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Evaluation of CSF Shunt Function: Value of Functional Examination with Contrast Material

Edward C. Benzel
Mansour Mirfakhraee
Theresa A. Hadden

Functional positive-contrast shuntography includes a patency check of both limbs of the shunt and the shunt valve by fluoroscopy following the injection of an iodinated contrast agent (anatomic shuntogram) and an assessment of the adequacy of ventricular fluid drainage under physiologic conditions by using serial CT scans to assess the rate of iodine dissipation from the ventricular system (physiologic shuntogram). To demonstrate its efficacy and utility, 82 functional shuntograms were obtained in 55 patients. Fifty-one of the 82 studies were abnormal. Of these, 22 demonstrated patency of both the proximal and distal limbs with an accompanying slow dissipation of contrast material after injection (21 of 22 patients were adults). Eighteen of these 22 patients improved following the reduction of shunt drainage pressure. In the case of frank shunt obstruction, the site of obstruction was delineated clearly in all 29 cases. Correlation of clinical outcome with test results confirmed the utility of this technique, especially when applied to the shunted adult hydrocephalic patient whose response to the shunt had been inadequate.

The technique described here allows the clinician to differentiate between physiologic and anatomic shunt failure and between shunt failure and normal shunt function. It also allows for precise localization of the shunt obstruction in anatomic shunt failure and for demonstration of physiologic shunt failure when shunt patency is demonstrated in the presence of the slow dissipation of intraventricular contrast medium.


The evaluation of postoperative shunt function is a challenging problem. The pathophysiology of CSF dynamics and its alteration by CSF shunting procedures are poorly understood. Complicating this is the fact that shunt failure may manifest itself in two ways: frank shunt obstruction and physiologic malfunction. A straightforward positive-contrast shuntogram should suffice for the evaluation of a frankly obstructed shunt. However, if a shunt is anatomically patent but not lowering the intraventricular pressure enough to ensure physiologic homeostasis (physiologic undershunting), a more comprehensive mechanism is needed for evaluating the shunt.

In order to evaluate both types of shunt failure, we have employed functional positive-contrast shuntography. This procedure includes a patency check of both limbs of the shunt (anatomic shuntogram) and an assessment of the adequacy of ventricular fluid drainage under physiologic conditions (physiologic shuntogram). The technique of functional shuntography has been outlined previously, specifically with respect to the Pudenz shunting system [1]. The linear relationship between iodine concentration and CT number (in Hounsfield units) has also been demonstrated [2]. The utility of this information when applied to the physiologic aspect of functional shuntography (i.e., the ability to quantitatively observe the rate of decline in iodine concentration following intraventricular injection) has been demonstrated [2]. However, clinical follow-up of a large number of patients was not included in the two previous reports [1, 2]. Therefore, in order to evaluate the
anatomic component and to evaluate and emphasize the dynamic (physiologic) component of functional positive-contrast shuntography for the assessment of shunt malfunction, we reviewed 82 shuntograms obtained in 55 patients over a 6-year period. The technique as applied to non-Pudenz systems is described also.

**Materials and Methods**

The study population comprised 55 patients who had previously undergone ventricular shunting procedures (either ventriculoperitoneal [40 patients] or ventriculopleural [15 patients]) and who were evaluated with functional positive-contrast shuntography at Louisiana State University Medical Center and the Veterans Administration Medical Center in Shreveport, LA, during a 6-year period ending December 31, 1987. All patients had been evaluated for suspected shunt failure. The suspicion of shunt failure was based on clinical criteria in all cases. Either the patient’s clinical condition deteriorated or did not improve following shunting. CT confirmation of the clinical suspicion was obviously necessary prior to shuntography. A total of 82 procedures were performed. Twenty patients underwent two or more studies. All but three of these 20 patients were children.

**Description of the Procedure**

Prior to the procedure, the patient is kept in the supine position for at least 1 hr. The patient is then placed on a fluoroscopy table in a supine position with a shoulder (ipsilateral to the shunt) elevated with a log roll. The region surrounding the reservoir is then shaved, cleansed, and draped. If a Pudenz-like shunting system has been inserted, the protocol described by Mirkhahrae et al. [1] is used.

