A new method for measuring cerebrospinal fluid flow in shunts

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An implantable device for measurement of cerebrospinal fluid (CSF) flow in a ventriculoperitoneal shunt tube has been developed. The unit is energized by an extracorporeal high-frequency generator (200 KHz), and electrolysis creates bubbles in the shunt tube. Velocity of bubble flow is detected by a pair of ultrasonic Doppler probes placed a certain distance apart on the skin surface and in parallel with the implanted tube. The CSF flow rate is calculated taking into account velocity and tube diameter, and is expressed in ml/min. The unit consists of a coil with a capacitor, a silicon diode to rectify the high frequency, and a Zener diode to regulate maximum output voltage of 20 V. The output is fed to a pair of platinum electrodes placed inside the unit's tunnel through which the CSF flows. These components are molded in epoxy resin and coated with medical-grade silicone rubber. In animal experiments, CSF flow rates ranging from 0.033 to 1.0 ml/min could be measured by this flowmeter. Clinically, CSF flow has been measured to date in several cases. In two cases of communicating hydrocephalus occurring after the onset of cerebrovascular disease, and in which the CSF flow was continuously monitored for 24 hours, the flow rate ranged between 0.05 and 0.78 ml/min. The CSF flow rate fluctuates in a 24-hour period, increasing in the morning, especially between 12 midnight and 6 a.m., which suggests a circadian rhythm.

KEY WORDS • cerebrospinal fluid flow • shunt • Doppler flowmeter

Materials and Methods

Instrumentation

Bubbles in the CSF artificially created by electrolysis are used as tracers to determine the CSF flow in the shunt tube. The electrical energy for this electrolysis is supplied by high-frequency transmission through the skin, a 200-KHz high-frequency generator* being used as the power source. A transmitting coil, 10 cm in diameter, is connected to the generator by a cable and placed on the skin at the point where the receiving unit is implanted subcutaneously. The receiving coil inside the unit is 2 cm in diameter, and tuned at 200 KHz with a capacitor. The high-frequency current induced in the coil is fed to a silicon

* Cardiac pacemaker, type w306 (modified to have a constant high-frequency output instead of the original intermittent output), manufactured by Sanei Sokki Co., Tokyo, Japan.
diode rectifier to obtain a direct current (DC) and then stabilized by a Zener diode to maintain a constant output voltage of 20 V. The DC output is connected to a pair of platinum electrodes (7 mm apart) exposed to the CSF which flows through the unit (Fig. 1). This electronic circuit and the electrodes are molded in epoxy resin and encapsulated in medical grade silicone rubber.† The unit measures 33 × 23 × 5 mm (Fig. 2) and weighs approximately 5 gm.

**Flow Calculation**

The bubbles thus created in the shunt tube are detected transcutaneously downstream by a pair of Doppler ultrasound probes‡ placed 5 to 10 cm apart on the skin overlying the shunt tubing. The Doppler signals are registered on a two-channel pen-recording oscillograph.

The CSF flow rate is calculated based on the distance between the two Doppler probes, the time required for the bubbles to travel between the two points, and the diameter of the tube. The rate is expressed in milliliters per minute using the following formula:

\[
V = \pi r^2 \times \frac{l}{t} \times 60 \text{ (ml/min)},
\]

where \( V \) = volume of CSF flow in shunt tube per minute; \( r \) = inner radius of shunt tube (cm); \( l \) = distance between the two Doppler probes (cm); and \( t \) = time required for bubble to travel between the two Doppler probes.

**Animal Studies**

The bubble-generating unit with shunt tubing connected to each end of the unit was implanted subcutaneously in the thoracoabdominal region of a dog anesthetized with Nembutal (pentobarbital). Each tube was brought out through a separate small skin incision, one in the thorax and the other in the abdominal area. The proximal tube was connected to an infusion pump§ instead of the ventricle in order to supply the system with several calibrated feedings of CSF by altering the speed of the pump. The caudal tube was placed in a graduated cylinder to measure the flow. Physiological saline was used as a substitute for CSF to fill the system and perform the experiment. A pair of Doppler probes were placed on the skin in parallel with the shunt tubing, as described above, to detect the flow of a bubble.

