RADIONUCLIDE ASSESSMENT OF CEREBROSPINAL FLUID SHUNT FUNCTION IN CHILDREN

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A reasonably simple radionuclide test for determining CSF shunt patency and function is described. Twenty-five microcuries of \( ^{99m}\text{TcO}_4^- \) were injected into the shunt reservoir, and images of the shunt were obtained with a gamma camera. Rate of clearance of radioactivity from the shunt was measured and expressed as a clearance \( T_{1/2} \) in minutes. Twenty-five subjects with normally functioning shunts showed spontaneous, continuous clearance with a \( T_{1/2} \) averaging 3 min. Subjects with malfunctioning shunts showed three different patterns: absent clearance, marked prolongation of clearance \( T_{1/2} \), or intermittent clearance. The findings correlated well with operative findings in those patients later operated upon for shunt revision. The technique is a reliable method for determining shunt patency and semi-quantitating CSF shunt flow and may also provide a means of identifying patients with "arrested" hydrocephalus.

Contemporary therapy of hydrocephalus routinely includes placement of a ventriculo-atrial or ventriculo-peritoneal shunt. This prosthetic device diverts cerebrospinal fluid (CSF) into a body space from which it can be reabsorbed. One of the major problems with this therapy is maintaining adequate shunt function. Malfunction can be due to mechanical failure of the shunt, occlusion of the shunt by debris, or the development of loculated spaces around the ventricular or the distal end of the shunt.

An additional problem of clinical importance is how to assess whether the patient has a continuing need for the shunt. For instance, are there patients initially shunt dependent who, at a later date, develop adequate intrinsic CSF resorption and no longer require the shunt? At present there are no reliable means of answering this question short of tying off the shunt.

Although there are a number of methods of testing shunt function, none of them is completely satisfactory. The available techniques fall into three categories: (A) direct measurement of ventricular pressure and pneumoventriculography to assess ventricular size, (B) clearance of intraventricularly injected dyes and radionuclides, and (C) palpation of the flushing device of the shunt and measurement of pressure within the shunt system. These methods have been reviewed in detail by Di Chiro and Grove (1). In none is the shunt directly visualized; hence they provide only indirect evidence of shunt patency, and the site of shunt obstruction, if present, cannot be localized. Also, the flow of CSF through the shunt is not directly measured, and little information is provided about the patient's continuing need for his shunt.

Di Chiro and his associates have described a technique in which radioactive \( ^{99m}\text{TcO}_4^- \) was injected directly into the shunt reservoir and the shunt and parotid glands scanned (1). Parotid gland radioactivity was an indicator that the \( ^{99m}\text{TcO}_4^- \) was entering the systemic circulation. This method has the advantage of directly visualizing the shunt lumen as well as providing evidence of function. The purposes of our paper are to describe a simple technique designed to assess both CSF shunt patency and rate of CSF flow and to report on the initial results of its use in the management of children with hydrocephalus.

MATERIALS AND METHODS

Description of typical shunt. A variety of CSF shunts are in common use and they all consist of three basic components: a proximal (ventricular) limb, a central reservoir or pump (flushing device), and a distal (systemic) limb. The proximal limb consists of a catheter which is inserted into the lateral ventricle through the skull. The reservoir is located...
voir and distal limb were obtained. Additional images were obtained after pumping the shunt when there was failure of spontaneous clearance. All studies were correlated with the clinical findings, shunt palpation, and the operative findings in those patients who subsequently had shunt revision or shunt removal.

RESULTS

Normal studies. Twenty-five studies were done on subjects subsequently diagnosed as being shunt dependent with normally functioning shunts. Immediately after injection, the shunt reservoir and distal limb were well-visualized. Clearance of radioactivity from the shunt reservoir was spontaneous and continuous and usually described a single exponential function. In the normal shunt, the repeat image at the conclusion of the study confirmed that almost all radioactivity had been cleared from the shunt. The clearance $\text{T}_{1/2}$ averaged 3 min (range less than 1-7 min). Figure 1 shows an example of a normal study.

Abnormal studies. Fifteen of the studies that were judged to be abnormal were characterized by three different patterns: (A) failure of spontaneous clearance of radioactivity from the shunt ($\text{T}_{1/2} = \infty$) (ten cases), (B) marked reduction in rate of clearance of radioactivity with $\text{T}_{1/2}$ of 20 min or more (three cases), and (C) intermittent (non-continuous) clearance (two cases). Figure 2 shows

Patients. Forty-two studies were performed on children aged from 2 months to 11 years. All had previously documented shunt-dependent hydrocephalus and indwelling ventriculo-peritoneal or ventriculo-atrial shunts. Patients with and without clinically suspected shunt malfunction were studied. Both the Spitz-Holter (2) and the Pudenz (3) shunts were studied satisfactorily.

