Several pathological entities in the posterior fossa may induce severe hydrocephalus; although the shunt procedure is rather simple, secondary complications frequently happen with all currently used shunt devices. Common complications occur either immediately (ascending transtentorial herniation) or long after surgical excision of the lesion, when the CSF circulation has been restored (slit ventricle syndrome, subdural hematoma, infection, and so forth).1,3,12,17

An alternative to the placement of an internal shunt device, such as a third ventriculostomy or external drainage, is considered in most centers to be the procedure of choice.4,7,15,21,22 In several patients, removal of the obstructing lesion restores CSF circulation. In cases of life-threatening hydrocephalus, however, placement of a shunt with gradual decompression is indicated12,17,21 because external drainage18,20,22 carries the risk of sudden decompression or bacterial contamination.1,20 Additionally, many of these patients continue to require long-term treatment for hydrocephalus due to tumor growth and recurrence of hydrocephalus.5,20

The authors have developed a VP CF shunt whose drainage capacity has been designed in accordance with the constant rate of CSF production in humans (~0.35 ml/minute), rather than in accordance with the parameters of IVP, as is the case with most shunt devices currently available.26,27 The main advantage of the CF shunt is that drainage is minimal but uninterrupted, preventing rapid decompression. Overdrainage, the most conspicuous complication of all other shunt devices, is prevented when the CF shunt is used.26,27 Imaging studies in patients whose hydrocephalus has been treated with the CF shunt demonstrate a gradual reduction in the ventricular enlargement, culminating in a normal-sized ventricle a few days after surgery.26 In more than 200 patients treated with the CF shunt, we have not observed a single case of slit ventricles. These findings support the idea that the CF shunt could be particularly useful in patients with hydrocephalus caused by lesions of the posterior fossa.

CONCLUSIONS: The CF shunt had a low rate of dysfunction and an absence of complications caused by overdrainage, which were frequently associated with the control shunts. The hydrodynamic properties of the CF shunt make it effective, even in severe cases of hydrocephalus caused by lesions of the posterior fossa.

KEY WORDS • continuous-flow shunt • ventriculoperitoneal shunt • hydrocephalus • intraventricular pressure • posterior fossa tumor • shunt complication

Clinical Material and Methods

Patient Population

This was a prospective, controlled trial that included all
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patients with severe hydrocephalus caused by a lesion of the posterior fossa who were treated at the National Institute of Neurology and Neurosurgery of Mexico between November 1997 and November 2001. At the time of the analysis, November 2003, the patients had participated in a minimal follow-up review of 2 years. Patient ages ranged between 18 and 71 years (mean 36 ± 15 years). All patients had intracranial hypertension, papilledema, headache, vomiting, and somnolence. Imaging studies (computerized tomography scanning and/or magnetic resonance imaging) demonstrated the hydrocephalus. All patients were considered to be in urgent need of decompression due to imminent risks associated with severe intracranial hypertension. In all cases the primary cause of the hydrocephalus was considered obstructive; patients in whom the primary cause was a compromised resorption, such as those with chronic arachnoiditis or meningeal fibrosis, were not included. Patients with complications due to surgical treatment of the primary lesion and those facing the risk of imminent death due to the natural course of their primary disease were excluded. In this way, the study was limited to those patients in whom ambulatory activity and a fair neurological status allowed follow up of the hydrocephalus and shunt performance. No patient had been surgically treated for hydrocephalus previously. Once selected for shunt placement, patients were assigned to the CF shunt group or the control shunt group in consecutive alternating fashion. The Institutional Review Division. Statistical comparisons were made using the Student t-test for independent values and the chi-square test modified by Mantel and Haenszel.

