Normal cerebrospinal fluid pressure

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The authors report studies of cerebrospinal fluid (CSF) pressure in 31 young normal volunteers. In half, a 22-gauge needle was used, and in the other half a 26-gauge needle. The opening CSF pressure was monitored for 10 minutes and also in some during the CSF withdrawal period and the 10-minute CSF reformation period. Cardiac CSF pulse amplitudes and Queckenstedt responses following the opening pressure-monitoring period were also recorded before and after the fluid withdrawal. The average opening pressure was 14.5 cm of 0.15 M sodium chloride (S.D., 3.7) with the 22-gauge needle, and 15.7 cm (S.D., 3.6) in subjects receiving the 26-gauge needle. In each subject the opening pressure tended to fluctuate around a characteristic individual level; in five perfectly relaxed normal volunteers an average value of 20 cm was observed, with a maximal value of 24 cm. The amplitude of the cardiac pulse had a direct relationship to the individual CSF pressure.

CSF was withdrawn at two different rates; both withdrawal rates generated approximately linear pressure decay curves. When the withdrawal rates were 5 and 1 ml/min, the average decline of pressure at the end of the period was 9.2 and 5.2 cm respectively. The mean CSF pressures increased only slightly during the 10-minute CSF reformation period. The data obtained should help to define whether a young adult patient does indeed have a CSF pressure elevation.

KEY WORDS - cerebrospinal fluid pressure - Queckenstedt test

Since the main purpose of this study was to determine as accurately as possible the undistorted physiological cerebrospinal fluid (CSF) pressure, three obvious prerequisites were established: 1) the group of subjects had to be healthy and not a surgical or psychiatric control group; 2) the pressure recording equipment had to be isovolumetric so that no CSF was displaced into the measuring device, as occurs with the open end manometer; and 3) the puncture hole in the lumbar theca had to be as small as possible to minimize seepage into the extradural space during the recording. These three demands have not been fulfilled in previously published studies, except for a study of 15 healthy volunteers by Gilland. In that study, however, the steady-state opening pressure was only recorded for approximately 1 minute.

Materials and Methods

Lumbar punctures were done on 31 healthy paid volunteers (22 men and nine women), all college students of normal weight and having an average age of 23 years (range 20 to 27 years). Before the
study each volunteer was given a regular medical work-up, with particular emphasis on evidence of no past neurological disease or current acute illness. The physical examination included blood pressure, cardiac auscultation, and a detailed neurological survey.

In 16 of the subjects a 22-gauge needle was used for lumbar puncture (O.D., 0.70 mm), and in 15 a 26-gauge needle (O.D., 0.45 mm). The opening CSF pressure was monitored for 10 minutes in all subjects. In addition, in some the pressure was monitored during the CSF withdrawal period (six subjects in the 22-gauge group and seven in the 26-gauge group). The fluid withdrawal with a syringe was timed with a stopwatch, and set at 5 ml/min for the 22-gauge needles, and at 1 ml/min for the 26-gauge needle group. In the same subjects the pressure was also monitored for a 10-minute period to estimate the rate of reformation of CSF.

Cardiac CSF pulse amplitudes and Queckenstedt responses following the opening-pressure-monitoring period were also recorded for the two needle groups.

All recordings were made with the subjects in the left lateral recumbent position with the legs half flexed. The head and spine were strictly horizontal. The subjects were allowed a few minutes of relaxation before the recording started, and it was ascertained that they felt comfortable throughout the recording period. They were requested to maintain a normal breathing pattern with mouth open. The puncture room was kept quiet, and no conversation nor any interruptions such as knocks on the door were allowed, as this was found to cause the pressure to rise. No sedation or local anesthesia at the puncture site was given.

The 26-gauge needles were introduced via a guiding cannula with a drop of sterile saline applied to the hub of the needle; when the needle tip passed the extradural space, the drop was drawn in, whereas it bulged out when the tip entered the CSF compartment. As soon as CSF appeared at the needle hub, the recording system was connected.