Five dogs were used for this study. Ten different flow rates, from 0.033 to 1.0 ml/min as determined by the volume measurements at the distal end of the tubing, were compared to the results calculated by the Doppler bubble method. Examples of the Doppler recordings showing two different flow rates are shown in Fig. 3. The measurements obtained in the five dogs are shown in Table 1. Figure 4 indicates mean flow rate calculated by the Doppler bubble technique and

† Medical elastomer, No. 382, manufactured by Dow Corning Co., Medical Products Division, Midland, Michigan.
‡ Doppler flowmeter, Type 1935 (frequency 5 MHz), manufactured by Sanei Sokki Co., Tokyo, Japan.
§ Nihonkoden constant-infusion pump, type TFV-1100, manufactured by Nihon Koden Kogyo Co., Inc., Tokyo, Japan.
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Fro. 3. Bubble flow velocity is detected by a pair of ultrasonic Doppler probes placed 10 cm apart on the skin surface overlying the implanted tube. The bubble signals are recorded as shown above. Flow rates are 0.22 ml/min (left) and 0.048 ml/min (right). Time mark: one second.

plotted against actual flow rate measured at the distal end of the shunt tubing. Statistical analysis shows a correlation coefficient of 0.995.

The animal study indicated that the system is capable of measuring a flow range of 0.033 to 1 ml/min. The upper range is limited by the frequency response of the Doppler system, including chart recorder. The lower range is limited by the Doppler effect, which is a velocity-dependent phenomenon.

Case Reports

Case 1

This 58-year-old man had acquired normal-pressure hydrocephalus following rupture of a right internal carotid aneurysm. After his recovery from disturbed consciousness, the aneurysm neck was clipped on the 60th day after onset. At the same time, a ventriculoperitoneal (VP) shunt was placed because of his normal-pressure hydrocephalus. The bubble-generating system was connected to the shunt system and implanted in the subcutaneous tissue of the upper chest area. After the operation, CSF flow was measured with the patient in the supine position. The flow rate measured at 3 p.m. was found to be 0.10 ml/min (Fig. 5).

Case 2

This 72-year-old woman had communicating hydrocephalus after rupture of a right anterior cerebral aneurysm. Two months after onset, a VP shunt was inserted with Raimondi’s high-pressure peritoneal spring catheter. The bubble unit was connected to the system and implanted in the subcutaneous tissue of

![Fig. 3](image-url)

**Table 1**

<table>
<thead>
<tr>
<th>Actual Flow Rate</th>
<th>Calculated Flow Rate</th>
</tr>
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<tbody>
<tr>
<td>0.028 ± 0.003</td>
<td>0.030 ± 0.002</td>
</tr>
<tr>
<td>0.058 ± 0.003</td>
<td>0.062 ± 0.001</td>
</tr>
<tr>
<td>0.095 ± 0.003</td>
<td>0.105 ± 0.004</td>
</tr>
<tr>
<td>0.199 ± 0.013</td>
<td>0.209 ± 0.014</td>
</tr>
<tr>
<td>0.301 ± 0.014</td>
<td>0.314 ± 0.009</td>
</tr>
<tr>
<td>0.404 ± 0.014</td>
<td>0.428 ± 0.020</td>
</tr>
<tr>
<td>0.509 ± 0.012</td>
<td>0.528 ± 0.015</td>
</tr>
<tr>
<td>0.607 ± 0.009</td>
<td>0.626 ± 0.010</td>
</tr>
<tr>
<td>0.742 ± 0.025</td>
<td>0.782 ± 0.018</td>
</tr>
<tr>
<td>0.822 ± 0.008</td>
<td>0.973 ± 0.037</td>
</tr>
</tbody>
</table>

* Values are mean ± standard deviation in five dogs for 10 different flow rates after infusion of saline.

![Fig. 4](image-url)
FIG. 5. Case 1. Flow rate measured by the Doppler bubble method was found to be 0.10 ml/min. The three peaks indicate three successive bubbles.