Shunt Characteristics and Surgical Techniques

Ventriculoperitoneal shunts were surgically implanted in an identical manner in all patients: the ventricular catheter was inserted into the lateral ventricle through a parietal trephination, and the peritoneal catheter was guided subcutaneously to the upper abdominal area and inserted into the peritoneal cavity. The performance of the CF shunt depends on a 100-cm-long peritoneal catheter made of Tygon with a precise cross-sectional internal diameter of 0.51 mm, which is connected to a regular ventricular catheter. The main advantage of the CF shunt lies in the thin inner diameter of the peritoneal catheter; it offers flow resistance but secures a continuous CSF flow and thus prevents fluid stagnation, which in shunts with valves leads to accumulation of cellular detritus and obstruction. Because the upper limit of calculated drainage is close to the physiological parameter of CSF production (0.35 ml/minute), overdrainage is also prevented. Previous reports have focused on the CF shunt’s performance in the laboratory during simulations of intracranial CSF hydrodynamics and drainage capacity under different conditions of ventricular pressure, fluid density, gravity (siphon) effect, and catheter length as well as the long-term results of this treatment in adult patients with hydrocephalus. The surgical method for the placement of the CF shunt is identical to that used for all commonly used VP shunt devices. The CF shunt was made in the bioengineering laboratory at our institute. The distinctive characteristic of the CF shunt is its lack of a valve; this allows a continuous flow, which under most physiological combinations of IVP and the siphoning effect drains approximately 0.35 ml/minute of CSF for a maximal total daily drain of approximately 500 ml, which is the mean daily production of CSF in humans. When the physiological values of the aforementioned parameters are surpassed, the flow increases or diminishes but maintains its continuous flow. For instance, when the IVP increases to values higher than 200 mm H2O, the injection pressure is raised and the CSF flow is augmented until the pressure descends to normal values (100–200 mm H2O); in contrast, when the IVP descends to values below 100 mm H2O, the flow decreases; but again, the uninterrupted drainage continues until the pressure reaches normal values. Also, when the patient is standing, normal IVP lowers but the siphon effect increases the flow. This effect disappears when the patient lies down. In either case the velocity and amount of drainage complies with physiological parameters to maintain an uninterrupted flow. Although this shunt is rather unsophisticated, the precise internal diameter along the peritoneal catheter (0.51 mm) is so critical that, due to the feature of continuous flow, minimal variations in internal diameter (larger or smaller) drastically change the amount of drainage, causing either under- or overdrainage. In a controlled study on the long-term performance of the CF shunts in adult patients with hydrocephalus, shunt revision or change was necessary in 7% of patients, in contrast with 39% of controls. Immediately after surgery all patients in whom a CF shunt had been implanted were maintained in bed at a 45° inclination to promote the gravity effect on the shunt, facilitating the drainage of excessive CSF. Patients assigned to the control group received a VP shunt with a valve (Medronic Pudenz–Schulte Medical, Goleta, CA) that corresponded to one of the most widely used shunt devices for the treatment of hydrocephalus, and whose mechanisms, performance, and potential complications have been previously described.

Results

In the present study 491 patients with lesions in the posterior fossa were treated at the National Institute of Neurology and Neurosurgery of Mexico; the etiopathogenesis of these patients’ lesions is described in Table 1. In 310 patients there was only discrete neuroimaging data of ventricular enlargement; these patients were treated surgically and given radio- or chemotherapy. In 98 patients a significant ventricular enlargement was found without evidence of severe cranial hypertension; hydrocephalus in this subgroup was managed by intraoperative ventriculostomy. Only 36 of these patients required placement of a permanent VP shunt for persistent hydrocephalus due to incomplete resection or obliteration of the ventriculostomy. Ninety-four additional patients needed immediate decompression of hydrocephalus due to severe intracranial hypertension (nasea, vomiting, papilledema, stupor, or coma). During the follow-up review of patients who received
Clinical signs of overdrainage developed in patients with CF shunts; chi-square test; Fig. 1). When compared with patients with CF shunts, 27 were excluded before 1 year because of severe neurological damage or death; none of these complications was a consequence of hydrocephalus or shunt failure. A total of 103 patients were included in this study; 50 had been treated with the CF shunt and 53 with a shunt with a valve. The mean follow-up period in these patients was 7.8 ± 5.4 months. Fifteen patients in the CF shunt group had been withdrawn in a previous report; at that time the median follow-up period was 14 ± 3 months.

