Treatment of hydrocephalus in adults by placement of an open ventricular shunt

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Object. Ventricular shunt placement is the neurosurgical procedure most frequently associated with complications. Over the years, it has been a growing concern that the performance of most shunting devices does not conform to physiological parameters. An open ventriculoperitoneal (VP) bypass with a peritoneal catheter for which the cross-sectional internal diameter was 0.51 mm as a distinctive element for flow resistance was evaluated for use in the treatment of adult patients with hydrocephalus.

Methods. During a 2-year period, open shunts were surgically implanted in 54 adults with hydrocephalus; conventional shunts were implanted in 80 matched controls. Periodic evaluations were performed using neuroimaging studies and measures of clinical status. All patients were followed from 12 to 36 months, 18.5 ± 4 months for patients with the open shunt and 19.1 ± 8.1 months for controls (mean ± standard deviation). The device continued to function in 50 patients with the open shunt (93%) and in 49 controls (61%; p < 0.001). The Evans index in patients with the open shunt was 0.33 ± 0.09 throughout the follow up. No cases of infection, overdrainage, or slit ventricles were observed; the index in controls was 0.28 ± 0.08; 60% of them developed slit ventricles. During the follow-up period occlusion occurred in four patients with the open shunt (7%) and in 31 controls (39%; p < 0.001).

Conclusions. The daily cerebrospinal fluid (CSF) drainage through the open VP shunt is close to 500 ml of uninhibited flow propelled by the hydrokinetic force generated by the combination of ventricular pressure and siphon effect. It complies with hydrokinetic parameters imposed by a bypass connection between the ventricular and peritoneal cavities as well as with the physiological archetypal continuous flow and drainage according to CSF production. The open shunt is simple, inexpensive, and an effective treatment for hydrocephalus in adults.

KEY WORDS • hydrocephalus • cerebrospinal fluid • ventricular pressure • ventriculoperitoneal shunt • siphon effect

The most frequently encountered complications of ventricular shunting for treatment of hydrocephalus are overdrainage, occlusion, and infection. Dozens of shunts have been designed, and their basic performance relies on parameters of IVP. However, complications associated with ventricular shunts are legion. The limited effectiveness of most shunting devices stands in sharp contrast with their increasingly complex mechanisms, with the correspondingly impressive costs, and with the substantial monetary demands on patients because of long-term dysfunction.

We have postulated that a valve mechanism might not be adequate for the treatment of hydrocephalus. The CSF is static when the valve is closed, fostering adherence to its walls of proteins or cells that may occlude the catheter. The valve is also frequently a site of bacterial colonization and there are no stable physiological parameters to serve as references for optimal opening and closure. The hydrostatic pressure of CSF in humans in the supine posture is homogeneously distributed anywhere within the cerebrospinal axis, a mean of 15 cm H₂O. In contrast, in the erect posture there is a pressure gradient toward the medullary cone; at the lumbar area the pressure is approximately 50 cm H₂O, which gradually decreases to zero at the lateral ventricles. Because any VP shunt is a parallel track to the cerebrospinal axis, an ideal

Abbreviations used in this paper: CSF = cerebrospinal fluid; ID = inner diameter; IVP = intraventricular pressure; NPH = normal-pressure hydrocephalus; UHF = unit of hydrokinetic force; VP = ventriculoperitoneal.
pressed in centimeters (Fig. 1). At long-term follow-up, the UHFs were calculated as the sum of gravity effect (38 UHF), resulting in a flow rate of 25.5 ml/hour through the shunt.

The theoretical foundations and methods for studying the performance of the open VP shunt in the laboratory have been reported previously. Our study used an open VP shunt with continuous flow, which, when subjected to variations of IVP and siphon effect (Fig. 1), could achieve a drainage capacity close to 500 ml/day. The ID of the peritoneal catheter was selected as the instrument for flow resistance. The theoretical foundations and methods for studying the performance of the open VP shunt in the laboratory have been reported previously. Initially, guided by our experimental studies, an open VP shunt was implanted in 52 adult patients with hydrocephalus. Its peculiar attribute was a 100-cm-long peritoneal catheter made of tyon, which had been fabricated specifically with a cross-sectional ID of 0.41 mm, and in which the flow capacity was 0.37 ml/UHF/hr.