If another type of shunting system has been placed (four patients in this series), the reservoir is punctured by a 25-gauge butterfly needle. If CSF does not return spontaneously following placement of the 25-gauge needle in the reservoir or after gentle aspiration with a syringe, the needle should be repositioned. If this is unsuccessful, less than 1 ml of water-soluble iodinated contrast medium (170–200 mg I/ml) may be injected. This is performed under fluoroscopic control. This allows for needle localization (necessary in only two patients). Care must be taken to avoid the injection of air into the system.

Metrizamide and iopamidol were the contrast agents used exclusively in this series. The last 12 patients injected in this series were injected with iopamidol; the remainder were injected with metrizamide.

Distal flow of the shunt is obstructed by applying pressure to the tubing distal to the reservoir (or by applying pressure to the distal reservoir in a multiple-reservoir system). Then, 1–1½ ml of the iodinated contrast agent is injected into the reservoir, allowing flow through the proximal limb of the shunt and into the ventricle. If this limb is patent, a jet of contrast material may be observed fluoroscopically [1]. If no flow is observed, a proximal limb obstruction exists.

In order to test distal limb function, the proximal limb of the shunt is obstructed by applying pressure to the shunt tubing proximal to the reservoir (or by applying pressure to the proximal reservoir in a two-reservoir system). Then, 2–3 ml of contrast agent is injected. This should opacify the distal tubing and spill into the absorptive cavity (i.e., peritoneal cavity) if the distal limb is patent. If no flow is observed, a distal obstruction is present.

The evaluation of other types of shunting systems requires an alteration of the shuntogram technique as indicated. The anatomy of the shunting system may be such that both the proximal and distal limbs cannot be checked for frank obstruction. This might occur, for example, when a valveless reservoir or no reservoir at all has been placed in the shunting system.

When frank patency of the shunt is observed by the above procedure, the ability of the shunt to drain adequately under physiologic conditions may be assessed. A cranial CT scan is obtained 0–4, 24, and possibly 48 hr following injection (a 48-hr CT scan was obtained in 18 of the 22 patients undergoing the dynamic aspect of the shuntogram). In this series, midventricular cuts only were obtained in patients who were believed to be especially sensitive to excessive radiation exposure owing to their young age or to the cumulative nature of previous radiographic procedures (five procedures in three patients were performed with midventricular cuts only). This limitation of the study did not interfere with the test accuracy in any of these patients.

In order to avoid pooling of contrast material in the ventricular system, the head must be gently shaken in both the supine position and especially the prone position. This should ensure adequate mixing of the contrast agent with the ventricular fluid for the initial scan (on subsequent scans, mixing is almost always complete). If two regions of interest are evaluated on the same scan, an average is obtained (the difference was not significant on the 24- and 48-hr scans in any study in this series).

The point of obstruction of a nonpatent shunt can be visualized by using the first part of the protocol and observing the location of the blockage of flow (anatomic shuntogram). Physiologic failure of the shunt in an undershunted patient may be evaluated by the dynamic aspect of the study with serial CT scans (physiologic shuntogram). If the CT number of the ventricular fluid at 24 hr is less than or equal to 18 H, the shunt is most likely functioning properly and/or the normal CSF pathways are draining adequately. If it is greater than 18 H, but less than or equal to 25 H, a repeat CT scan at 48 hr is indicated. If the CT number is greater than 25 H at 24 hr, neither the normal CSF pathways nor the shunting system is draining the ventricular fluid rapidly enough. These criteria were derived from previous clinical experience [1] and from midventricular CT numbers observed in 48 control patients [2].

**Results**

Thirty-one of the 82 studies did not demonstrate an abnormality of function. Fifty-one studies were abnormal. Of these 51 studies, 22 demonstrated patency of both the proximal and distal limbs of the shunt, while also demonstrating the slow dissipation of contrast material from the ventricular system (undershunting). Most cases of undershunting were observed in adults (21 of 22 studies). Of the 22 undershunted patients (22 studies, one study in each patient), 18 were diagnosed by demonstrating a CT number of greater than 18 H at 48 hr while only four patients were diagnosed with a 24-hr scan demonstrating a CT number greater than 25 H. In 25 studies, the CT number was between 18 and 25 H at 24 hr and a 48-hr scan was required. Seven 48-hr scans demonstrated a CT number less than or equal to 18 H. These studies did not result in a shunt revision. Of the 18 patients who had a CT number greater than 18 H at 48 hr, 14 improved. All four patients whose 24-hr CT scan demonstrated a CT number greater than 25 H improved following shunting.

