Experimental transcerebral fistula

Perineural olfactory CSF flow in the normal, hydrocephalic, and postoperative hydrocephalic dog shown by radionuclide ventriculography

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Cerebrospinal fluid dynamics were studied in eight dogs during normal, hydrocephalic, and postoperative phases. Radionuclide-labeled substances introduced into the normal ventricular system flow out of the exits from the fourth ventricle to the convexity subarachnoid spaces superiorly to be absorbed in the sagittal sinus, and basorosstrally to the exits from the perineural olfactory sheath into the nose to produce physiological cerebrospinal fluid (CSF) rhinorrhea. Serial radionuclide ventriculography of the head following intraventricular isotope injection of labeled proteins and chelate into the kaolin-induced hydrocephalic system shows a high degree of ventricular stasis with no perineural olfactory nerve flow (rhinorrhea). An operative transcerebral fistula, fashioned from a dilated lateral ventricle to the convexity subarachnoid space, reestablishes perineural olfactory flow of CSF into the nose, as demonstrated by the radionuclide ventriculography studies. This suggests a potential method for treatment of hydrocephalus. Serial imaging studies in this surgically modified system clearly demonstrate radionuclide flow through the patent fistula to distal absorption sites, thereby bypassing the basal obstruction. Moreover, augmented CSF pressures associated with obstructive hydrocephalus can be controlled by such treatment. The application of this method in treating clinical hydrocephalus is discussed with emphasis on fistula arachnoid closure to assure fistula patency.

KEY WORDS · hydrocephalus · transcerebral fistula · perineural olfactory flow · rhinorrhea · cerebrospinal fluid pressure · radionuclide ventriculography

Treatment of hydrocephalus by external shunt systems requires long-term vigilance and repeated revisions. Intracranial operations to achieve cerebrospinal fluid (CSF) flow from ventricles to subarachnoid spaces are limited in number, and include ventriculo-posterior fossa cisternostomy (Torkildsen's procedure), third ventriculostomy, and pericallosal sump ventriculostomy.24-26 These procedures have achieved only limited clinical success, partly due to inadequate arachnoid seal techniques and inadequate absorption of CSF in the distal space.

In a preliminary report we described the transcerebral fistula as another possible ventricle-to-subarachnoid space procedure5 (Fig. 1). The distal space must of course be adequate to absorb the CSF (M Sayers, personal communication, 1980). Subsequent technical refinements in the surgical procedure to assure satisfactory arachnoid closure have greatly improved postoperative fistula patency. This current study further evaluates this method by the use of CSF pressure studies (CSF mean and pulse pressure before and after the procedure), radionuclide ventricular imaging for clearance measurements, and direct determination of radionuclide in the olfactory perineural flow (CSF bulk flow evaluation), vital dye injections (fistula patency), and clinical status.

The dog was chosen as the experimental animal because of our previous successful experience in producing hydrocephalus in this model.69,30 Our prior report on the success of the fistula indicated the need for significant improvement in methodology.5 However, the olfactory perineural flow of CSF, especially in dogs, gained attention as a possible indicator of patency of the transcerebral fistula.48,30 Other studies indicate that normal CSF flow in dog proceeds from the ventricles to the basal subarachnoid spaces to the olfactory lobe.
**FIG. 1. Illustration summarizing ventricle-to-subarachnoid space operations for diversion of cerebrospinal fluid (CSF) flow.** These are: Torkildsen's ventriculocisternal shunt (A); third ventriculostomy (B), and a transcerebral fistula (C) connecting the obstructed ventricular system to the cerebral convexity subarachnoid space for distal CSF absorption at the pacchionian granulations.

Two radioactive-labeled proteins were selected for this study. Serum albumin is a large-molecule (MW 68,000) bulk-flow tracer used widely in CSF bulk flow studies. It exhibits little transependymal absorption normally. Similar findings were observed with labeled fibrinogen. Diethylenetriaminepentaacetic acid (DTPA) is a small-molecule (MW 492) tracer chelate widely used for CSF flow studies, which has both bulk flow and significant transependymal absorption characteristics. Since CSF bulk flow restriction and CSF transependymal flow are abnormal in hydrocephalus, protein and chelate tracers were used simultaneously to assure validity of the observations. Such observations might demonstrate a different mechanism of CSF flow for large and small molecules in normal and hydrocephalic animals.