Fig. 1. Graph showing data generated in the laboratory that illustrate the flow characteristics, in units of hydrokinetic force, of the open VP shunt equipped with a 0.51-mm ID peritoneal catheter under varying intraventricular and hydrostatic pressure combinations meant to represent the spectrum between the supine and the upright posture. For instance, if the patient’s posture is reclined approximately 45° or he would have 8 cm H2O of IVP plus 30 cm of gravity effect (38 UHF), resulting in a flow rate of 25.5 ml/hour through the shunt.

mm, which raised the flow capacity to 0.52 ml/UHF/hr. An open, uncontrolled pilot study was then conducted in 12 patients, whose results were better after a mean follow-up of 11 ± 3 months, but still two of them (17%) developed NPH, which was the only postsurgical complication (unpublished results). Based on the findings in these two studies we concluded that a further increase in ID to 0.51 mm, which yielded a flow capacity of 0.67 ml/UHF/hr, would achieve optimal efficacy; its hydrokinetic performance in the laboratory is shown in Fig. 1.

Clinical Material and Methods

Patient Population

In an observational, controlled, prospective study conducted in 54 adult patients with hydrocephalus, open VP shunts were surgically implanted between March 1997 and March 1999. The study group consisted of 23 women and 31 men whose mean age was 39 ± 15 years (range 16–77 years). The ± values represent the standard deviation throughout the text. After detailed explanation, informed consent was obtained from the patients or their legal guardians. Control volunteers were 80 patients with hydrocephalus (37 women and 43 men), in whom either a Pudenz type (56 cases, 70%) or Biomed shunt (24 cases, 30%) was implanted during the same period. The mean age of patients in the control group was 38 ± 15 years (range 16–75 years). The study was approved by our Institutional Research Board. For all patients it was their first shunt placement. Patients were randomly allocated alternately to either group because the protocol was designed for a case-control study; all participants were selected with the same clinical criterion of chronic or subacute hydrocephalus, and those who presented with a life-threatening condition as the underlying cause of hydrocephalus (for example, malignant tumors or active brain hemorrhage) were excluded. In all cases, ambulatory activity was expected after shunt placement. Those patients who were initially allocated to receive the open VP shunt but did not accept it were included in the control group. No significant differences in age, sex, or primary diagnosis were found between cases and controls. The origin of the hydrocephalus is shown in Table 1. The diagnosis was made on the basis of the clinical picture and confirmed on imaging studies.

Shunt Placement Procedure

Shunt insertion was made through a precoronal burr hole on the right side by the traditional method for VP shunting; the peritoneal catheter of the open VP shunt was inserted without shortening it. After surgery, patients who had received the open VP shunt were placed in a 45° reclined bed to facilitate the siphoning effect of the shunt, and the day after surgery ambulation was started. All patients remained in the hospital for a mean of 4 days, and at discharge the patients and their relatives were instructed on the importance of keeping an upright posture (sitting or standing) for considerable periods of time to promote optimal functioning of the open VP shunt. Follow-up neuroimaging studies were obtained the day after the shunt procedure and repeated approximately every 3 months; the
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Evans index, as the ratio of frontal horn distance to maximal biparietal diameter (normal 0.30 ± 3.0), was measured in each subsequent study. The possibility of shunt dysfunction was considered when surgical revision was necessary, either for shunt removal or for flow restoration. Statistical comparisons were made using the Student t-test for independent values.

Open VP Shunt

The hydrokinetic performance of the open VP shunt relies on the peritoneal catheter (ID 0.51 mm, length 100 cm), which is directly connected to a conventional ventricular catheter. Both the IVP and the siphoning effect drive a similar flow per UHF through the open VP shunt; in the case of IVP the unit of measure is centimeters of an H2O column, and in the case of siphoning effect the unit of measure is centimeters of vertical distance, in relation to the center of gravity, between the ventricular and peritoneal cavities (the mean straight distance between the floor of the lateral ventricles and the middle of the peritoneum in adults is 50 ± 5 cm; Fig. 1). Although independent of each other, the IVP and the siphoning effect have an inverse relationship that was used to advantage: in the upright posture the main hydrokinetic force acting on the open VP shunt is the siphoning effect, whereas the IVP is absent; when the patient is supine the main hydrokinetic force is the IVP, whereas the siphoning effect is absent (Fig. 1). The patient’s posture changes according to daily activities and resting habits; therefore, the amount of flow differs constantly. However, the expected performance of the open VP shunt is tied to constant flow; the upper drainage capacity would not exceed the daily amount of CSF production, which is approximately 300 ml.

