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Evaluation of Shunt Malfunction Using Shunt Site Reservoir

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Key Words
Shunt malfunction · Shunt site reservoir

Abstract

Objective: To determine the usefulness of a separate reservoir placed at the site of the shunt in evaluation of shunt malfunction. ***Methods and Materials:*** A ventricular catheter was placed alongside the proximal catheter of the shunt and connected to a subgaleal reservoir in 17 patients, in 9 a double-lumen catheter with integrated reservoir and in 13 patients a dual catheter with a double-port reservoir was used. At presentation of suspected shunt malfunction, a standard shunt function evaluation using shunt tap, CT scan or shunt injection was performed, and subsequently, the pressure from the tap of the reservoir was obtained. ***Results:*** Thirty-three patients presented with symptoms of malfunction at an interval of 2.3 ± 3 months (range 2–429 days). The pretest probability of shunt malfunction in this population was 73%. Posttest probability of shunt malfunction was 82.5% with standard evaluation and improved to 100% by the separate reservoir tap pressure measurement. In 4 patients in whom the shunt tap was dry, shunt infection was diagnosed prior to revision using CSF obtained at the reservoir tap. In 5 patients with proximal malfunction and bradycardia, the reservoir tap allowed early ventricular decompression. ***Conclusion:*** This study shows that a reservoir placed at the site of the shunt remains patient even when the shunt malfunctions, suggesting that flow rather than catheter position is important in proximal malfunction. It is superior to shunt tap for detection of shunt malfunction and infection, and it allows early ventricular decompression in a sick patient awaiting surgery for shunt revision.

Introduction

Cost-effective evaluation of shunt malfunction is a perplexing problem. The shunt tap test has been effectively used to screen patients with suspected shunt malfunction [1]. A complete radiological examination including a shunt survey, shunt injection test and CT scan may cost well over a thousand dollars. Each of these tests, however, has drawbacks. In a patient with partial proximal obstruction or inadequately functioning shunt and slit ventricles; the shunt tap may show low pressure and some flow, the shunt injection may clear in presence of some flow, the CT scan may not show ventricular enlargement, and yet the intracranial pressure may be high. Intracranial pressure may be the only true guide to shunt function in these patients. Presence of a reservoir not in line with the shunt may be more helpful in estimating the pressure and evaluating shunt function based on the *hypothesis* that in

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absence of flow, the reservoir ventricular catheter will not attract debris or choroid plexus and is unlikely to get obstructed.

