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Cerebrospinal Shunt Flow in Adults: Radionuclide Quantitation with Emphasis on Patient Position[1]

Radionuclide quantitation of cerebrospinal fluid (CSF) flow through a ventricular shunt using a Cordis-Hakim valve was performed in 78 adults (138 studies). All remained supine for at least two hours before the study to avoid possible depletion of ventricular CSF. The absolute flow rate distinguished shunt adequacy from patency by defining flow of <0.1 ml/min. as abnormal. Measurements were performed with the patient first supine and then erect. When abnormal supine flow was the criterion of malfunction, all obstructions were detected but there were 6 false positives. When abnormal erect flow was considered, there were 5 false negatives. Abnormal flow in both supine and erect positions is a reliable indication of malfunction. The authors conclude that this technique is valuable for neurosurgical management of ventricular shunts.

Index terms: Cerebrospinal fluid, flow dynamics • Cerebrospinal fluid, radionuclide studies (Skull and contents, radionuclide examination, 1[0].1299) • Shunts, ventricular (Skull and contents, shunt, 1[0].451)

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CLINICAL deterioration may develop following placement of a ventricular cerebrospinal fluid (CSF) shunt inserted to relieve hydrocephalus. This may occur for a variety of reasons, of which shunt malfunction is one of the most common. Since such malfunctions can often be readily rectified, it would be desirable to have a safe, reliable, and simple method of assessing shunt patency and adequacy. Radionuclides have been widely used for this purpose since Bell's report of his studies of CSF shunt patency involving intrathecal injection of I-131-human serum albumin (1) in 1957. In 1966, Di Chiro and Grove injected Tc-99m-pertechnetate directly into the reservoir of the shunt system and performed radionuclide shuntography (2). Quantitation of CSF flow in the shunt was described in 1970 by de Rougement *et al.* using a non-imaging detector (3). Numerous reports have documented the value of radionuclide techniques in studying diversionary CSF shunts (4–10) as well as their possible pitfalls (11). Virtually all published work has involved pediatric patients.

While measurement of CSF shunt flow using a radiotracer is simple in principle, interpretation of the results depends on many factors, including intracerebral pressure, which in turn can be influenced by movement or coughing. The position of the patient before and during the examination can also affect the results and their interpretation (11). In the present work, quantitative results were obtained and efforts were made to ensure that the conditions of the flow measurements were as reproducible as possible.

MATERIALS AND METHODS

All non-pediatric patients receiving a Cordis-Hakim CSF shunt[2] in the last four years, which is to say since standardization of our procedure, were included in this study. A total of 78 patients 15 to 84 years of age (mean, 46 yr.) satisfied these conditions. There were 75 ventriculo-peritoneal and 63 ventriculo-cardiac shunts. Indications for shunt placement included idiopathic hydrocephalus with normal intracranial pressure in 47 patients, trauma in 10, aneurysmal hemorrhage in 8, a primary intracerebral tumor in 12, and cerebral metastases in 1. The patients were divided into two groups. In 84 studies there was relatively sudden deterioration (headaches, loss of memory, gait or sphincter problems, and possibly confusion), requiring that we establish whether the valve was permitting adequate flow of CSF. After clinical assessment and a plain radiograph of the shunt system, computed tomography (CT) and a radionuclide flow study were performed. In 54 studies, valve function was checked soon after the shunt was placed (or replaced) in order to confirm satisfactory function.

All patients lay supine for at least two hours before the examination. After the region around the valve (usually the temporal zone) had been prepared, the patient continued to remain supine while his head was strapped in position with the valve facing upward. A total of 100–200 μCi (3.7–7.4 MBq) of sterile Tc-99m-pertechnetate in less