In the laboratory, we simulated all drainage circumstances through the open VP shunt according to physiological changes of IVP (or injection pressure) between 0 and 20 UHF and siphoning effect (or gravity force) between 0 and 50 UHF, as described earlier. Briefly, in a 240-ml closed chamber simulating the ventricular cavity, an input catheter was connected to a pump injecting saline solution at an internal pressure of between 0 cm and 20 cm of an H2O column, which comprises the physiological spectrum of IVP. The output catheter was the open VP shunt connected to a graduated receptacle that simulated the peritoneal space. The closed chamber could be displaced upward; the vertical distance to produce a siphoning effect between the closed chamber and the receptacle ranged between 0 cm and 50 cm from the proximal to the distal end of the open VP shunt, which comprises the normal spectrum of the siphoning effect in adults. The amount of flow collected during 24 hours for any given combination of pressure within the chamber and the siphoning effect was recorded (Fig. 1).

In our experimental model, if the patient was upright for 16 hours and supine for 8 hours, the daily drainage through the open VP shunt would be calculated as follows, according to data from Fig. 1: (16 × 33.5) + (8 × 13.4) = 643 ml, exceeding by 143 ml the ideal of 500 ml. However, these postures are attained only for brief moments; most of the time the posture varies between the extremes; thus, the actual daily flow would be close to the expected 500 ml. Also, if the drainage momentarily exceeds the production rate, the IVP would change to negative values, diminishing the flow.

<table>
<thead>
<tr>
<th>Disease</th>
<th>No. W/ Open Shunt (%)</th>
<th>No. of Controls W/ Shunts (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>neurocysticercosis</td>
<td>27 (50)</td>
<td>4</td>
</tr>
<tr>
<td>benign neoplasm</td>
<td>22 (41)</td>
<td>0</td>
</tr>
<tr>
<td>posthemorrhage</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>chronic meningitis</td>
<td>2 (4)</td>
<td>0</td>
</tr>
<tr>
<td>NPH</td>
<td>3 (5)</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>54 (100)</td>
<td>4 (7)</td>
</tr>
</tbody>
</table>

Results

The open VP shunt remained functional in 50 patients (93%) after 18.5 ± 4 months, with a follow-up period of 12 to 36 months. In control volunteers, the shunt remained functional in 49 patients (61%) after 19.1 ± 8.1 months, with a follow-up of 12 to 36 months (p < 0.001). All four patients with shunt dysfunction in the open VP shunt group had neurocysticercosis; of the 31 control volunteers with shunt dysfunction, 24 (78%) had neurocysticercosis, five (16%) had a benign neoplasm, one (3%) had posthemorrhage hydrocephalus, and one (3%) had sequelae of meningeval tuberculosis. The time to shunt dysfunction post surgery was 5 ± 4.8 months in patients with open VP shunts and 9.5 ± 7 months in controls.

The presurgery Evans index was 0.47 ± 5 in all patients in the study (range 0.35–0.60); no differences were seen between patients with open VP shunts and controls. The Evans index at follow-up review in patients with the open VP shunt was 0.34 ± 3.5 days after surgery, and remained 0.33 ± 0.09 throughout the observation period. The long-term Evans index in control volunteers was 0.28 ± 0.08; it was considerably lower than that in patients with the open VP shunt because in 60% of them the slit ventricle syndrome developed.

Symptoms attributable to hydrocephalus improved the day after surgery in all patients with open VP shunts. This improvement was remarkable after ambulatory activity was started and was maintained in subsequent clinical assessments, except in the four patients in whom intracranial hypertension recurred due to shunt occlusion. In these patients the open VP shunts were removed and replaced with conventional shunts.

During the follow-up period one patient in the open VP shunt group, a 25-year-old woman developed a gastrointestinal infection 5 months after shunt placement. She remained in bed for 5 days, and ultimately the infection was cured but she developed signs of intracranial hypertension. A new computerized tomography scan demonstrated hydrocephalus, her bed was reclined 45°, and the next day ambulatory activity started. A repeated computerized tomography scan demonstrated remission of hydrocephalus with a notable reduction of ventricle size. We concluded
that multiple days of absence of the siphoning effect on the open VP shunt provoked CSF retention that was alleviated as soon as she resumed the upright posture. The patient became asymptomatic and was discharged 48 hours after admission, and she remained asymptomatic until the end of the observation period.