FIG. 6. Case 2. Flow-rate curve showing fluctuation between 0.05 and 0.78 ml/min. There were two major peaks, one at 12 midnight to 2 a.m., the other at 7 to 8 a.m.

the upper chest wall. For 24 hours after the operation, CSF flow was measured at intervals of between 30 minutes and 1 hour, while the patient was in the supine position. Figure 6 shows a graph of the CSF flow rate during the 24-hour period. The flow rate was not constant but ranged between 0.05 and 0.78 ml/min. A high flow rate was observed between 12 midnight and 2 a.m., and between 7 and 9 a.m. The total 24-hour volume of CSF was 350 ml.

Case 3

This 57-year-old man had communicating hydrocephalus after hypertensive brain-stem hemorrhage. To decrease intracranial pressure, a VP shunt operation was performed using the same type of catheter and bubble unit as in Case 2. The CSF flow rate recorded in this patient is displayed graphically in Fig. 7. The flow rate in a 24-hour period varied between 0.12 and 0.55 ml/min. Two peaks were seen, one between 3 and 4 a.m. and the other between 2 and 3 p.m. The total 24-hour volume of CSF was 350 ml.

Discussion

Shunts to bypass CSF are widely used in the treatment of infant hydrocephalus, normal-pressure hydrocephalus, and increased intracranial pressure. Clinically, it is of the utmost importance to know whether or not the shunt is functioning efficiently. Furthermore, continuous CSF flow monitoring for an extended period of time would provide valuable information concerning the physiology and pathology of CSF circulation.

There have been many studies on how to judge CSF flow in a shunt tube, such as assessment of clinical symptoms themselves, the degree of rebound of a flushing device, the use of radioisotopes as tracers, a heat-sensitive “chameleon print” sheet method, a thermistor device for heat clearance method, and radiopaque material for x-ray visualization. Most of these methods, however, merely provide qualitative information on the CSF flow, and some of them require an invasive procedure for each measurement.

Harbert, et al., reported a method in which they injected technetium-99m into the shunt reservoir and then calculated the CSF flow from the clearance curve. Puncturing the reservoir poses the possibility of infection, and retrograde isotope leakage from the reservoir may create inaccuracies in measurement. Furthermore, repeated measurements at short intervals are not possible.

Go, et al., stated that if a moving column of liquid is cooled at a certain point, the drop in temperature can be recorded some distance away in the direction of the flow. Based on this principle, they applied an ice cube to a site over the shunt tube. A thermosensor was placed on the skin some distance away from where the shunt tube was implanted to detect temperature changes. In animal experiments, they measured flow rates ranging from 160 to 1866 ml/day. The accuracy of this technique may be influenced by the thickness of the tissues over the catheter as well as local vasomotor reactions of the skin.

Yamasaki, et al., reported a method using a “chameleon print” sheet, a plastic sheet coated with heat-sensitive colored liquid crystals. When placed on the skin, the color turns from red to violet with a change of 5°C. This method is subject to error because of the thickness of the subcutaneous fatty tissue. It could not detect a CSF flow of less than 0.15 ml/min.

Using the device we have developed, it is possible to monitor flow in the shunt tube almost continuously. Since the Doppler phenomenon depends on the velocity of the moving target, the present method is somewhat limited in the lower ranges of CSF flow measurement.
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![Flow-rate curve showing fluctuation between 0.12 and 0.55 ml/min. There were two large peaks, one at 2 to 3 p.m., the other at 3 to 4 a.m.](image)

**FIG. 7.** Case 3. Flow-rate curve showing fluctuation between 0.12 and 0.55 ml/min. There were two large peaks, one at 2 to 3 p.m., the other at 3 to 4 a.m.

The data obtained in Cases 2 and 3 indicate that CSF flow in the shunt tube is not constant. In Case 3, there were two peaks of flow, one at 2 p.m. and the other at 3 a.m. The 2 p.m. peak may be due to physical activities associated with mental alertness. These results indicate that the CSF flow has a pattern of fluctuation during a 24-hour period, showing a peak between midnight and 3 to 4 a.m. and another peak in the afternoon. These fluctuations in flow may be caused by alterations in cerebral blood flow, production of CSF, intracranial pressure, and patient’s movement.

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**References**


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