In the only previous report on transcerebral fistula treatment in hydrocephalus, only 60% of the fistulas remained patent. The tissue fibrosis that occluded the fistulas may have been induced by the suture technique used for arachnoid closure. Adequate arachnoid membrane closure over the cerebral fistula is critical. A nonsuture closure is preferable to suturing. Therefore, a half-thickness Gelfilm patch was placed over the arachnoid incision to minimize scarring of the subarachnoid space and encourage arachnoid regeneration.

**Materials and Methods**

Eight healthy adult mongrel dogs, each weighing 6 to 9 kg, were used. Each animal underwent 1 week of observation to assure that they were healthy, stable, and normal animals. The study was a five-step sequence of experiments conducted over a 4-month period. All operations were performed under barbiturate anesthesia (sodium pentobarbital, 25 mg/kg) regulated at anesthetic levels to maintain spontaneous respirations through a cuffed tracheal tube following tracheostomy. Rectal temperature was maintained at 37° to 38°C by a heating pad. Stereotaxic surgical techniques were used for head fixation and cannula placement when required. Comprehensive postoperative care was given when required, including antibiotic therapy, intragastric feeding, and exercise.

All eight animals showed normal CSF pressure studies (Step 1). They were then rendered hydrocephalic by intracisternal infusion of kaolin (Step 2). The animals were tested for hydrocephalus by CSF pressure measurements (Step 3). Three animals were retained as untreated controls (without fistula), while the remaining five underwent the fistula operation (Step 4). Finally, the fistula was tested for patency in the five treated animals (Step 5).

These animals were studied at the normal, hydrocephalic, and postoperative fistula stages. The evaluations used in Steps 1, 3, and 5 of this study were: 1) CSF pressure recordings; 2) radionuclide ventriculography and radionuclide analysis of olfactory secretions; 3) clinical status; 4) dye infusion studies at the time of

"...and from the perineural olfactory spaces to the nasal mucosa. In the usual kaolin-induced hydrocephalus model, inflammatory obstruction to CSF flow occurs mostly in the proximal basal cisterns, which should obstruct CSF flow to the olfactory lobe and perineural olfactory spaces. Radionuclide flow patterns should show this loss of nasal CSF under kaolin-induced hydrocephalus, although a problem might exist in selection of large-molecule versus small-molecule isotopic tracers since different-sized molecules may be handled differently in the CSF. Simultaneous use of a large-molecule and a small-molecule tracer allows direct and simultaneous evaluation of any difference in these pathways.

Therefore, if the transcerebral fistula (by open operation) is successful in bypassing the basal kaolin block to CSF flow, the perineural CSF olfactory flow should reappear. This method to establish that the CSF fistula is patent involves only minimally invasive techniques and can be repeated.

Simultaneous CSF pressure records to show mean pressure and pulse pressure relationships sequentially for each animal in the normal, hydrocephalic, and postoperative (treated hydrocephalus) phases would give the dynamic CSF pressure data needed to further define CSF pressure characteristics in hydrocephalus. Such CSF pressures can be only indirect indicators of the patency of the fistula. These data probably do not yet define arrested or progressing hydrocephalus."
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sacrifice; and 5) postmortem gross pathological examination and light microscopy. Each step is described as follows.

**Step 1: Baseline Measurements (Normal)**

Following the induction of anesthesia and tracheostomy, the animal was placed in a large-animal stereotaxic frame* in the "sphinx position." The electrocardiogram and respirations were recorded with a Grass 7-B polygraph† with hard-copy write-out. Under sterile conditions a parietal ventriculostomy was performed using a No. 20 blunt spinal needle. Proper needle position was confirmed when an attached pressure transducer§ in connection with the polygraph recorded CSF pulsations and clear CSF backflow occurred.