Overall, a lowering of the shunt drainage pressure was performed in all 22 cases with an abnormal physiologic shuntogram. Eighteen patients improved following this procedure,
A patient with the syndrome of dementia, ataxia, and urinary incontinence underwent a routine CT study and positive-contrast CT cisternography with 5 ml of iopamidol (200 mg/l/ml) injected into the lumbar subarachnoid space. A 6-hr scan reflects a high concentration of ventricular contrast material. Band C, 24- and 48-hr scans show midventricular CT numbers to be 26 and 21 H, respectively. Since the contrast material did not dissipate from the lateral ventricles rapidly (≤18 H by 48 hr), a ventriculoperitoneal shunt (high-pressure Pudenz system) was placed. The patient did not respond well clinically. Therefore, functional positive-contrast shuntogram was obtained. Patency was noted fluoroscopically in both the proximal and distal limbs of the shunt.

D, CT scan 1 hr after intraventricular injection of 3 ml of iopamidol (200 mg/l/ml). E and F, Although the midventricular CT number at 24 hr was 23 H (E), the CT number at 48 hr was 15 H (F). Despite lack of desired clinical response, the shunt was judged to be effectively draining the ventricular fluid and a second operation was not performed.

Fig. 1.—A patient with the syndrome of dementia, ataxia, and urinary incontinence underwent a routine CT study and positive-contrast CT cisternography with 5 ml of iopamidol (200 mg/l/ml) injected into the lumbar subarachnoid space.

while three were unchanged (Fig. 1) and one worsened. The latter patient developed a subdural hematoma 2 weeks after surgery. He did not recover his baseline neurologic status following evacuation of the hematoma.

When frank obstruction was present (29 studies), its site was clearly delineated by the procedure. Most cases of frank shunt obstruction were located in the distal limb (17 of 29 studies) and most were noted in children (24 of 29 studies). No difference in outcome was noted regarding the type of shunt placed.

Twenty-nine normal shuntograms were obtained (in 27 patients). Seven of these required a 48-hr scan (CT number less than or equal to 18 H at 48 hr). Two procedures were unsuccessful in demonstrating abnormality secondary to an inability to successfully cannulate the ventricular reservoir. No complications (including contrast toxicity, cortical injury, shunt infection, and disruption of or injury to the shunt system) were associated with functional shuntography. No difference with respect to complications or efficacy was noted between the use of ionic (metrizamide) or nonionic (iopamidol) injection.
Functional positive-contrast shuntography was most useful in determining the absence of physiologic shunt patency in adults (21 of 22 patients with physiologic shunt failure were adults) and the location of a frank shunt obstruction in children (24 of 29 patients with frank shunt obstruction were children).

Discussion

The clinical problem of shunt malfunction has plagued neurosurgeons for decades. Both the diagnosis of obstruction, as well as the location of the obstruction, are of importance [3–6]. There are many cases in which the shunt may function properly under high pressures (such as under the pressure of the injected contrast agent during a shuntogram), but does not drain under physiologic conditions. This is an undershunting phenomenon and should be considered as a specific type of shunt failure (physiologic failure). This type of shunt malfunction, which perhaps has previously been underdiagnosed, was found to be relatively common in the adult population reported here. French and Swanson [7] likewise have documented the common occurrence of physiologic shunt malfunction, but it is rare in the pediatric population. A low-pressure shunt is usually placed in the pediatric hydrocephalic patient in order to compensate for high brain parenchymal compliance. These patients are much more likely to have complications associated with overshunting (such as the slit ventricle syndrome or subdural effusions) than those associated with undershunting (physiologic shunt failure). On the other hand, a higher-pressure shunting system is usually placed in adults in order to avoid the complications of overshunting (such as formation of subdural hematomas). Adult patients, therefore, susceptible to the complication of inadequate ventricular fluid drainage (an undershunting problem). This in turn may result in a less than optimal response to a shunting procedure, for which French and Swanson [7] coined the term “deceptive patency,” implying a nonobstructive physiologic failure of a shunt. They observed this problem in 40% of their patients who were evaluated by radionuclide shuntography.

