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CSF shunt physics: factors influencing inshunt CSF flow

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Abstract Cerebrospinal fluid (CSF) in a shunt does not have a constant flow rate. The flow fluctuates from 0.01 ml/min to 1.93 ml/min according to each patient's own daily supine rhythmic pattern. We determined and evaluated the factors influencing CSF flow in a shunt in 19 cases of hydrocephalus. Postural changes, such as head elevation, led to increases by over 0.04 ml/min in inshunt CSF flow, while inshunt CSF flow in the supine position was less than 0.04 ml/min. Respiratory changes, such as coughing and apnea-hyperventilation, also influenced inshunt CSF flow. Changes in intracranial pressure (ICP) corresponded to changes in inshunt CSF flow. Inshunt CSF flows were higher than average during the night, the flows being stimulated by increases in ICP especially during REM sleep.

Key words Hydrocephalus · CSF shunt · CSF dynamics · Inshunt CSF flowmeter · Intracranial pressure

Introduction

Cerebrospinal fluid (CSF) shunts have been used as a standard method in treating the excess accumulation of CSF as in cases of hydrocephalus [17]. However, it is very difficult to determine whether or not the CSF shunt is solely responsible for the improvement observed in clinical findings. Despite X-ray studies, computed tomography (CT), standard magnetic resonance (MR) imaging, and palpation of the CSF reservoir in the shunt, there is frequently some uncertainty as to whether a shunt is functioning. Thus, ascertaining and understanding shunt function and inshunt CSF physics are important and necessary for neurosurgeons to treat cases of hydrocephalus. We have, therefore, developed a new non-invasive method to determine the actual inshunt CSF flow [15] which supports our above mentioned claim, and which has previously been reported. We found that inshunt CSF flow is not constant and fluctuates from 0.01 ml/min to 1.93 ml/min with each patient's own rhythmic pattern in spite of constant CSF production (Fig. 1) [9, 11]. In this study, we describe inshunt CSF physics and factors influencing inshunt CSF flow.

Patients and methods

Nineteen patients with either communicating or non-communicating hydrocephalus, comprising 10 females and 9 males aged from 18 to 70, were studied to determine actual inshunt CSF flow with a new method which we have developed. All of the cases had received a ventriculo-peritoneal shunt with the Raimondi peritoneal catheter of medium pressure (Heyer-Schulte Corp., USA) and inshunt CSF flowmeter.

All inshunt CSF flows were calculated non-invasivley and intermittently using our technique reported in 1983 [9] which consists of an inshunt bubble producing device implanted under the skin and a Doppler flowmeter above the skin to detect the movement of the bubbles induced in the CSF as they flow downward in the shunt (Fig. 2).

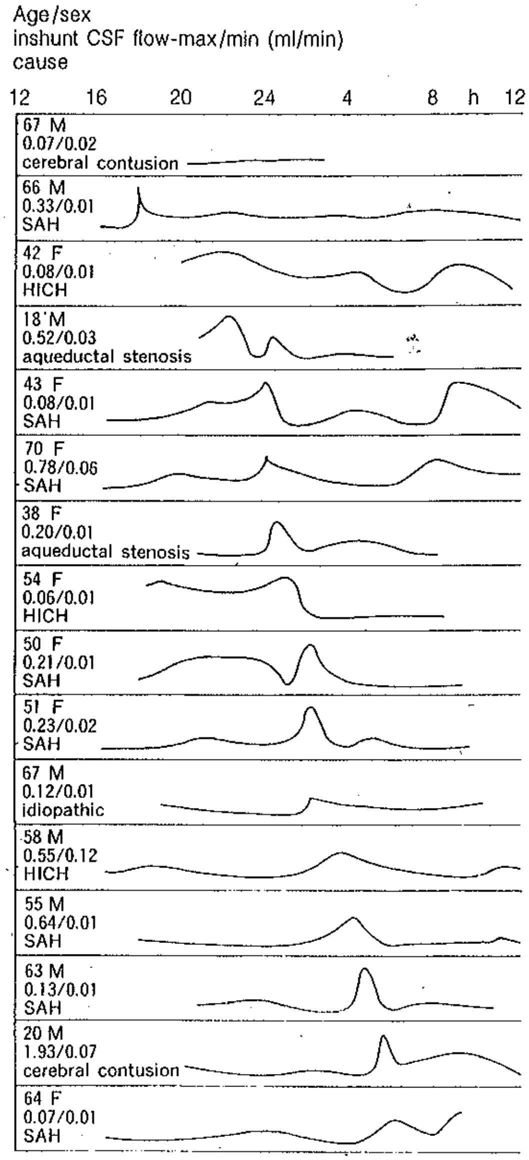

Fig. 1 Volumes (maximum/minimum) of inshunt CSF flow, and daily patterns of inshunt CSF flow in 16 cases