Method. With the patient supine, after aseptic preparation of the skin over the shunt reservoir, 25 $\mu$Ci of $^{99m}$TcO$_4^-$ in a volume less than 0.2 ml were injected percutaneously into the shunt reservoir. The small volume was chosen so that volume displacement per se would alter the shunt dynamics as little as possible. An immediate image was obtained with a gamma camera (30-sec exposure, 4,000 counts), and the clearance of radioactivity from the reservoir was monitored for 15 min with the head shielded except for the shunt reservoir. Counts were recorded digitally at 10-sec intervals. Removal of radioactivity from the shunt was expressed as a clearance half-time ($\text{T}_{1/2}$) in minutes. After the clearance measurement, repeat images of the reservoir and distal limb were obtained.
an example of an obstructed shunt. In Groups A and B obstruction was confirmed when subsequent pumping of the reservoir failed to clear additional radioactivity from the shunt. Both patients in Group C (intermittent clearance) were symptomatic and subsequently required shunt revision (Patients 14 and 15 in table). Of the 15 patients with abnormal studies, 9 had symptoms of increased intracranial pressure and were treated by shunt revision. In all cases, obstruction of the distal limb of the shunt was confirmed at surgery. The remaining six patients did not have signs of increased pressure although their shunts were not functioning. We believe these patients represent a group with "arrested" hydrocephalus who no longer need shunt drainage. One of these patients has subsequently had his shunt removed and has remained asymptomatic for over 9 months. The abnormal studies are summarized in Table 1 (Patients 1–15).

There were two additional studies (Patients 16 and 17 in table) in which the radionuclide test apparently gave misleading results. The first was an 8-month-old infant with increasing intracranial pressure in whom there was no evidence of shunt obstruction by palpation and whose radionuclide clearance also appeared normal. Direct measurement of the shunt revealed that its transmission pressure was relatively high (greater than 300 mm of water). Replacement of the distal limb with a lower pressure valve relieved the child’s symptoms and signs. Another patient had intermittent shunt obstruction related to head position. This was not detected by the radionuclide study since his head was not in the obstructing position when the study was performed. Subsequent revision of his shunt system alleviated this intermittent obstruction.

Correlation with shunt palpation. Ten of the 25 subjects who were determined to have normally functioning shunts and radionuclide clearance values were thought to have abnormal shunt function on the basis of palpation (excessively firm flushing device, slow refill of the flushing device, or failure of the flushing device to depress). In 6 of the 17 patients subsequently determined to have obstructed shunts, palpation of the shunt did not suggest any abnormality (see Table 1).

Dosimetry and complications. The radiation exposure from 25 μCi of 99mTcO₄⁻ as quite low, amounting to only 0.3 mrad to the total body and 2.5 mrad to the colon. To date we have observed no complications as a result of the procedure.

**COMMENT**

The radionuclide technique described is rapid, reasonably simple to perform, and has the following advantages: (A) The shunt is directly visualized, and patency or obstruction can be established by examination of the gamma camera images. (B) The clearance measurement allows a quantitative estimate of the flow of CSF through the shunt and provides a basis for comparison of serial studies in any given patient. (C) The test offers a means of identifying

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**TABLE 1. STUDIES ON PATIENTS WITH MALFUNCTIONING SHUNTS**

<table>
<thead>
<tr>
<th>Clinical Findings</th>
<th>Shunt Palpation</th>
<th>Images</th>
<th>T₁/₂ (min)</th>
<th>Followup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal</td>
<td>Obstruction ?</td>
<td>D.L.O.</td>
<td>0</td>
<td>SA</td>
</tr>
<tr>
<td>2. Normal</td>
<td>Normal</td>
<td>D.L.O.</td>
<td>40</td>
<td>SA</td>
</tr>
<tr>
<td>3. Normal</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>SA</td>
</tr>
<tr>
<td>5. Normal</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>SA (shunt removed)</td>
</tr>
<tr>
<td>6. Normal</td>
<td>Normal</td>
<td>D.L.O.</td>
<td>120</td>
<td>Revised</td>
</tr>
<tr>
<td>7. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>8. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>20</td>
<td>Revised</td>
</tr>
<tr>
<td>9. Symptomatic</td>
<td>Normal</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>10. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>11. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>12. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>13. Symptomatic</td>
<td>D.L.O.</td>
<td>D.L.O.</td>
<td>0</td>
<td>Revised</td>
</tr>
<tr>
<td>15. Symptomatic</td>
<td>Normal</td>
<td>Intermittent clearance</td>
<td>Revised</td>
<td></td>
</tr>
<tr>
<td>16. Symptomatic</td>
<td>Normal</td>
<td>Normal</td>
<td>1</td>
<td>Revised</td>
</tr>
<tr>
<td>17. Symptomatic</td>
<td>Normal</td>
<td>Normal</td>
<td>2</td>
<td>Revised (obstructed when head turned)</td>
</tr>
</tbody>
</table>