The problem of undershunting is complicated further by the requirement of large hydrocephalic ventricles for a lower drainage pressure than that required by smaller ventricles. This is according to the law of La Place [8]. A fine line, therefore, exists between overshunting (with associated complications such as subdural hematoma, subdural hygroma, and the slit ventricle syndrome) and undershunting (inadequate drainage resulting in the failure of effective ventricular pressure reduction). In some patients this fine line may present a situation that is impossible to respond to effectively and safely.

The pressure within the shunt system during injection of the contrast agent at the time of shuntography is higher than that during normal ventricular drainage. Patency of a shunt system, as demonstrated by such an injection, might not reflect a true evaluation of ventricular fluid flow under normal conditions. However, the observation of appropriate dissipation of the contrast agent on serial CT scans, combined with routine shuntography, offers a complete evaluation of a shunt system. This is illustrated here with respect to positive-contrast cisternography and shuntography (Fig. 1). Others have used 3- and 9-min radiographs of the reservoir after the injection of the positive contrast agent [1, 9]. The dye should be radiographically imperceptible 9 min after injection into a shunt system that flows properly. If contrast material within the reservoir is observed on the 9-min film, the shunt may not be draining properly. This implies the presence of an undershunting phenomenon. However, it might also indicate that the ventricular system is draining by another pathway (i.e., normal CSF pathways) and that contrast stasis in the reservoir is a manifestation of a shunting system that was placed in a ventricular system that was adequately draining through existing pathways. This might be the case, for example, in a patient with Alzheimer disease who harbors large ventricles. This test, therefore, may lead to erroneous conclusions.

Positive-contrast CT cisternography, ventriculography, and shuntography are proven useful tools [1, 2, 10]. The utility of these tools can be increased by quantifying the test. The CT number (in Hounsfield units) can be used to assess the intraventricular iodine concentration following injection of the contrast agent (Fig. 1) [2]. The CT density of the normal ventricular system is 18 H or less [2]. Dissipation of intraventricular contrast material to an insignificant level (a midventricular CT number less than or equal to 18 H) within the first 24–48 hr following injection, therefore, is indicative of a physiologically normal system. Any excess intraventricular contrast material indicates a situation of apparent undershunting.

French and Swanson [7] believed that patients undergoing functional shuntography should be left in the horizontal position for a short period prior to the injection of a contrast agent. It was conjectured that the intraventricular pressure should be allowed to equilibrate before a study of CSF dynamics could be performed accurately. The delayed examination of the shunt by the protocol presented herein should minimize this potential inaccuracy. This precaution was undertaken despite the fact that there is a substantial delay from the time of injection to the time of the first CT scan in order to ensure maximum test reproducibility and accuracy.

Various other techniques have been used to evaluate shunt patency. These include subarachnoid infusion tests [11], sonography [12], temperature change evaluations [13], and radionuclide imaging [7, 14–16]. Each of these techniques has drawbacks and none is able to completely evaluate a shunt for both physiologic and frank anatomic patency. Specific advantages of functional positive-contrast shuntography over other dynamic techniques, such as radionuclide cisternography, are related to its ability to quantify the extent of intraventricular contrast retention and to the clear definition of the point of shunt dysfunction in the case of frank shunt obstruction. The extent of intraventricular contrast retention is an indicator of the degree of obstruction of flow of ventricular fluid, either through conventional anatomic pathways or through the existing shunt system.

It is not known whether or not the CT number changes described here are affected by the type of contrast material used (ionic or nonionic). The type of contrast agent used, however, appears to not affect the efficacy or risks of the procedure.
In summary, anatomic localization of the point of shunt obstruction allows one to tailor the procedure of shunt revision. This aspect of the procedure is most helpful in children and occasionally in adults. The physiologic evaluation of shunt function allows one to differentiate between the undershunted patient (who may improve clinically following shunt pressure reduction) and true nonresponders. This aspect of the shuntogram procedure is used almost exclusively in shunted hydrocephalic adult patients. It allows for a true physiologic evaluation of a shunt and may accurately predict the phenomenon of physiologic undershunting in patients who otherwise would have been inadequately treated.

REFERENCES
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