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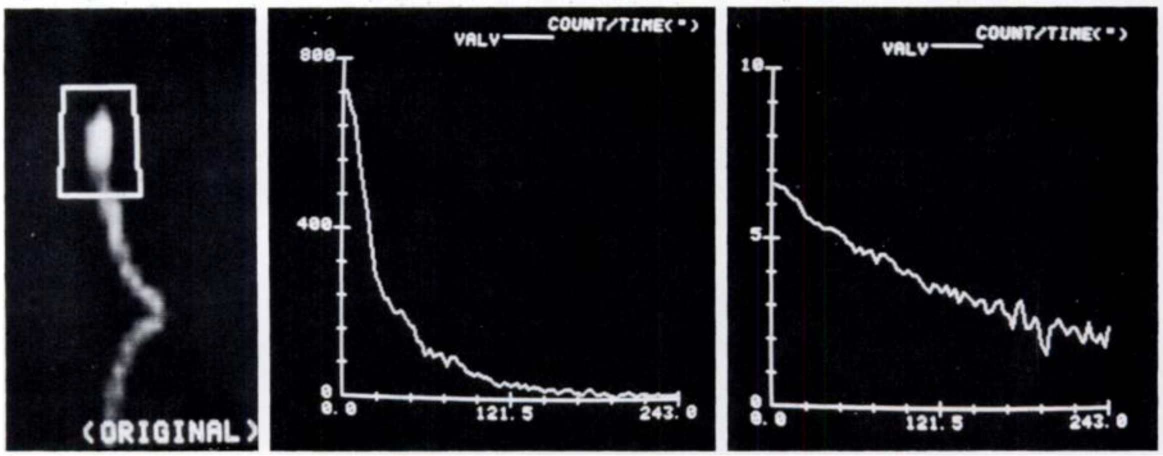
Figure 1



a. b. c.

a. Computer image obtained after injection of Tc-99m-pertechnetate into a Cordis-Hakim valve chamber in a functioning shunt. The valve chamber (inside the area of interest) and distal drainage are shown.
b and c. Normal tracer clearance curves, obtained with the computer from the area of interest drawn around the valve chamber. The X axis represents time and the Y axis represents activity, given in linear coordinates in **b** and in semilogarithmic coordinates in **c**. Note the monoexponential decay in **c**.

than 0.1 ml of isotonic saline was injected into the more distally situated valve chamber (6) using a needle 0.45 mm in external diameter, taking care to exclude all air from both syringe and needle. Immediately afterward, the head was placed beneath a large-field-of-view gamma camera interfaced to a computer and a series of 100 3-second images was recorded while simultaneously following the tracer on the oscilloscope. A time-activity curve was derived from the area of interest, including the valve chamber (Fig. 1), and shunt flow was calculated as described below. If flow was absent or insufficient in the supine position, the study was repeated with the patient sitting up, generally without a repeat injection. Orgogozo *et al.* have shown that activity in the Cordis-Hakim valve chamber decreases monoexponentially (Fig. 1), so that calculations of absolute flow based on the slope of the time-activity curve and the volume of the injected chamber are valid for flow rates in the range of 0.085–1.7 ml/min. (12). We calculated the flow rate in this manner, using a chamber volume of 0.2 ml for the adult model. While one would expect normal shunt flow to be on the order of 0.4–0.5 ml/min., which is the average rate of CSF production, this is modified by transventricular absorption of CSF and by the fact that blockage of CSF pathways is often incomplete. From previous studies (not included in this report), we empirically derived a lower limit of 0.1 ml/min. for normal shunt flow.

Table I: Measurements of Shunt Flow in 138 Studies

Clinical Indication	Results: Abnormal Supine Flow — Abnormal Erect Flow	Results: Abnormal Supine Flow — Normal Erect Flow	Results: Normal Supine Flow
Suspicion of shunt malfunction [n = 84]	59* (59)†	9 (5)	16 (2‡)
Valve placement or replacement [n = 54]		2 (0)	52 (0)
	59 (59)	11 (5)	
Total	70 (64)		68 (2)

* Two patients demonstrated intermittent flow.
† All figures in parentheses indicate those studies which indicated a need for revision. In each case the patient's clinical condition improved after surgery.
‡ In these 2 patients, intermittent obstruction was subsequently diagnosed following a repeat flow study.