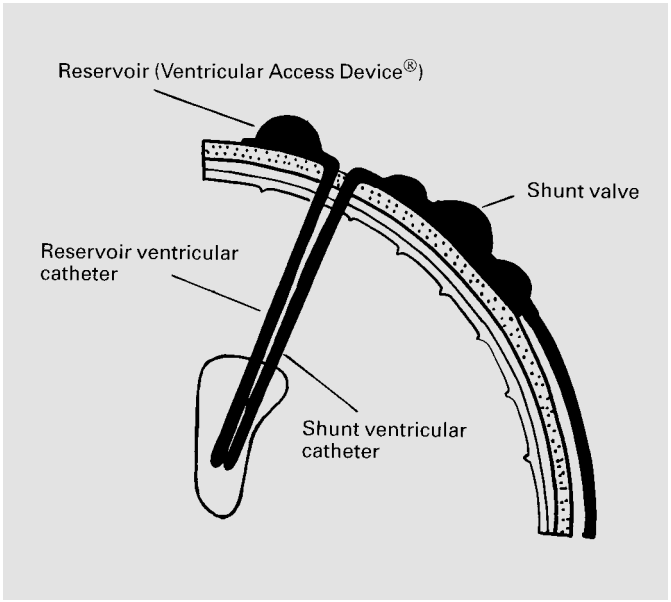
Material and Methods

In 17 patients at the time of proximal revision, two catheters were placed in the ventricle. One was connected to the valve completing the shunt revision, and the other was connected to the PS Medical Ventricular Access Device® (reservoir) which was placed in the subgaleal space opposite the shunt valve. Alternatively, in 9 patients a double-lumen catheter with integrated reservoir and in 13 patients a dual catheter with double-port reservoir (fig. 1) was implanted. Patients were followed until the time they presented with a suspicion of shunt malfunction. A standard evaluation was performed that included shunt tap, shunt injection or CT scan, as was considered necessary by the treating surgeon. A shunt was considered to function if the shunt tap had normal opening pressure with spontaneous flow, a good drip rate and good distal run off [1]. If the patient continued to be symptomatic during the course of observation despite suggestion of a functioning shunt on shunt tap, a CT scan or a shunt injection was obtained depending upon the past experience with the patient's ventricular size. If there was no flow on shunt tap and difficult aspiration, the shunt was considered to malfunction, and operative intervention was sought. In these instances, a CT scan was performed only to obtain information with regard to the position of the catheter. The Ventricular Access Device was tapped after the above or in the OR just prior to exploration of the shunt, or if the patient was in extremis, and no fluid could be accessed from the shunt tap.

For statistical analysis, likelihood ratio (LR) was used to compare the diagnostic potential of the standard evaluation versus assessment of pressure from the reservoir tap. LR is the likelihood that a given test would be expected to be positive in a patient with a shunt malfunction (sensitivity) compared to the likelihood that the same test would be positive in a patient without the shunt malfunction (1-specificity). A high LR expresses the usefulness of the test in separating out the patients with and those without the disease. Estimate of the prevalence of shunt malfunction in this population was used to calculate the pretest odds and pretest probability. The product of LR to the pretest odds was then used to calculate the posttest probability of shunt malfunction with each test (Appendix).

Results

The mean age of patients included in this study was 8.2 ± 7 years (range, 1 month to 30 years), and the majority had hydrocephalus secondary to intraventricular hemorrhage of prematurity. All patients were chronically shunted with an average of 6.7 ± 5 shunt revisions. The mean interval since last revision was 5.5 ± 10 months. Excluding the 6 who had an interval of more than 6 months, the mean interval dropped to 39 ± 44 days. Nine patients had presented with a shunt infection and



a

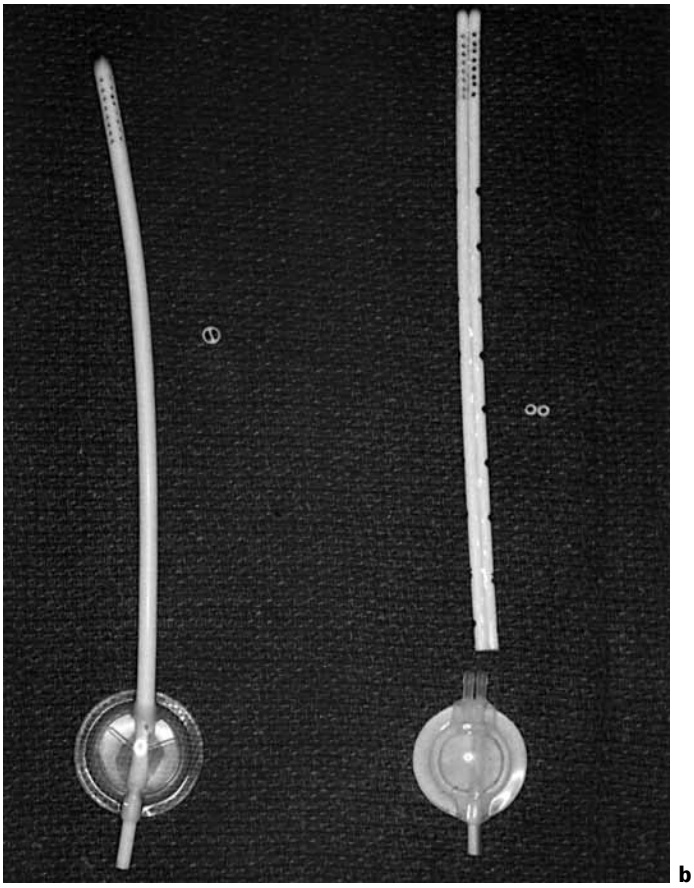


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Fig. 1. a Separate ventricular reservoir. **b** Double-lumen catheter with integrated reservoir (left) and dual catheter with double-port reservoir (right).