The pressure-recording system (Fig. 1) consisted of a Statham SP 37 minitransducer attached to the lumbar needle via a 10-cm-long piece of fairly rigid-walled polyethylene tubing, with adaptors and a three-way stopcock. The system was primed with sterile 0.15 M sodium chloride solution isotonic saline before being connected to the needle. Direct write-outs were obtained on a thermographic recorder, run with a standard chart speed of 5 mm/sec. The calibration was set to make 1 cm of isotonic saline correspond to 1 mm on the chart. Baseline and gain drifts were checked every few minutes throughout the recording with an open-end manometer, connected to the system as shown in Fig. 1. Drifts exceeding +2% of full scale were adjusted as shown in Fig. 2. It should be emphasized that the tip of the lumbar puncture needle was in the same horizontal plane as the transducer and the zero point of the calibrating open-end manometer at all times. This was accomplished by placing enough spacers under the manifold, which rigidly held the transducer and the zero point of the calibrating open-end manometer at a constant level, to raise the level of the transducer to the estimated level of the lumbar puncture needle in the subarachnoid space.

With use of the "exploding balloon technique" to test the dynamic fidelity of the pressure-recording system, a square wave response was found for 22-gauge
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needles, whereas with 26-gauge needles there was a modest overdamping of the response.

The average pressure for each minute was calculated for the first 20 seconds of the minute, permitting several respiratory cycles to be included at random. The average pressure for each 20-second period was estimated by placing a ruler in an intermediate horizontal position between the maximum and minimum pressures during the period. For estimates of the cardiac pulse amplitude, the average of three cardiac pulse amplitudes at any given pressure level was taken. All pressures are reported in centimeters of isotonic saline.

Results

The calculated mean CSF pressures for each minute of the 10-minute opening-pressure-monitoring period are presented separately for the 22- and 26-gauge needle groups (Table 1). The data show a statistically significant (0.02 < p < 0.05) but small (+7.9%) increase in the pressure with the 22-gauge needle, from 13.9 cm at Minute 1 to 15.0 cm at Minute 10. Over the entire 10-minute period, the mean pressure was 14.5 cm (S.D., 3.7). The observed range of single CSF pressure readings with the 22-gauge needle was 8.5 to 23.5 cm. If a normal CSF pressure is defined as any pressure in the central 95% region of the distribution of all CSF pressures, calculation of the 95% tolerance limits for this region reveal that normal subjects have CSF pressures between 4 and 25 cm. Therefore, when a 22-gauge needle is used, there is only a 1 to 20 chance for an individual to be normal if his CSF pressure falls outside of the range of 4 to 25 cm.

With the 26-gauge needle, the mean CSF pressure rose from 15.2 cm at Minute 1 to 15.8 cm at Minute 10, representing a small (+3.9%) and statistically insignificant increase. Over the entire 10-minute period, the mean pressure was 15.7 cm (S.D., 3.6).
The observed range of single CSF pressure readings was 8 to 24 cm. The 95% tolerance limits for CSF pressure using the 26-gauge needle were 5 to 26 cm.

Comparison of CSF pressures in the two needle groups (Table 1) shows that with the 26-gauge needle the CSF pressures were higher than those with the 22-gauge needle at every minute of the 10-minute opening-pressure-monitoring period. However, none of these differences was statistically significant (all p’s were >0.20). The CSF pressures associated with the 22-gauge needle appeared to increase more (+7.9%) from Minutes 1 to 10 than did those associated with the 26-gauge needle (+3.9%). This had the effect of reducing the initial difference between the mean CSF pressures in the two needle groups in the later minutes of the opening-pressure-monitoring period.