Severe postoperative complications attributable to the shunting procedure occurred in four patients (8%) in the control group. Two of these patients had a transtentorial herniation and two others had a parenchymal or epidural hematoma. These complications were believed to be caused by sudden decompression. Two of the patients died as a direct consequence of the complication: one death was caused by an ascending transtentorial herniation and the other by a parenchymal hematoma. Another patient succumbed to an irreversible vegetative coma. No similar complication due to the shunting procedure was observed in patients who had received the CF shunt. Neuroimaging studies obtained between 1 and 3 days after surgery demonstrated the collapse of ventricular cavities in most patients in the control group; in contrast, images obtained in patients with the CF shunt demonstrated a significant diminution of the ventricles, but ventricle cavities were apparent in all cases. Differences in the sizes of ventricles after surgery in patients with the CF shunt and controls have been previously reported.

At the end of the observation period, the shunt device had been withdrawn in four patients (8%) with the CF shunt: in two because of infection and in the other two because of underdrainage with persistence of hydrocephalus, although in both of the latter cases the shunt was still patent at the time of withdrawal. In contrast, at the end of the observation period, the shunt device had been withdrawn in 33 patients (62%) in the control group: in 16 because of occlusion, 10 because of overdrainage, five because of infection, and two because of death (p < 0.003 when compared with patients with CF shunts; chi-square test; Fig. 1). Clinical signs of overdrainage developed in 18 patients (34%) in the control group. It was necessary to withdraw the shunt for this reason in eight patients, four of whom had slit ventricle syndrome with at least three episodes of severe symptoms of cranial hypotension. In four additional cases, subdural hematoma developed, requiring surgical drainage; the shunt was withdrawn in two patients and replaced by a CF shunt in two patients. These complications were not seen in patients who originally had received a CF shunt (Table 2). At the end of the study 46 shunt devices (92%) remained functional in the CF shunt group and 20 (38%) remained functional in the control group (p < 0.0001; chi-square test).

The pathological condition that induced the highest rate of shunt complications was papilloma of the choroid plexus at the fourth ventricle; in three of four cases the patient’s shunt device malfunctioned. Other conditions frequently accompanied by shunt complications were fourth ventricle cysticercosis, hemangioblastoma, and medulloblastoma (Table 1).

### Discussion

Most authors recommend conservative management of hydrocephalus due to lesions in the posterior fossa because resection of the obstructive lesion may restore CSF circulation without further intervention. Patients with severe hydrocephalus caused by posterior fossa lesions, however, are in immediate danger of fatal complications. In these cases, hydrocephalus must be resolved before the lesion can be resected. Malignant tumors and large benign neoplasms are particularly prone to induce severe hydrocephalus.

In contrast with other studies, a significant number of patients treated at our institute presented with a large (<5 cm) neoplasm. Because our institution is a tertiary care center, we receive patients from all over the country. Many come from remote areas where they have received deficient primary medical attention; thus, it is common to see patients with very large lesions, an event rarely encountered at centers in industrialized countries. That was the case in 17 patients with schwannoma of the eighth nerve (12% of all such cases) who required shunts. The percentage of such patients who needed shunts contrasts with approximately