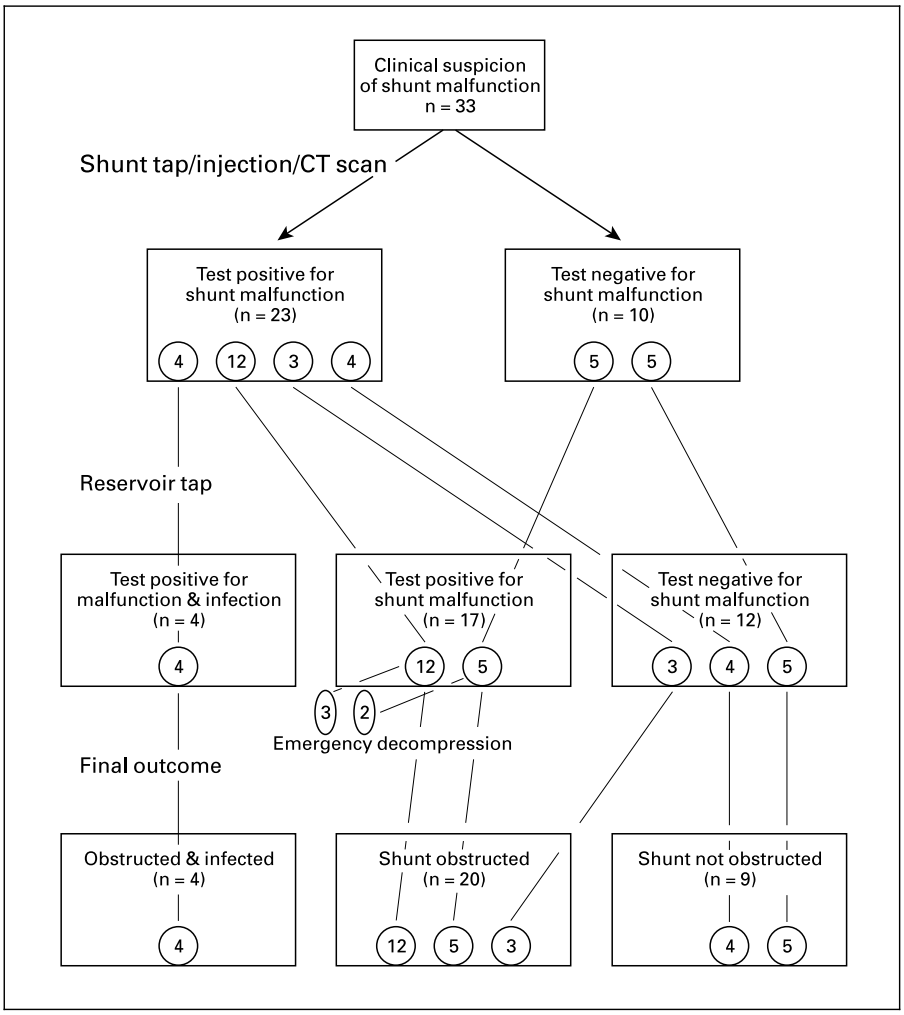

Fig. 2. Results of standard evaluation and reservoir tap.

were treated with external ventriculostomy and antibiotics prior to placement of the reservoir.

A separate ventricular reservoir (Ventricular Access Device, Medtronics®) was implanted at the site of the shunt in 17 patients, in 9 a double-lumen catheter (Medtronics) with integrated reservoir and in 13 patients a dual catheter (Radionics®) with dual-port reservoir was used (fig. 1).

At follow-up, 33 patients presented for suspected malfunction at an interval of 2.3 ± 3 months range 3–429 days). In the final analysis (fig. 2), 20 patients had an obstructed shunt, 4 patients had a shunt infection along with an obstructed shunt and 9 had no malfunction. A test was considered positive if it suggested malfunction. The standard evaluation was positive for malfunction in 23 patients with a false positive in 4 patients. It was negative for malfunction in 10 patients with 5 false negatives. It could not diagnose shunt infection in 4 patients in whom the shunt tap was dry, but the diagnosis was made preoperatively from the CSF obtained at the reservoir tap.