Factors evaluated influencing the inshunt CSF flow in this study were:

- The inshunt CSF flow was determined with patients at varying inclination of the body. The inshunt CSF flow altered according to the degree of head elevation.
- The inshunt CSF flow was determined during various breathing conditions, such as apnea and hyperventilation. Changes in the inshunt CSF flow corresponded to changes in respiration.
- The inshunt CSF flow was observed during changes in intracranial pressure (ICP) over a 24-h period. There was a correlation between fluctuation in the inshunt CSF flow and changes in ICP.

Results

Changes in inshunt CSF flow related to postural change

While the patient was in supine position, the inshunt CSF flow was invariably less than 0.04 ml/min. With head and upper half of body elevated to 15°, the inshunt CSF flow increased slightly to between 0.04 ml/min and 0.07 ml/min. At 30° elevation, the inshunt CSF flow increased to between 0.04 ml/min and 0.28 ml/min. With a further increased to 80°, nearly sitting position, there was a further increase up to between 0.14 ml/min and 0.43 ml/min (Fig. 3).

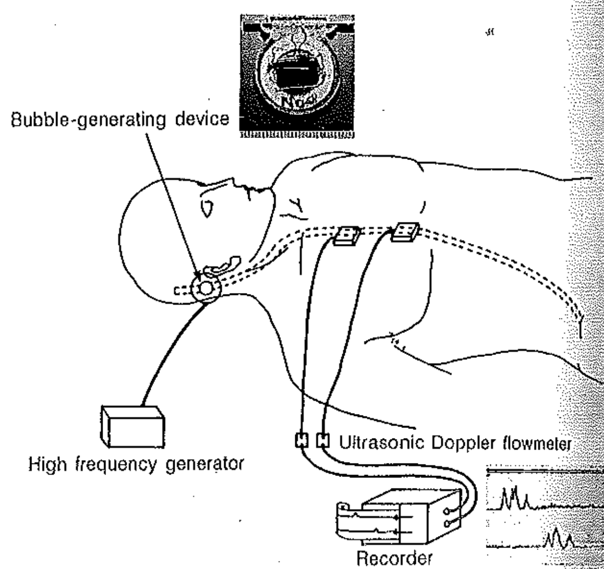

Fig. 2 Diagram of the inshunt CSF flowmeter

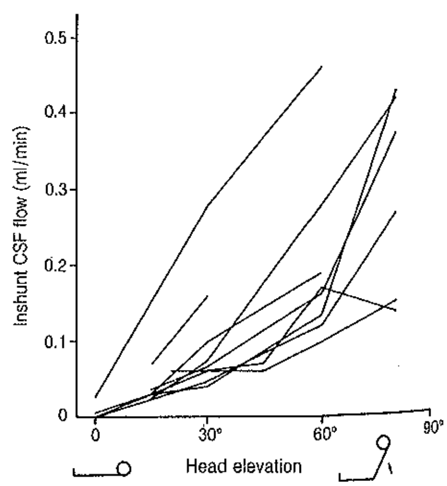

Fig. 3 Changes in inshunt CSF flow related to postural changes in 9 cases

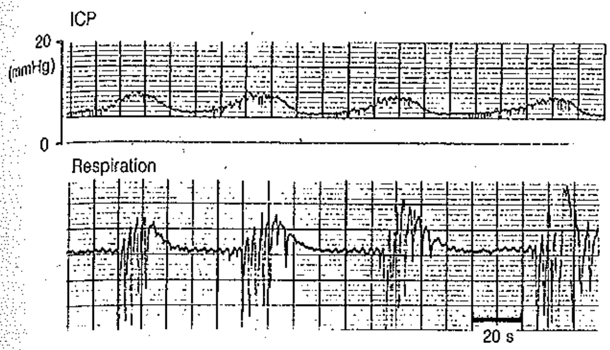

Fig. 4 Changes in ICP corresponding to changes in respiration

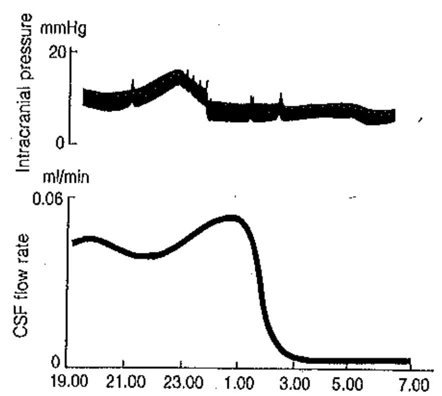

Fig. 5 Changes in inshunt CSF flow related to changes in ICP over a 12-h period

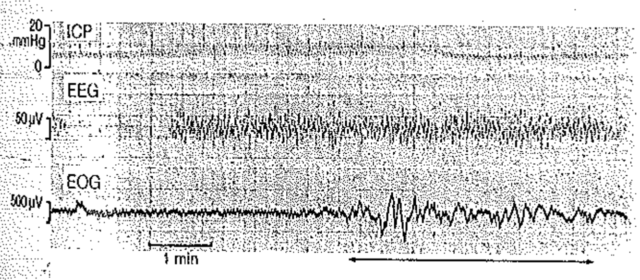

Fig. 6 Changes in ICP corresponding to the movement of eyeballs suggesting REM stage of sleep

Changes in inshunt CSF flow related to respiration

Transient increases in ICP corresponded to changes in respiration in most cases (Fig. 4). In particular, acute increases in intrathoracic pressure associated with a coughing fit led to rapid increases in ICP and inshunt CSF flow reflected in the rapid movement of the bubbles induced in the shunt.

Changes in inshunt CSF flow related to changes in ICP over a 24-h period

The inshunt CSF flow fluctuated in each case with peak CSF flows of between 0.06 ml/min and 1.93 ml/min, and individual changes over a 24-h period with 1–3 peaks for each case.

Changes in the inshunt CSF flow were related to changes in ICP in some cases. The inshunt CSF flow fluctuated almost parallel to the changes in ICP during a 24-h period in the 3 cases.

The following is a representative case.

A 54-year-old female showed changes in inshunt CSF flow corresponding to changes in ICP over a 12-h period from 7 p.m. to 7 a.m. as shown in Fig. 5. The inshunt CSF flow fluctuated from 0.01 ml/min to 0.06 ml/min with 2 peaks at 7.30 p.m. and 1 a.m. The mean ICP also fluctuated with a peak of 14 mmHg and a minimum of 8 mmHg, and this was thought to be responsible for the corresponding changes in inshunt CSF flow.