**Discussion**

The open VP shunts with continuous flow were adequate for treatment of hydrocephalus in adults. In all patients the ventricular cavities were evident on neuroimaging studies even after long periods (Fig. 2). No case of slit ventricles, overdrainage, or infection was seen. In some instances (approximately 10% of cases) the ventricle size remained slightly larger (mean Evans index 0.35). However, transependymal edema was not observed on magnetic resonance imaging, the subarachnoid spaces were apparent, and no signs of NPH developed, which is evidence of adequate brain compliance. In this regard it has been asserted that the presence of small ventricles after shunting strongly suggest ventricular tautness and that the ideal ventricle size is greater than 0.33 on the Evans index.43 Occlusion or insufficient flow were the only reasons for surgical revision, which was significantly less likely in patients with open VP shunts than in controls, 7% compared with 39%, respectively (p < 0.001). Coincidentally, all four cases of open VP shunt dysfunction involved neurocysticercosis, the form of chronic hydrocephalus in adults that is most difficult to treat because of chronic inflammation in CSF.41,42,43

The open VP shunt works according to hydrodynamic parameters that differ greatly from those in all VP shunts currently in use. A logical concern about the open VP shunt, which has such a small ID, is the risk of occlusion. The primary argument would be that if the most commonly used shunts, with a peritoneal catheter of 2- or 3-mm ID, are so prone to occlusion, a catheter with a 0.51-mm ID would increase such a possibility. However, in our study the occlusion rate for open VP shunts was significantly lower than for conventional shunts. This apparent discrepancy is explained by several factors: the uninterrupted flow of the open VP shunt prevents stasis of CSF, and promotes continuous transit of cells and proteins that might otherwise adhere to the walls of the catheter during periods of stagnation, inducing occlusion.41,42 Also, at any given moment the amount of flow is small, consisting almost exclusively of newly produced ventricular CSF, in which the content of cells and proteins is low, approximately half that in spinal CSF.20,48 This difference becomes drastic in inflammatory disorders of the subarachnoid space, like neurocysticercosis, in which the cell and protein contents of ventricular CSF are frequently within normal limits, whereas in spinal CSF they are greatly increased.41

The continual flow of minimal amounts of CSF, close to the rate of production prevents a common occurrence in shunts with valves: the sudden passage of large amounts of fluid that may invert the CSF circulation toward the shunt, leading to retrograde passage of spinal CSF into the ventricles and into the shunting device, which facilitates occlusion.41,42,43 Because of the small ID of the peritoneal catheter, the suction of fluid created by the siphoning effect on the open VP shunt is constant but discrete and localized, and is insufficient to produce upward motion of CSF from lower cavities to the ventricles; the remnant CSF continues its transit to the subarachnoid space, maintaining the natural pressure gradient toward the medullary cone and preserving any residual capacity for absorption at the subarachnoid space. Because of the high incidence of overdrainage in currently available VP shunts, a frequent complication is the shunt-dependence syndrome, in which the natural mechanisms of CSF absorption are precluded.

The open VP shunt has only one connection, that between the peritoneal and ventricular catheters, with no additional obstacles to CSF passage. This is in contrast with the complicated tracks of devices with valves that impose mechanical barriers to the CSF transit and foster occlusion or bacterial colonization.20,43,44,45 In this way, the
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basic function of the open VP shunt is as an unsophisticated bypass rather than a complex device engineered for flow control. Under physiological conditions the CSF transit is constant, with no interruptions. The open VP shunt imitates this function, whereas shunts with valves change it by periodic interruption of CSF circulation, which generates an unphysiological on/off phenomenon of accumulation and depletion.\(^{1,3,16}\)

Open, plain catheters for ventricular fluid shunting have been used previously, particularly before the development of complex shunting devices, and in institutions that could not afford the high costs of the latter.\(^{2,3,30,48}\) However, a catheter with a very precise ID calculated to achieve a defined amount of uninterrupted flow propelled by the combination of IVP and siphoning effect has not been used. The 0.51-mm ID of the peritoneal catheter used in this study, although rather simple in design, is of paramount importance to achieve CSF drainage according to its production rate, because even minimal variations produce drastic changes. This is illustrated in the catheters that we have tested clinically; the initial catheter had a 0.41-mm ID,\(^{20}\) when the ID was increased 0.05 mm, the amount of flow through the open VP shunt rose more than 40%; when an additional 0.05 mm was added to reach 0.51 mm ID (the one used in this study), the amount of flow rose 81% in comparison with the first catheter and 29% compared with the second. These three catheters were identical in appearance; only cross-sectional examination with the microscope revealed the differences in diameter.