Tap of the reservoir (table 1) on the ventricular access device was positive for malfunction in 21 patients, and it correctly diagnosed malfunction in the 5 patients that were false negative on the standard evaluation. There were no false-positive diagnoses on the reservoir tap. Reservoir tap test was negative for malfunction in 12 patients, of whom 4 had been false positive on the standard evaluation. There were 3 false-negative diagnoses. The catheter was intraparenchymal in 1, the reservoir port was defective in the other with complete occlusion of the port (defect in manufacturing), and in the third patient, increased pressure from an isolated ventricle caused the ventricular walls to collapse over the reservoir catheter and partially obstruct it. In this particular pa-

tient, low pressure was obtained on tapping the reservoir with poor flow. However, after the isolated ventricle was decompressed at surgery, spontaneous flow was obtained from the reservoir catheter, suggesting that occlusion was temporary and secondary to collapse of the ventricular wall from raised pressure in the isolated ventricle. The mean opening pressure on tapping the reservoir in patients who were eventually found to have an obstructed shunt was 35.8 cm CSF compared to 6.8 cm CSF in patients with functioning shunt.

All patients had a patent Ventricular Access Device® catheter. The lumen of the double-lumen or dual catheter that was linked to the reservoir remained patent and free of ingrowth of choroid plexus despite occlusion of the lumen linked to the shunt (fig. 3). In 5 patients with no flow on shunt tap who had presented to the ER in extremis with bradycardia, tap of the reservoir with ventricular decompression had averted a potential serious outcome.

In the studied population, the pretest probability of a patient presenting with a suspicion of shunt malfunction actually having an obstructed shunt was 73%. This was increased to 82.5% by shunt tap/shunt injection/CT scan, but to 100% by the reservoir tap. The pretest probability that the shunt may be adequately functioning was 27%. This was increased to 49% by a negative standard evaluation and to 75% by a negative reservoir tap test, suggesting no malfunction.

Table 1. Results tabulated in 2 × 2 format

	Shunt obstructed	Shunt not obstructed	Total
Reservoir tap[1]			
Test positive (suggesting malfunction)	21	0	21
Test negative (suggesting no malfunction)	3	9	12
Total	24	9	33
Shunt tap/CT scan/shunt injection[2]			
Test positive (suggesting malfunction)	19	4	23
Test negative (suggesting no malfunction)	5	5	10
Total	24	9	33

[1] LR = ∞, posttest probability malfn. = 100%; posttest probability of no malfn. = 75%.
[2] LR = 1.75, posttest probability malfn. = 82.5%; posttest probability of no malfn. = 49%.

Discussion

Rickham's reservoir has been implanted at a frontal site in addition to the placement of the shunt in patients with hydrocephalus to facilitate the diagnosis of shunt malfunction and at the same time decompress the ventricle in the event of acute shunt malfunction [2–4]. Direct tap of the reservoir has been effectively used to estimate the pressure and hence the shunt functions. This method has, however, not gained popularity amongst surgeons since it requires an additional incision and placement of extra hardware potentially increasing the risk of infection. Further, in the event of shunt infection, it warrants removal of the reservoir system through a second incision to completely eradicate infection.

Our method, using a shunt system in which a separate ventricular reservoir or a two-lumen catheter is placed at the same site, would minimize some of the disadvantages of the previously tried method. The results suggest that a reservoir ventricular catheter remains patent at the time when a ventricular catheter present in close proximity gets obstructed, irrespective of the implantation site. This confirms a previous observation that a proximal catheter gets obstructed only if there is flow through it, forcing the choroid plexus to grow towards the inlet holes and cause obstruction [5]. It also supports the observation that the shunt implantation site is not a significant factor in repeated shunt failures [6], and probably the flow pattern through the proximal catheter may be more critical in this regard. Further, from this small series of patients it is quite apparent that a reservoir tap is superior to the assessment of shunt function obtained from shunt tap and CT scan together. Finally, the patent reservoir offers an ideal opportunity to decompress the ventricles in an acutely sick patient with proximal malfunction in whom ventricle decompression cannot be achieved by tapping the shunt. The reservoir also offers an opportunity to obtain CSF specimen to diagnose infection in a patient with obstructed proximal shunt catheter.