In the individual subject, the pressure fluctuations over the 10-minute period were found to vary around a characteristic individual level. This can be seen quantitatively by comparing the coefficients of variation (C.V.)* of the observations within subjects to the coefficients of variation of the observations across subjects. The average of the within-subject C.V.’s was 7.5% (range 5.0% to 14.4%) for the 22-gauge needle group and 7.4% (range 3.3% to 11.9%) for the 26-gauge needle group. The average of the across-subject C.V.’s for each minute of the 10-minute period was 26.3% (range 22.6% to 30.0%) for the 22-gauge needle and 24.0% (range 21.8% to 25.9%) for the 26-gauge needle group. Thus, there was considerably more variation in the observations from subject to subject than on the same subject.

The average cardiac pulse amplitude was studied in 14 of the volunteers who had a 22-gauge needle lumbar puncture (Fig. 3). At a mean opening CSF pressure of 19.5, the mean cardiac pulse was 2.8 cm (S.D., 1.2). At a mean CSF pressure of approximately 40 cm produced by jugular compression (pressures obtained with the neck in midposition and extension were averaged), the cardiac pulse amplitude averaged 8.5 cm (S.D., 4.6). A plot of cardiac pulse amplitudes versus CSF pressures during the pulse cycles sampled showed a direct relationship between the two (Fig. 3).

The pulse amplitude in 14 volunteers receiving the 26-gauge needle averaged 1.5 cm at an average opening CSF pressure of 20 cm, and about 5 cm at a CSF pressure level of 38 cm produced by jugular

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*Coefficient of variation (C.V.) = (S.D./mean) x 100. The larger the C.V., the more the variability in the observations.
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Fig. 3. Cardiac CSF pulse (recorded via 22-gauge needles) amplitude, including means and standard deviations versus CSF pressures in 14 healthy volunteers. Data are shown for opening pressure levels and for peak pressures during jugular compression.

Compression (pressures obtained with the neck in midposition and extension were averaged). Since the rapid cardiac pulse oscillations are overdamped by the system incorporating the 26-gauge needle, these cardiac pulse amplitude figures are misleadingly low.

After the 10-minute opening-pressure-monitoring period, jugular compression responses were recorded in all subjects and were found to be identical with those previously reported in another series of healthy volunteers.\(^2\,^3\)

The mean CSF pressures of a subgroup of patients were monitored during withdrawal of 20 ml of CSF at two different rates. The CSF pressures declined linearly in both groups (Fig. 4). When the rate was 5 ml/min, the average decline of pressure at the end of the period was 9.2 cm (S.D., 1.3) (Table 2); whereas when the rate was 1 ml/min, it was 5.2 cm (S.D., 1.6).

Figure 4 also presents the mean CSF pressures for the same subjects monitored during a 10-minute CSF reformation period. The mean CSF pressures increased in both groups, but these increases were not statistically significant.

Discussion

The best estimate of the true CSF pressure should be the one obtained with the
TABLE 2

CSF pressures (cm of 0.15 M sodium chloride) in the 22- and 26-gauge needle groups during CSF withdrawal

<table>
<thead>
<tr>
<th>CSF Withdrawn (ml)</th>
<th>22-Gauge Needle (n = 6)</th>
<th>26-Gauge Needle (n = 7)</th>
<th>Difference Between Means*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min CSF Pressure Mean (S.D.)</td>
<td>Min CSF Pressure Mean (S.D.)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>10 14.9 (1.7)</td>
<td>10 17.3 (4.5)</td>
<td>2.4 n.s.</td>
</tr>
<tr>
<td>5</td>
<td>11 11.9 (2.0)</td>
<td>15 16.2 (3.8)</td>
<td>4.3†</td>
</tr>
<tr>
<td>10</td>
<td>12 9.8 (1.6)</td>
<td>20 14.6 (3.7)</td>
<td>4.8†</td>
</tr>
<tr>
<td>15</td>
<td>13 7.8 (1.0)</td>
<td>25 13.9 (3.4)</td>
<td>6.1§</td>
</tr>
<tr>
<td>20</td>
<td>14 5.7 (1.8)</td>
<td>30 12.1 (3.2)</td>
<td>6.4§</td>
</tr>
<tr>
<td>pressure change from beginning to end of withdrawal period‡</td>
<td>-9.2 (1.3)§</td>
<td>-5.2 (1.6)§</td>
<td>4.0§</td>
</tr>
</tbody>
</table>

* t-test for unrelated samples used to test for significant differences between means, n.s. = p > 0.05.
† p ≤ 0.05.
‡ Paired t-test used to test for mean changes in pressure significantly different from zero.
§ p ≤ 0.01.