### TABLE 1

<table>
<thead>
<tr>
<th>Type of Lesion</th>
<th>Total</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>all lesions</td>
<td>491 (100)</td>
<td>103 (100)</td>
</tr>
<tr>
<td>schwannoma</td>
<td>147 (30)</td>
<td>17 (12)</td>
</tr>
<tr>
<td>meningioma</td>
<td>57 (12)</td>
<td>17 (30)</td>
</tr>
<tr>
<td>dermoid cyst</td>
<td>46 (10)</td>
<td>3 (7)</td>
</tr>
<tr>
<td>glioma</td>
<td>42 (9)</td>
<td>6 (14)</td>
</tr>
<tr>
<td>hemangioblastoma</td>
<td>38 (8)</td>
<td>8 (21)</td>
</tr>
<tr>
<td>medulloblastoma</td>
<td>36 (7)</td>
<td>14 (47)</td>
</tr>
<tr>
<td>metastatic lesion</td>
<td>28 (6)</td>
<td>6 (14)</td>
</tr>
<tr>
<td>fourth ventricle cysticercosis</td>
<td>24 (5)</td>
<td>10 (42)</td>
</tr>
<tr>
<td>vascular malformation</td>
<td>23 (5)</td>
<td>6 (24)</td>
</tr>
<tr>
<td>ependymoma</td>
<td>14 (3)</td>
<td>9 (30)</td>
</tr>
<tr>
<td>papilloma</td>
<td>4 (1)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>other</td>
<td>30 (6)</td>
<td>9 (30)</td>
</tr>
</tbody>
</table>

* Percentages of patients are given in relation to the total number of patients (491); percentages of patients requiring a shunt is based on the number of patients with the same disease.
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4% of similar cases in other reports. Usually, third ventriculostomy is the best alternative. In most cases it resolves the hydrocephalus; however, in some patients it is difficult to perform on an emergency basis and a ventricular shunt is required.

Despite the abundance of shunt devices, it is widely known that all available shunts are prone to overdrainage, which in the case of a lesion in the posterior fossa is a potential source of life-threatening complications. There is a high risk of ascending herniation through the tentorium as a result of raised pressure within the posterior fossa combined with a sudden decrease in supratentorial resistance after drainage of ventricular contents. Additionally, as a consequence of overdrainage, slit ventricle syndrome develops in approximately 30% of all patients. It is characterized by headache, nausea, vomiting, diplopia, and difficulties in ocular supraversion; imaging studies demonstrate ventricular collapse. Subdural hematoma due to overdrainage develops in 5 to 21% of patients with shunts; in most cases it is caused by the rupture of cortical veins. The aforementioned complications may develop even months after shunt placement.

The cause of overdrainage through VP shunts is mostly due to the siphon effect, which is produced by changes in the posture of the patient, rather than to mechanical deficiencies of these devices. Prevention of this complication is difficult considering that most shunts with valves are designed to respond almost exclusively to variations in IVP, disregarding the siphoning effect that the force of gravity imposes on the CSF drainage through a shunt connecting the ventricles with the peritoneal cavity. This force is directly related to the vertical distance between the ventricular and peritoneal cavities as they relate to the earth’s gravity, which reaches a mean upper value of approximately 50 cm H2O when the patient is standing and disappears when the patient lies down horizontally. While the patient is in the upright posture, these events produce a hydrodynamic force greater than that generated by IVP.

Under normal physiological conditions, the CSF circulation is not sensibly affected by postural changes because there are no differences in hydrostatic pressure between the main sites of production and absorption of CSF, which are the choroid plexus and the sagittal sinus, respectively. When a VP shunt is installed, a gradient of 50 to 70 cm H2O between orthostatic pressure and abdominal pressure develops, inducing under normal circumstances a mean decrease of 30 mm Hg of intracranial pressure. This unavoidable physical circumstance has been approached using a variety of antisiphon devices aimed at preventing excessive drainage through mechanisms that close the flow when the distal pressure reaches subatmospheric values, which in fact occur during erect posture. The effects of these devices, however, has not been satisfactory.

Instead of counteracting the siphon effect, the CF shunt uses its force to contribute to the maintenance of a constant flow, calculated to comply with the mean physiological parameter of CSF production (0.35 ml/minute) regardless of the posture of the patient. In the two extreme postures in humans, horizontal and vertical, the CF shunt complies with the main hydrodynamic force as it acts in a given moment on the flow. When we stand, the main force is gravity (siphon effect), whereas when we lie down it is IVP. Intermediate postures result in a variable but predictable combination of these two forces. In all instances, the main characteristic of the CF shunt is the maintenance of uninterrupted flow. These features place the design of this shunt in sharp contrast with all other currently used devices, whose principal characteristic is the interposition of long lapses of fluid stasis according to the valve mechanisms of the shunt, which in turn respond to changes in IVP.