With an average of 6 prior revisions, it was not surprising that 24/39 shunts malfunctioned within an interval of 2.3 ± 3 months. The shunt survival curves for this population were comparable to the published survival curves in multiply revised patients [6] (fig. 4), suggesting that presence of a second catheter or use of a double-lumen or dual catheter did not adversely affect the shunt survival. The short shunt survival that was expected in this population of multiply revised patients has certainly limited the

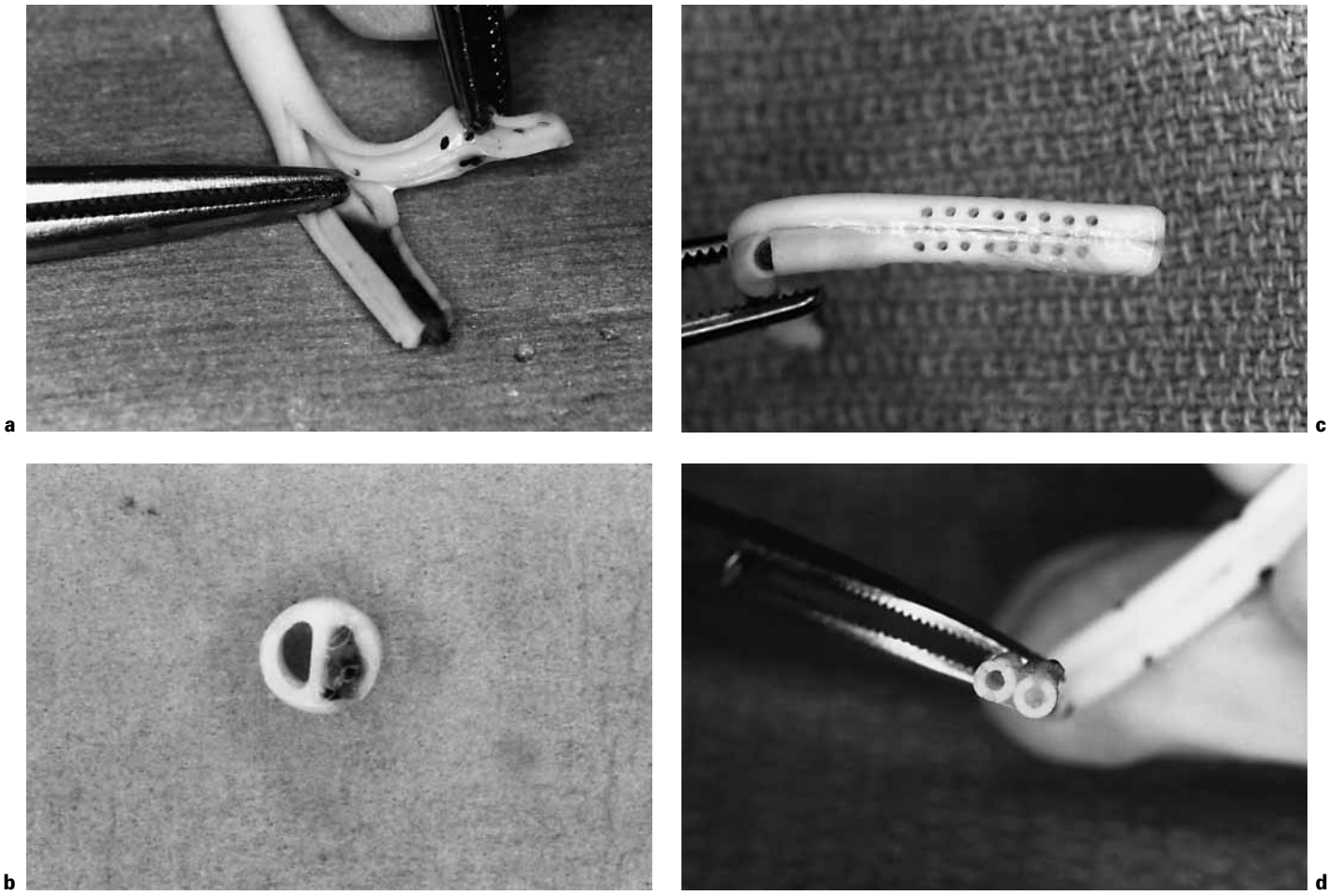

Fig. 3. This figure shows patent reservoir catheter and obstructed ventricular catheter on longitudinal (**a**) and cross-section (**b**) of double-lumen catheter, and longitudinal (**c**) and cross-section (**d**) of dual catheter.

evaluation of this technique over a long follow-up period. However, in none of the patients did the reservoir catheter get obstructed at the same time or prior to the obstruction of the ventricular catheter and continued to be functional even in a patient who had presented as late as 14 months after implantation. Four patients who had presented after 6 months and 2 after 3 months had a functioning reservoir catheter despite obstruction of the ventricular catheter. Averaging out with the cases that were revised within 1 month has resulted in the mean interval to presentation that appears short.