Mean and pulse CSF pressures were recorded at a sensitivity of ± 0.05 mm CSF with an expectant CSF pressure range of 0 to 200 mm CSF. The latency and slope of the CSF pulse waves were calculated for descriptive data analysis.†† Manometric calibration was in mm CSF, reference to the level of the skull vertex.

Indium-111 (111In) was used to label DTPA. Albumin and fibrinogen were labeled with iodine-125 (125I), iodine-131, or technetium-99m (99mTc) in doses of 50 to 100 μCi for the imaging studies. In the direct-measurement studies doses of 20 μCi were used. The labeled compounds were prepared in a syringe (0.3 cc) prior to intraventricular injection. The injection of radioisotopes was made with manual barbotage to facilitate fluid mixing within the ventricle. Immediately following the injection, imaging with the gamma camera§ with computer interface was initiated to establish baseline radioactivity (nasal sinus versus ventricular system) at the time of injection. Imaging was performed over the head and neck to outline radionuclide activity within the cranial system (hotspot within the injected lateral ventricle). Radioactivity analysis was done on each hourly scan (total 6 hours) by an on-line computer for quantitative imaging. However, in most early and in certain random experiments, scintillation counts of nasal pledgets were performed for direct measurement of radiolabeled CSF rhinorrhea.

**Step 2: Induction of Hydrocephalus**

At no less than 1 week after Step 1, anesthesia was again induced. The same stereotaxic procedure was followed except a brow-down sphinx position was used in the frame. A No. 20 spinal needle was introduced into the cisterna magna under sterile conditions, and its position verified by CSF pulsations and backflow.

The CSF pressures were recorded. A volume of 1.5 cc CSF was withdrawn from the system, and an equal volume of kaolin suspension (70 mg/kg in 1.5 cc Elliot's B solution) was injected over 5 minutes.‡‡ Immediately following injection, the animal's head was lowered for 20 minutes to assure kaolin deposition in the basal cisterns. The animals recovered for 1 to 2 weeks before Step 3 was begun. During this time, the animals required comprehensive postoperative care as various degrees of hydrocephalic symptoms developed, including somnolence, anorexia, nausea, behavioral change, and ataxia.

**Step 3: Test for Hydrocephalus**

As in Step 1, the animal underwent frontoparietal stereotaxic ventriculostomy with a No. 20 spinal needle. Elevated CSF pressures within the obstructed ventricular CSF system were recorded. After removing 0.2 cc CSF from the system, the same combination of radioisotopes as in Step 1 was injected with barbotage. A similar 6-hour radiological evaluation was performed. The animal was allowed to recover for 1 to 2 weeks, depending on the severity of the hydrocephalus and need for operative relief.

**Step 4: Transcerebral Fistula Operation**

At 3 weeks (± 3 days) after the intracisternal injection of kaolin, the hydrocephalus was treated with the transcerebral fistula. The animal was prepared for sterile surgery and a right lateral craniectomy was performed under barbiturate anesthesia (25 mg/kg sodium pentobarbital). The CSF pressures were recorded prior to and after the skull was opened. A 1.5-cm curved incision was made in the dura and reflected medially. The fistula site was lateral to the suprasylvian sulcus, in a large sulcus connected to the suprasylvian sulcus. A small 5-mm vertical incision was made in the arachnoid with a diamond knife. Hydrodissection with warmed lactated Ringer's solution was performed to loosen underlying arachnoid trabeculae from the pia-cortex. A glass pipette suction tip (1.5 mm in outer diameter) connected to a standard surgical vacuum of 50 cm H2O was used to remove a 3.0-mm diameter core of brain tissue to establish a connection with the lateral ventricle. Complete hemostasis was achieved with bipolar electrocoagulation. The arachnoid was approximated by float-
ing the arachnoid flaps on irrigation fluid. A rectangular piece of gelatin film (half-thickness Gelfilm*) was placed over the arachnoid incision, overlapping the incised arachnoid and extending peripherally beyond all the edges of the dural opening. The entire exposed arachnoid-cortex area was covered with the Gelfilm. The dura was sutured over the Gelfilm with 5-0 silk, the bone flap was replaced, and the scalp was sutured. Adequate intravenous fluids were given to assure CSF formation and flow through the fistula during the immediate postoperative period.