The CF shunt does not have a mechanism to prevent retrograde flow; however, the narrow inner diameter of the peritoneal catheter prevents retrograde flow and facilitates unidirectional flow from the sources of hydrokinetic forces (IVP and gravity) toward the peritoneum. The peritoneum’s internal pressure is equal to or slightly lower than the atmospheric pressure in the upper abdominal area, which is the usual place for insertion of the distal end of the shunt—a feature that favors constant drainage through the distal end of the CF shunt precluding distal occlusion.

When one is in the upright position the flow of CSF (0.56 ml/minute) is higher than the classic mean value of CSF production (0.35 ml/minute), whereas when one is in the horizontal position the flow (0.22 ml/minute) is less than this value. The value of 0.35 ml/minute lies in between; in this way, when there is a tendency to overdrain CSF (when in the upright position) the IVP will lessen and diminish the flow velocity; in the opposite situation when there is a tendency to retain CSF (while in the horizontal position), the IVP will become greater, increasing the flow velocity. Theoretically, through these two physiological parameters an equilibrium between over- and underdrainage can be reached. The fact that the ideal rate of drainage, according to CSF production, lies in between the limits of the two postures assumed by humans promotes uninterrupted drainage through the CF shunt, which is equilibrated by natural (not by mechanical) sources, simultaneously preventing fluid stasis, which may lead to shunt occlusion. Even in extreme postures such as upside down, the flow would become momentarily interrupted but without retrograde flow, mainly due to the very thin inner diameter of the peritoneal catheter; because the peritoneal cavity is a virtual space, no accumulation of fluid is found under normal conditions.

Previous studies have demonstrated that the CF shunt is superior to shunts with valves for the treatment of hydrocephalus in adults. Because of its basic mechanisms the CF shunt is not useful in newborns; it can only be used for hydrocephalus after the child begins to walk. The major advantage of the CF shunt in the treatment of hydro-
drocephalus caused by neoplasms of the posterior fossa is that, due to the thin diameter of the peritoneal catheter, its drainage performance is a constant narrow flow. Sudden decompression of the ventricular cavities is thus prevented, maintaining an equilibrium of supratentorial tension that poses barriers to a sudden ascending herniation of structures from the posterior fossa. The CF shunt provides an effective, simple, and inexpensive alternative to other VP shunts, to external shunts, or to third ventriculostomy.

Conclusions

The CF shunt is a rather simple device that provides a bypass between the ventricular and the peritoneal cavities. The shunt’s drainage parameters comply with the physiological limits of CSF production, according to the two main hydrodynamic forces imposed by the IVP (injection force) and the siphon effect (suction force). The prominent feature of the CF shunt is a highly precise internal diameter of 0.51 mm along the peritoneal catheter; this provides an uninterrupted flow whose amount and velocity vary according to IVP and/or the siphon effect. One of the advantages of the CF shunt is the absence of overdrainage, which is a common complication of shunts with valves. This feature is particularly useful in cases of hydrocephalus caused by lesions of the posterior fossa. In this study, the CF shunt failed in 8% of such cases in comparison with a 40% rate of failure in patients in the control group, who had been treated with shunts with valves. The CF shunt, as shown in previous reports, is effective for the treatment of hydrocephalus in adults, even in cases of severe hypertension due to expanding lesions of the posterior fossa.

Disclaimer

The conceptual and experimental frameworks for the CF shunt were developed by one of the authors (J.S.) in our laboratory; however, no commercial interests exist because the advantage of the device is based on the internal diameter of a catheter and the device does not contain a valve mechanism.

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