There was bias towards previously infected patients with 9 patients (9/39, 23%) that were treated for shunt infection prior to implantation of the reservoir system. This bias reflects the availability of these patients for a new shunt system implantation after treatment of infection and entry into the study rather than any preselection. It also resulted in a slightly higher rate of infection (4/39, 10%) than the normal expected 4–8% reported in the literature for shunts placed in newly diagnosed patients.

There is a general reluctance to perform shunt tap for evaluation of a patient with shunt malfunction based upon risk of introduction of infection into the shunt system. This has, however, not been substantiated by our experience [7] or that of others [8]. Alternative noninvasive methods using shunt-based in-line telemetric pressure transducers have also become popular recently [9]. However, results from these transducers may be difficult to interpret in the presence of a partial proximal obstruction [9] and may require complex waveform analysis to exact information regarding shunt function in such a situation. Further, a baseline waveform pattern should be

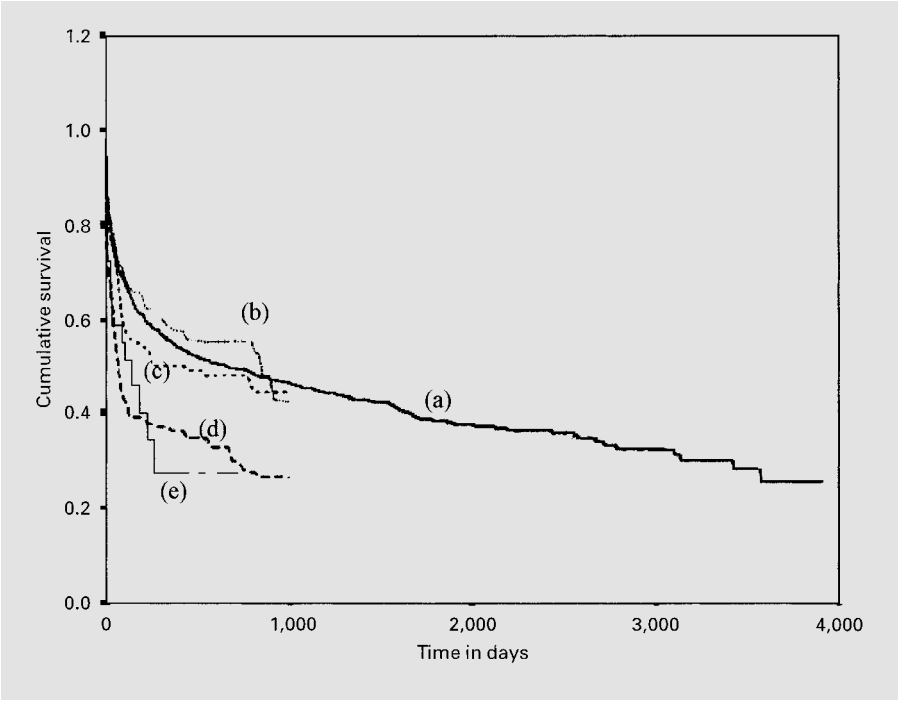

Fig. 4. Survival curve of patients in the present study (e, mean of 6.7 (SD 5) revisions) superimposed on survival curves of multiply revised patients: one revision (a), two revisions (b), three revisions (c) four revisions (d) [6].

available for comparison. Inability to obtain CSF specimen and the expense involved does not make them superior to our method. A telemetric sensor connected to a second catheter at the same site as the shunt may be a better guide to the intracranial pressure and shunt function based on the hypothesis tested in this study. Changes in the pulsatility index on transcranial Doppler are not widely accepted because of the relative expertise required in interpreting the data [10]. Use of noninvasive methods to assess shunt flow is not practical in an ER setting. The marked variation in the shunt flow in the patients with otherwise optimally working shunts makes results from these studies difficult to interpret.