**Step 5: Postoperative Evaluation**

At 2 to 4 weeks following placement of the fistula, a right ventriculostomy was performed by stereotaxis for measurement of CSF pressures and injection of radioisotopes. A subsequent 6-hour radiological study was performed as before. Three days later, the fistula was exposed under anesthesia. Evans blue dye was instilled into the opposite ventricle while flow of this dye through the fistula was assessed by direct observation. The animals were immediately sacrificed by intracardiac perfusion of saline and 10% formalin. The brains were removed, examined for gross pathology, and photographed. Histological preparation of the brains was performed for paraffin embedding and hematoxylin and eosin staining. Light microscopy was performed.

**Results**

**Cerebrospinal Fluid Pressures**

Table 1 shows the mean and pulse CSF pressures for each animal at normal, hydrocephalic, and postoperative fistula stages. Eight animals were in the normal CSF study (Step 1). The averaged mean pressure for this group was 85.6 mm CSF. The averaged pulse pressure was 11.3 mm CSF.

Eight animals were made hydrocephalic by intracisternal injection of kaolin. One animal died during induction of kaolin hydrocephalus. The averaged mean pressure for the seven hydrocephalic animals tested in Step 3 was 114.0 mm CSF (an increase of 28.4 mm CSF from Step 1) with a pulse pressure of 22.7 mm CSF (an increase of 11.4 mm CSF from Step 1).

Two weeks after the hydrocephalus fistula operation, five animals were again tested (Step 5). Two animals (Dogs HD-2 and HD-6) died prior to this test, apparently from untreated and progressing hydrocephalus. The averaged mean pressure for this treated group was 76 mm CSF (a decrease of 38.0 mm CSF from Step 3, and 9.6 mm CSF below Step 1). The averaged pulse pressure was 13.6 mm CSF (9.1 mm CSF below Step 3, and 2.3 mm above Step 1).

The data show an increase in CSF pressures during hydrocephalus and a lowering of CSF pressures to near normal following the transcerebral fistula operation (Fig. 2).

**Radiological Evaluation**

Neuroradiological data were collected from eight normal animals (Step 1), seven hydrocephalic animals (Step 3), and five fistula animals (Step 5). These five treated animals showed olfactory CSF flow in the normal stage, loss during the hydrocephalus, and recovery after the fistula treatment (Table 2). These changes occurred for both the large- and small-molecule tracers.

Criteria were established for measurement of CSF olfactory tracer flow by two nuclear medical techniques: radionuclide ventriculography and direct radionuclide measurements of the olfactory secretions. Positive olfactory flow was predefined in each case: 1) in the nasal regional imaging, 2% of the total injected dose of radionucleotide was required in the nasal region; and 2) in the nasal pledget samples, gamma emission counts three times that of background counts were required.

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* *Gelfilm is a registered product of the Upjohn Co., Kalamazoo, Michigan. It is a sterile, non-antigenic, absorbable gelatin film approximately 0.075 mm in thickness.

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**TABLE 1**

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Normal (mean/pulse)</th>
<th>Hydrocephalic (mean/pulse)</th>
<th>Fistula (mean/pulse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-1</td>
<td>113/6</td>
<td>115/20</td>
<td>100/16</td>
</tr>
<tr>
<td>HD-2</td>
<td>115/8</td>
<td>100/20</td>
<td>95/8</td>
</tr>
<tr>
<td>HD-3†</td>
<td>95/19</td>
<td>80/13</td>
<td>76/19</td>
</tr>
<tr>
<td>HD-4†</td>
<td>87/12</td>
<td>125/26</td>
<td>57/15</td>
</tr>
<tr>
<td>HD-5†</td>
<td>51/8</td>
<td>145/22</td>
<td>76/0</td>
</tr>
<tr>
<td>average mean pressure</td>
<td>85.6</td>
<td>114.0</td>
<td>76.0</td>
</tr>
<tr>
<td>average pulse pressure</td>
<td>11.3</td>
<td>22.7</td>
<td>13.6</td>
</tr>
</tbody>
</table>