The hydrokinetic forces acting on the flow through the open VP shunt have contrasting differences; the siphoning effect at its upper limit (50 UHF in the erect posture) is a propulsive force more than twice as intense as the IVP at its upper physiological limit (20 UHF in the supine posture), and it lasts twice as long throughout the day when comparing the erect with the supine posture (approximately 16 hours compared with 8 hours, respectively). Consequently, approximately two thirds of the driving energy behind the CSF fluid is obtained from the siphoning effect; the other third is obtained from the IVP (Fig. 1). Because the siphoning effect is an unavoidable feature of any VP shunt system in humans,\(^{3,12,42,52,53,55}\) and because this effect at supine and increasing body angles in conventional VP shunts is increased to 50 cm, as is the case in adult patients staying in an erect posture.\(^{40}\) Other experimental studies have shown similar results.\(^{22,21}\) Based on these findings, various failings of conventional VP shunts become evident: 1) the CSF drainage is intermittent, with long periods of stasis; 2) a valve mechanism set to open at an IVP of 10 cm H\(_2\)O is overturned just by 10 cm of siphoning effect; 3) the valve is useful only while the patient is supine and the siphoning effect is absent; and 4) the antisiphoning device is not physiologically useful because, if effective, when the patient is upright the device induces an increase of IVP to more than 10 cm H\(_2\)O to open the valve; because the normal IVP in this posture is usually negative, the antisiphoning device promotes intraventricular hypertension in the upright posture. Recent clinical observations support this point.\(^{5,21,22,23}\)

Endogenous mechanisms involved in the homeostasis of intracranial pressure\(^{19,22,29,52,53}\) seem to compensate for differences between individuals with the open VP shunt. The 100-cm length of the peritoneal catheter fits most adults; no differences in outcome were related to stature. Nevertheless, because the siphoning effect is considerably inferior in patients with very short stature, the flow can be augmented approximately 10% for every 10 cm that the peritoneal catheter is shortened. For example, if the catheter is cut to 80 cm the flow increases 20%. If cut to 60 cm it increases 40%. In these cases, the UHF produced by the siphoning effect would decrease but the flow per UHF would be higher because of a decrease in resistance due to the shorter length of the catheter. Therefore, the drainage equilibrium can be fairly maintained for a universal shunt. This feature might be important for shunts implanted in children or adolescents. Also, although in this study the 100-cm length of the peritoneal catheter was not cut in any patient, at follow up it is possible to shorten the catheter at its peritoneal end by a simple operation in those patients with evidence of insufficient drainage. The absence of infections or slit ventricles in the group with open VP shunts contradicts most traditional reports, which quote 5 to 10% complication rates; it seems that the maintenance of continuous flow prevents the fluid stasis that favors bacterial growth. Also, the drainage capacity of the open VP shunt dependent on CSF production rather than on IVP prevents overdrainage.

Additional advantages of the open VP shunt are its low cost and the lack of metal components that could produce artifacts on neuroimaging studies. The open VP shunt is a continuous bypass without interfering appliances, and a reservoir was not used to maintain maximal simplicity; in agreement with other authors we are not convinced of its usefulness.\(^{21}\) Because of its design and basic performance, the open VP shunt system is not adequate for treatment of hydrocephalus in newborns. In a pilot study we implanted three shunts in newborns with congenital hydrocephalus. Despite continuous patency of the shunt, hydrocephalus continued, and all three devices were withdrawn and substituted by a conventional VP shunt. Theoretically, the open VP shunt could be useful in children once they start to walk and the siphoning effect is conspicuous. However, our experience has been limited to adults.

Conclusions

An open shunt with a peritoneal catheter in which the cross-sectional ID measures precisely 0.51 mm is adequate for the treatment of hydrocephalus in adults. This

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rather simple device complies with most hydrokinetic parameters imposed by a bypass connection between the ventricular and peritoneal cavities in humans; it also complies with the physiological ideal of continuous CSF flow and drainage according to CSF production. The occlusion rate was significantly lower than that with conventional valve shunts, and infection and overdrainage were absent. In all cases the ventricular cavities and the subarachnoid spaces of the brain convexity were apparent on long-term neuroimaging studies as evidence of appropriate brain compliance.

References
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