonstrated that compliance increases in hydrocephalus, enhancing the ability to store volume (7,9). This occurred in the face of relatively small increases in the resistance to the absorption of CSF. In order to determine whether primary alterations of compliance would lead to volume storage without alterations of the outflow resistance, the following experiments were performed.

Materials and Methods

Thirty adult mongrel cats weighing 3–5 kgs. were anesthetized with pentobarbital (30 mgs/kg, I.P.) followed by endotracheal intubation. Indwelling arterial and venous catheters were inserted for measurement of systemic arterial blood pressure and administration of drugs. The animals were paralyzed with gallamine (4 mgs/kg), mechanically ventilated using a conventional Starling respirator with a 2:1 mixture of nitrous oxide and oxygen and secured in the sphinx position in a stereotactic frame. PaCO$_2$ was maintained between 28–35 torr and PaO$_2$ greater than 90 torr.

A burr hole was made at the bregma. The sagittal sinus was cannulated using saline-filled PE-50 tubing coupled to a strain gauge transducer to measure sagittal sinus pressure. A 19-gauge saline-filled scalp vein needle was connected to a strain gauge transducer and inserted into the cisterna magna. The output for all transducers was recorded on conventional strip charts and referenced to the right atrium.

The calvarium between the coronal and lambdoidal sutures was removed bilaterally. Cruciate incisions were made in the exposed dura. The integrity of the arachnoid was confirmed by slowly infusing mock CSF through the cisterna magna and visualizing the distended arachnoid through an operating microscope.

After a steady state baseline CSF pressure was established, bolus manipulation of CSF was performed by injecting mock CSF (0.1–0.4 ml) into the cisterna magna and
continuously recording CSF pressure. Successive injections were performed to establish the pressure volume curve from 5–50 mmHg. Using the Pressure Volume Index (PVI) technique, PVI and the resistance to the absorption of CSF ($R_O$) were calculated using Marmarou's equations (4,5). $R_O$ was also determined using the continuous infusion technique (3) in selected animals. Rates for infusion varied between 0.06 ml/min to 0.18 ml/min.

Following these perturbations the scalp was closed in 16 cats. Silastic was attached to the dural edges in the other 14 cats and the scalp closed. The animals were allowed to recover. Three to five weeks later the animals were re-anesthetized and subjected to the same PVI and $R_O$ determinations. The brains were removed and fixed in formalin for sectioning.

Results

In the acute preparations the mean intracranial pressure ($P_O$) was 8.5 ± 1.2 (SD) mmHg after craniectomy and durectomy. This was similar to that determined in the intact state and after craniectomy alone (8). At the time of chronic monitoring 3–5 weeks after initial alteration of container, the $P_O$ was 10.4 ± 1.5 (SD) mmHg for the cats with the silastic inserted and 10.8 ± 2.2 (SD) mmHg for the craniectomized-durectomized chronic preparation without silastic. In the acute post-durectomy preparation PVI was 3.6 ± 0.2 (SEM) ml while $R_O$ was 8.9 ± 0.7 (SEM) mmHg/ml/min. In the chronic silastic preparations the PVI was 4.2 ± 0.5 (SEM) ml and the $R_O$ was 11.7 ± 4.7 (SEM) mmHg/ml/min. In the chronic control animals the PVI was 1.3 ± 0.1 (SEM) ml and the $R_O$ 82.3 ± 9.2 (SEM) mmHg/ml/min (Fig. 1).

The sagittal sinus venous pressure was 8.24 ± 1.3 (SD) mmHg in both groups of chronic preparation, similar to that measured in the acute phase ($p > .1$).

Upon removal of the brains, dense scarring was found between the scalp and brain in the animals without interposed silastic but not in those with silastic. Upon sectioning of the brain, ventricular size was normal in both groups.

Discussion

These studies demonstrate that alterations of the brain's container produce marked enhancement of volume buffering capacity (PVI) in the acute phase. Compared to PVI values obtained in intact cats (8), these maneuvers increase PVI fivefold. Conceptually, this increased PVI should facilitate volume storage by creating a more compliant pressure-volume curve so that volume can accumulate without intracranial hypertension. However, this enhanced volume buffering capacity decreases over time which we attribute to scarring between the temporalis muscle and the opened dura. The PVI in the chronic control group was the same as the acute post-craniectomy preparation with the dura intact (8). In the preparations in which silastic was inserted to prevent this scarring, enhanced volume buffering capacity was preserved over time as evidenced by PVI values which were similar to those found immediately after opening the skull and dura. Despite these maneuvers which preserve enhanced volume buffering capacity, the ventricular size remains normal in both chronic states.