RESULTS

Of the 84 studies requested because of recent deterioration in the patient's condition, flow was absent or insufficient in the supine position in 68 and adequate (>0.1 ml/min.) in 16 (Table I). Of the 68 studies which failed to show adequate flow, intermittent flow suggesting transient obstruction was observed in 2. In 59 of these 68 examinations, flow was also inadequate in the erect position, necessitating surgical revision; this resolved the problem in all 59 cases, resulting in significant clinical improvement. Of the 9 patients whose studies demonstrated normal flow in the erect position, 4 subsequently showed spontaneous and marked clinical improvement; since the CT scan remained unchanged, the shunt was not adjusted. Five patients continued to deteriorate, requiring surgical revision which resulted in improvement. Of these 5 patients, 3 demonstrated partial obstruction of the shunt, 1 exhibited excessive opening pressure of the valve, and 1 had insufficient ventricular pressure due to depletion of CSF *via* the shunt. Of the 16 studies which demonstrated adequate flow, 2 revealed continued deterioration, and a repeat CT scan led to a second flow study. This showed no progression of the radiotracer in the shunt system in either the supine or erect position. Intermittent obstruction at the cardiac end of a ventriculo-cardiac shunt was diagnosed and treated successfully by revision. Based on the results of CT and the flow study, the other 14 patients did not undergo surgery, since their poor clinical condition was attributed to other causes (including cerebral tumor, post-irradiation encephalopathy, or the reversible effect of a neuroleptic drug) or in 3 cases could not be explained.

Of the 54 shunts evaluated just after valve placement or surgical correction of malfunction in patients showing clinical improvement, normal flow was noted in the supine position in 52 (Table I). In the other 2, flow was normal only in the erect position. No further treatment was given, since clinical improvement was maintained and the patients subsequently did well.

In 2 cases the injection was found to be outside the valve chamber. Instead of the tracer-filled chamber, the image consisted of a central focus of activity surrounded by diffuse uptake over an area larger than the valve. On a repeat injection made shortly thereafter, the flow rate in the shunt could be derived by taking into account the background activity from the first injection. No complications, adverse reactions, or infections were reported after any of our studies.

DISCUSSION

Of the many methods described for assessing the function of a ventricular CSF shunt, the simplest is physical examination, which may be misleading. Other techniques include injection of contrast material (13), subarachnoid infusion tests (14), and more recently thermosensitive techniques (15) and ultrasound studies. The latter are used either to monitor ventricular size in children (16) or to measure flow in the shunt directly, based on the Doppler effect (17). Of the various techniques which involve injection of a radionuclide into the shunt, some do not measure flow directly but merely indicate that the tracer has traversed the shunt (18, 19); however, passage through the shunt system is usually followed with a gamma camera (4–11). Some authors measure a clearance rate (4, 9) or flow rate (6) through the shunt. Others also routinely measure CSF valve pressure in association with the radioisotope measurement in children (9), thereby providing information about the level of the obstruction. A combination of pressure and flow measurements appears to be less useful for adults, who usually do not have raised CSF pressure in the presence of shunt obstruction.

The series of 138 shunt flow studies reported here has certain characteristics which we feel are important for evaluation of ventricular CSF diversionary shunts. They were performed with a gamma camera, thereby permitting direct observation of the adequacy of the injection. Quantitative flow analysis allowed reduced flow to be defined as abnormal, thereby allowing distinction between adequacy and patency. The small amount of tracer injected into the valve would be unlikely to cause spurious results by disturbing shunt function. All patients had the same type of valve, which is relevant for the purpose of quantitation since different types of valves exhibit varying degrees of clearance for the same flow rate (6). All patients remained supine for at least two hours before the study, which has been our policy for the past four years, since in an earlier series of patients who were supine only during the actual study we encountered numerous false positives; and comparison with CT has led us to conclude that some of these erroneous results could be explained only by insufficient ventricular pressure due to depletion of CSF before the study in ambulatory or seated patients. Finally, whenever flow was insufficient or absent in the supine position, the measurements were repeated with the patient erect; this seems justified by the fact that 0.1 ml/min. as a lower limit of normal adult shunt flow may be too rigid, especially in the supine position. Indeed, flow in a ventricular diversionary shunt will differ from one patient to another depending on the amount of ventricular CSF available and particularly the degree of transventricular CSF absorption. In extreme cases, a patient will no longer require any flow in the shunt. Thus by establishing a fixed lower limit for flow, a deduction of shunt obstruction or malfunction can be incorrect and in fact the patient may be no longer shunt-dependent or have reduced dependency. Repetition of flow measurements in the erect position can reduce the likelihood of such a misinterpretation, since normal "erect flow" is then likely to be observed due to differences in hydrostatic pressure (20). Under these conditions, we observed no spurious shunt obstruction on the 59 occasions when measured flow was either absent or less than 0.1 ml/min. in both supine and erect positions, *i.e.*, all of these patients improved clinically after surgical revision. This seems to justify our lower limit of 0.1 ml/min. for flow normality, at least with regard to interpretation of lower values in both positions as abnormal.