* Values are in mm of cerebrospinal fluid (CSF).
† Animals treated with the transcerebral fistula.
Table 2 shows the results of large- versus small-molecule CSF olfactory tracer flows in the five fistula-treated animals for Steps 1, 3, and 5. All five animals showed positive CSF olfactory flow for both tracers in the normal study. Hourly gamma-camera images showed a steady mixing and flow of both isotopes throughout the ventricular system and flow to convexity subarachnoid space for reabsorption. The $^{111}$In DTPA diffusion rates were visibly greater than rates with labeled protein. Most CSF absorption occurred at the sagittal sinus with a portion of CSF flowing caudally down the spinal cord and rostrally to the olfactory nerve exits (rhinorrhea). In those animals tested for CSF olfactory flow by nasal pledget samples, the ratio of radioactivity over background for $^{99m}$Tc albumin was greater than for $^{111}$In DTPA. Presumably, considerable $^{111}$In DTPA was taken out of CSF flow by diffusion prior to reaching olfactory flow sites.

In the hydrocephalic group, gamma-camera imaging indicated a slow diffusion of both radiolabeled compounds throughout the obstructed ventricular system during the 6-hour study (greatest concentration in the injected ventricle, less so in the contralateral third and fourth ventricles). Labeled albumin appeared to remain localized within the ventricular system as above, while $^{111}$In DTPA showed greater diffusion ability and appeared to diffuse more readily through brain tissue to the convexity subarachnoid space. In three of five animals with basal obstruction, sufficient $^{111}$In DTPA escaped the ventricular system to register a positive CSF olfactory flow result. While in four animals the labeled protein remained strictly within the ventricles, one animal showed a minimal flow of the radioprotein beyond the point of obstruction. The $^{125}$I albumin scintillation counts from nasal pledgets were lower in this group than in the normal group (three times background or less for three of five animals).

The postoperative fistula group showed positive CSF olfactory flow for both radiolabeled compounds. Immediately following the injection of both radioactive compounds into the treated ventricle, serial gamma images showed a migration of both radionuclides out of the fistula to subarachnoid space absorption sites and rostral to olfactory drainage (Fig. 3). These results were clearly demonstrated in four animals, less so in the fifth. Scintillation counts from nasal pledgets were taken from only one animal in this treated group. In this animal, radiiodoprotein activity compared to background was nearly the same as the result achieved in the pre-hydrocephalic state.

Figure 4 shows the combined $^{125}$I albumin results from both radiological tests in Dog HD-4, treated with the transcerebral fistula. Scintillation counts from nasal pledgets were taken from only one animal in this treated group. In this animal, radioiodoprotein activity compared to background was nearly the same as the result achieved in the pre-hydrocephalic state.

![Gamma camera images, lateral (upper) and vertex (lower) views, taken in Dog HD-4 after the fistula operation showing progressive movement of intraventricular radionuclide toward the nasal region at the 5th hour compared with the 1st hour. Arrow shows the site of cerebrospinal fluid (CSF) radionuclide flow from the fistula to the vertex subarachnoid space.](image)
Blood was eliminated as a possible source of isotope contamination during direct measurements in this study by obtaining serial venous blood samples concomitant with radiological scans and pledget samples in two of five animals. Blood radioactivity in these samples taken over the 5-hour study was very low compared to the CSF samples taken from the nasal sinuses. It was calculated that a 0.5- to 1.0-cc blood equivalent would be necessary within a 0.02-cc pledget to produce the amount of registered radioactivity found in the scintillation counts. In addition, any pledget vial containing visible blood contamination was discarded. Therefore, blood did not contribute to radioactivity in CSF nasal samples.