Traditionally, shunts have been designed with a valve in the proximal or the distal part of the reservoir connected to the ventricular catheter proximally and the peritoneal or the atrial catheter distally. The purpose of the reservoir is to be able to 'flush' the system proximally and distally; diagnose proximal or distal malfunction by pumping or tapping the reservoir; and to obtain CSF for diagnosis of shunt infection. Shunt pumping has been shown to be an inefficient way of diagnosing shunt failure. Extrapolating the data from the paper by Piatt et al. [11], the shunt-pumping test has an LR of 1 (sensitivity 19%, specificity 81%, see Appendix for definition), which means that it does not improve upon the pretest odds at all. The interval pumping test described by the same authors has a marginally improved the LR to 1.3 [12]. The shunt tap measures the intrashunt pressure and not the intracranial pressure. In presence of a partial proximal obstruction, the tap pressure may be fallaciously low. Ability to aspirate fluid is accurate in only 40%. This test as described previously has a LR of 19 [1]. The inability to obtain CSF for the diagnosis of a malfunction or for decompressing the ventricle remains the drawbacks of this procedure.

Shunt flow studies using clearance of radio-opaque contrast media or radionuclide tracers are reported to have a high sensitivity of 90–99% [13–17]. French and Swanson [15], in their series of 78 radionuclide imaging shuntograms, reported a high rate of deceptive patency (40%). This is attributed to intermittent obstruction; partial obstruction and 'incomplete anatomical information' related to the presence of isolated cystic areas or isolated ventricles. Vernet et al. [16] also reported a misdiagnosis rate of 25% with radionuclide imaging. While absence of ventricular reflux may be a highly reliable scintigraphic feature in proximal obstruction, clearance studies were particularly deceptive in proximal malfunction with 7 of their 12 patients with proximal obstruction demonstrating a normal clearance curve. More recent data by May et al. [17] also reiterates the limitation of shuntography in

presence of partially obstructed proximal catheters and partially working shunt, because in these cases the elevated intracranial pressure may overcome partially working parts of the shunt and suggest adequate patency on flow studies.

The CSF infusion [18–20] into the shunt or through a lumbar puncture has been described to estimate the outflow resistance in the shunt system. The nature of these tests makes its utility in the pediatric population and in an emergency setting rather limited. Lumbar infusion to estimate the outflow resistance is able to clearly separate out patients who have either very high or very low clinical probability of shunt malfunction but may be of limited help in patients with clinically equivocal diagnosis [20]. The pressure measured at lumbar puncture may be a simple and reliable test of shunt function. However, patients who have obstructed hydrocephalus or a chronically shunted communicating hydrocephalus in whom secondary aqueductal stenosis may have developed, there is a definite risk to a lumbar puncture evaluation. Further it is not repeatable, patient friendly or recommended in myelomeningocele population.

Reliance on only the clinical presentation may be particularly deceptive in the pediatric population in whom confounding illness may present with headache, vomiting, lethargy or fever. Of the patients referred to a pediatric neurosurgical service for suspected shunt blockage, the diagnosis is correct only in a minority of the patients. While parents are very sensitive to the changes in the child behavior and often correctly predict a malfunctioning shunt, in the prospective analysis by Watkins et al. [21], the parent, general physicians and hospital referrals were correct in less than half of the instances. There is clearly a need for a reliable, repeatable, reproducible test for assessment of shunt function. The preliminary results of our method are certainly encouraging.

Appendix

LR is the likelihood that a given test would be expected in a patient with the target disorder compared to the likelihood that the same result would be expected in a patient without the target disorder. Unlike positive predictive value, it does not depend upon the composition of the population from which is estimated or which it is applied to.

LR = sensitivity/(1 – specificity); prevalence = number of patients with the disorder/total number of patients; pretest odds = prevalence/(1 – prevalence); pretest probability = pretest odds/(1 + pretest odds); posttest odds = pretest odds × LR; posttest probability = posttest odds/(1 + posttest odds).

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