D.L.O.—Distal limb obstruction.
Revised—Shunt operated upon, obstruction confirmed, and shunt revised.
SA—Spontaneous arrest.
∞—Infinity.
those patients with arrested hydrocephalus in whom the shunt is no longer necessary. Such patients could then be considered for shunt removal.

Based on our initial experience, it seems apparent that the radionuclide test is a more accurate indicator of shunt patency and function than simple palpation of the shunt flushing device. Shunt palpation was misleading in 16 of 42 patients while the radionuclide technique was properly interpreted in all but two cases. Therefore, it may provide a simple and rapid means of confirming or refuting suggested abnormalities based on shunt palpation without resorting to hospitalization of the patient or the use of more invasive procedures.

Certain limitations are also apparent. Since pressure within the shunt system is not measured, it is possible that a normal clearance rate may be observed even though the patient cannot tolerate the pressure at which the shunt is functioning. We have observed one such case to date (see Patient 16 in table). Furthermore, obstruction proximal to the flushing device (ventricular end obstruction) would not be visualized by this method although there should be an absence of spontaneous clearance.

Theoretically, if the volume of the shunt reservoir were known and instantaneous mixing of the radionuclide in the reservoir occurred, it would be possible to calculate flow of CSF through the shunt, thus giving an absolute measure of the amount of CSF being handled by the shunt system (see Appendix). The data in our patients with normally functioning shunts suggest that CSF flow through the shunt is in the range from 0.05 to 0.25 ml/min. This observed flow rate is somewhat less than the reported “normal” CSF production rate of 0.35 ml/min (4). This difference is probably best explained by the fact that the shunt represents only one of several routes available for resorption of CSF.

The rate of clearance through the shunt must also be considered in the light of other factors which may influence flow of CSF through a shunt system. All of our studies were made with the patient supine and the effect of position on clearance is unknown. Other variables such as crying, straining, and status of patient’s hydration were not controlled.

CONCLUSIONS

Based on our initial experience, the following conclusions can be made: Shunt-dependent patients with functioning shunts show spontaneous and continuous clearance of radioactivity which usually is described by a single exponential function with a clearance half-time averaging 3 min. Failure of clearance of radioactivity from the shunt indicates either shunt obstruction or a patent but nonfunctioning shunt. Pumping should discriminate these two types of patterns. Intermittent clearance of radioactivity probably indicates a malfunction of the shunt.

The technique may permit identification of patients who no longer require a CSF shunt without the provocative test of occluding or removing the shunt system.

The test should always be carefully correlated with the clinical findings and other tests of shunt patency. When used in this context, it appears to have definite clinical usefulness as a diagnostic procedure in the management of hydrocephalus.

REFERENCES


APPENDIX

Absolute measurement of CSF flow through the shunt: The clearance appears to be a logarithmic function and may be expressed mathematically as:

\[ A = A_0 e^{-\lambda t} \]

where

\[ A = \text{activity at time } t \]
\[ A_0 = \text{activity at time } 0 \text{ (or } t - t) \]
\[ e = \text{base of natural logarithm} \]
\[ \lambda = \text{a constant for the function measured (in this case slope of the line).} \]

The slope (\( \lambda \)) is expressed per unit time and can be determined by the following equation:

\[ \frac{\lambda}{\text{min}} = \frac{0.693}{T_{1/2} \text{ (min)}} \]

Clearance \( (C_{\text{ref}}) \) of CSF can then be estimated as follows:

\[ C_{\text{ref}} = \frac{\lambda}{\text{min}} \times V, \]

where \( V = \text{volume of distribution.} \)

For example, assume a volume of distribution of 0.3 ml (volume of shunt reservoir) and clearance \( T_{1/2} \) of 3 min:

\[ \lambda = \frac{0.693}{T_{1/2}} = 0.23 \]

\[ C_{\text{ref}} = 0.23 \times V \]

\[ C_{\text{ref}} = 0.07 \text{ ml/min.} \]