26-gauge needle (15.7 cm). The lower value for the average CSF pressure obtained with the 22-gauge needle (14.5 cm) is probably due to more seepage of fluid around the needle in situ and cannot be ascribed to the overdamped characteristics of the fine gauge needle recording system. The fine needle acts as a damping capillary, used in some cardiac pressure-monitoring systems, and rapid pressure oscillations will appear flattened. The average pressure over a period of a few seconds or more will not be distorted if the different frequencies are integrated to a true average. A leak between arachnoid-dura and an inserted lumbar needle was strongly implicated by Lundberg and West, who found that the intraventricular pressure fell and remained low when a lumbar needle was introduced and left in place without any fluid withdrawal.

The data correspond to those reported by Gilland with a 24-gauge needle and an isometric technique. The average pressure (14.4 cm, S.D. 3.1) was almost identical to that found in the present study with the 22-gauge needle. The data also correspond to those found by Tourtellotte, et al., in a series of 105 healthy volunteers submitted to conventional lumbar pressure recording with an open-end manometer. In that study the average opening pressure was found to be 15 cm (S.D., 3.3) when the manometric data for 18-, 20-, and 22-gauge needles were lumped together. As pressure data were not of primary concern in that study, only spot determinations were made. It may

![Image](https://via.placeholder.com/150)

**Fig. 4.** Left: CSF pressure curve when CSF was withdrawn at the rate of 5 ml/min through a 22-gauge needle. Right: CSF pressure curve when CSF was withdrawn at the rate of 1 ml/min through a 26-gauge needle.
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be that the error inherent in spot determinations, with little time for relaxation, is evened out by the slight pressure drop caused by fluid displacement into an open-end manometer.

The present finding that healthy subjects may have a CSF pressure fluctuating around 20 cm, with peaks as high as 24 cm, has not been reported previously, nor do the data conform with earlier criteria for the normal CSF pressure range. It has frequently been stated that pressures up to 15 cm are normal, that pressures in the range of 15 to 20 cm are questionable, and pressures above 20 definitely abnormal. With the increasing clinical use of long-term (intracranial) CSF pressure-monitoring in various neurological conditions, the clarification of the borderline of normal and abnormal pressure has become even more of an issue.

Intracranial recordings can obviously never be obtained in healthy subjects. Under normal conditions, however, the lumbar CSF pressure will equal the intraventricular pressure except for a difference in respiratory and cardiac pulses. The average intraventricular and lumbar pressures will be identical in a true horizontal position.

The CSF pressure data obtained on fluid withdrawal at a controlled rate may be helpful also in deciding whether the pressure fall is abnormally steep. It turned out that 20 ml withdrawal gave a linear pressure-volume curve; however, it is well recognized that for larger volumes withdrawn, the curve is by no means linear.1

It has been stated1 that measurement of the CSF pressure for a period of time after the removal of a known amount of CSF can give information that can be used to estimate the formation of CSF. Our data indicated that, with the rates of withdrawal performed and the 10-minute period used, only an insignificant increase in pressure was generated so that formation calculations could not be carried out.

It is hoped that the data presented here will be of value in deciding whether young adult patients do indeed have a CSF pressure elevation. Furthermore, it is possible that the data may help to clarify the terminology in regard to normotensive or low-pressure hydrocephalus; however, to be more precise, it may be necessary to repeat this study in age-matched normal subjects.

References


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