In addition, fluctuations in ICP were also seen corresponding to the movement of respiration, eyeballs and swallowing indicating a rapid eye movement [REM] sleep stage in three out of four cases studied (Fig. 6). Coinciding with these changes during REM sleep, inshunt CSF flow increased transiently.

Discussion

While the CSF shunt has been adopted in treating cases of hydrocephalus regardless of the cause, malfunctioning of the shunt can occur rendering it difficult to accurately assess the shunt function. There are many reports of different methods of assessing shunt function, including external palpation, thermal dilution [2, 8, 18], radionuclide clearance [10, 13], shuntgram with contrast medium and radionuclide [4], ultrasonic flow studies [6] and magnetic resonance flow studies [1, 7]. However, to accurately assess shunt function it is necessary to fully clarify the physics of inshunt CSF flow, especially areas such as whether an adequate amount of CSF is flowing through a shunt [14], and what factors influence the CSF flow through a shunt [20].

We have developed and adopted an inshunt CSF flowmeter in clinical practice in an attempt to clarify the inshunt CSF dynamics in cases of hydrocephalus [9, 11, 12]. Lorenzo [13] and Cutler [13] reported that the formation rate of CSF was 0.30 ml/min ~0.35 ml/min. However, our results showed that the inshunt CSF flow did not coincide with the amount of CSF produced, and that CSF flow is not constant, varying from 0.01 ml/min to 1.93 ml/min. Even under the same conditions, the inshunt CSF flow varied between each case, showing an individual rhythmic fluctuation during a 24-hour period in each case. We also studied our patients under varying conditions to clarify what factors influence the inshunt CSF flow and what the resulting changes are.

As Portnoy [16] described, the hydrodynamics of a shunt are mainly related to changes in intraventricular pressure (IVP) and hydrostatic pressure (HP) in the shunt. Further to his findings, our results indicate that increases in ICP/IVP lead to increases in inshunt CSF flow. Our findings indicate that in the supine position, the inshunt CSF flow seems to be due to the fluctuations in IVP/ICP. While the head is elevated, despite IVP/ICP occasionally reduced to negative [5, 19] the inshunt CSF flow increased resulting from increases in inshunt HP. And rapid and transient increases in IVP/ICP associated with respiratory changes also corresponded to increases in inshunt CSF flow. And it appeares that increases in ICP which occur during the REM sleep could be influencing the inshunt CSF flow.

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