In 11 studies, flow was normal only in the erect position. This phenomenon of "immediate erect patency," interpreted as a sign of adequate shunt function by French and Swanson (11), was observed in 4 studies performed to assess possible shunt malfunction and in 2 out of 54 studies involving patients who were doing well after shunt placement or replacement. However, in 5 cases surgical revision was necessary and disclosed the abnormalities mentioned earlier. Thus our data seem to indicate that one should be cautious in interpreting a combination of abnormal supine flow and normal erect flow. It is possible that flow rates greater than 0.1 ml/min. in the erect position are associated with impaired shunt function.

Overall, using abnormal supine flow (with or without normal erect flow) as a criterion of shunt obstruction, all obstructions (or malfunctions) were detected: however, there were 6 false positives, since clinical improvement and satisfactory CT findings ruled out the need for surgical revision. Thus the predictive value of this criterion for obstruction, derived by dividing 64 true positives by 70 abnormal supine results, was 91%. If the criterion of obstruction was abnormal flow in the erect position, there were no false positives, resulting in a predictive value of 100%; however, surgical revision was necessary in 5 patients and produced clinical improvement in each case, so that there were 5 false negatives out of 64 obstructions for an actual sensitivity of 92%.

It is more difficult to evaluate the accuracy of the flow study when flow is adequate in the supine position in a patient thought to have shunt malfunction, as was the case in 16 studies. Although "deceptive patency" has rarely been discussed, French and Swanson (11) observed it in 29% of their patients and noted that it must have been due to intermittent or partial obstruction or to incomplete knowledge of the extent of involvement, since disease could affect circulation of CSF. However, only 2 of our 16 patients were clearly recognized as having a shunt problem following diagnosis of intermittent obstruction on a repeat flow study. Three others may also have had an intermittent shunt problem. In the 11 remaining cases, as described earlier, there were additional causes which explained the poor clinical condition. These equivocal results make it difficult to determine the overall accuracy of our technique. When calculated as the sum of true positives and true negatives divided by the total number of cases, our method proved to be 92–94% accurate (depending on how our three most equivocal results were classified) regardless of the criterion of shunt malfunction, *i.e.* abnormal supine flow or abnormal erect flow. By comparison, Hayden *et al.* (9) reported an accuracy of 96%, Graham *et al.* (10) 93%, and French and Swanson (11) 70%. These last authors suggest that the significantly lower rate of accuracy in their study may have been due to the fact that they concentrated on patients whose shunt function remained uncertain even after clinical examination, CT, and plain radiography, who would therefore be more likely to have equivocal results after radionuclide studies as well. They also recognized that a patent shunt may not be equivalent to adequate flow. The deceptive patency they frequently observed might be partially overcome by quantitation of shunt flow. We feel that the rate of accuracy afforded by the radionuclide study can greatly facilitate neurosurgical management of ventricular diversions if shunt malfunction or obstruction is suspected. To be sure, it is impossible to say whether the patient is still shunt-dependent, and, if so, to what degree. However, the question of shunt dependency never arose in this series, probably because patients who no longer require a shunt are usually in satisfactory clinical condition.

CONCLUSION

In this report concerning a homogeneous series of adults, particular attention was paid to CSF hydrodynamics, especially the position of the patient before and during the shunt flow study. Abnormal supine flow is a very sensitive criterion of shunt malfunction, but it may lead to false-positive results. Abnormal erect flow is very specific as a criterion for obstruction, but it is not as sensitive as abnormal supine flow, since it can give false-negative results. From a practical point of view, our results show that absence of flow or a value <0.1 ml/min. in both supine and erect positions indicates shunt obstruction or malfunction. Abnormal supine flow associated with normal erect flow is more difficult to interpret. Finally, one should keep in mind the rare possibility of intermittent obstruction when flow is normal in a patient thought to have shunt malfunction, emphasizing the importance of considering the clinical findings, CT, and follow-up before making the final diagnosis.

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