Precautions were taken to assure that no significant leak of radioisotope occurred along the tract of the needle through which the isotope injections were made. The five animals treated with creation of a fistula exhibited comparable overall results. Cerebrospinal fluid rhinorrhea was present in all the animals prior to kaolin-induced hydrocephalus. After basal obstruction had been induced, a marked decrease in both large- and small-molecule CSF flows occurred. Following the fistula operation, CSF distal bulk flow returned in all five animals as measured by radioactivity from both labeled compounds in the nasal areas.

Clinical Evaluation
The animals were observed for 1 week before the study to assess normal behavior. All eight animals were healthy and free of CNS deficits.4-6 Standard clinical observations were made throughout the study, in which somnolence, appetite, and gait were assessed qualitatively.

Normal animals were steady, balanced, and had a normal gait. Posturing and weight were within normal ranges. During hydrocephalus, the animals became irritable and tremulous, anorexia appeared, and movements were slow. In the seven animals that survived initial kaolin-induced hydrocephalus, three animals presented with a transient head-tilt to one side. Two animals deteriorated following kaolin injection and required early sacrifice. One animal died from ventriculitis.

Once the fistula operation was performed, the symptoms of hydrocephalus were markedly reduced within 2 days. The animals ate well, gained weight, and were no longer irritable; normal gait returned.

Dye Infusion and Postmortem Examination
Five animals treated with the transcerebral fistula underwent ventricular injection of Evans blue dye for visual study of CSF flow through the fistula. Evans blue
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FIG. 6. Coronal section of a hydrocephalic dog brain with an operative transcerebral fistula visible on the inside surface of the lateral ventricle (arrow). The size of the treated ventricle is markedly smaller than that of the contralateral ventricle.

dye was manually injected into the untreated ventricle while simultaneous observations of the fistula opening (arachnoid intact) were made. In four of five animals, the dye readily flowed out through the fistula under the arachnoid and into the subarachnoid channels (Fig. 5). In the fifth animal, the flow of dye through the skull was slow.
The animals were then perfused with 0.9% saline and 10% buffered formalin through an intracardiac catheter. Examination revealed perfused brains with normal contours and a clear appearance of the attached arachnoid and dural membranes. Kaolin-induced arachnoiditis was present in the basal cisterns including the optic chiasm cisterns. The openings of the fourth ventricle were occluded by the basal inflammation.

With the dura removed, the transcerebral fistula appeared as a round 5-mm surface lesion in the region of the supra-ectosylvian fissure with a small bridge-like suspension of arachnoid membrane covering the opening.

Coronal sections of these brains revealed various stages of ventriculomegaly (hydrocephalus). Evans ratios of these brains were 0.28 to 0.58:1 (Table 3). The Evans ratio is defined as the width of the frontal ventricles compared to the width of the frontal brain mass. An Evans ratio of 0.25:1 is considered normal. The lateral ventricle with the transcerebral fistula was noticeably smaller than the contralateral ventricle (Fig. 6). This observation was present in three of five treated animals, particularly in those animals with greater ventriculomegaly.

Light Microscopy Evaluation

Microscopic evaluation of the fistula and adjacent subarachnoid space showed traumatic inflammatory changes (Fig. 7). Infiltration by macrophages and granulocytes was present in the walls of the lateral ventricles, the fistula tract, and at the margins of the fistula in the margins of the subarachnoid space. Moderate gliosis was present along the inner portion of the tracts, ependyma did not line the tracts, and the middle and distal fistulas showed naked glial lining only. Stenosis and synechial ridges were present in the tracts in animals with only moderate ventriculomegaly.

Gelfilm, which had been used as a subdural implant (interposed between the dura and arachnoid during fistula closure) was not present in any of the brains (90 to 120 days following the operative implantation).

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Evans Ratio</th>
<th>Ventriculomegaly</th>
<th>Control/Fistula</th>
<th>Time After Fistula (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-1</td>
<td>0.46</td>
<td>moderate</td>
<td>control*</td>
<td>0</td>
</tr>
<tr>
<td>HD-2</td>
<td>0.32</td>
<td>mild</td>
<td>control</td>
<td>0</td>
</tr>
<tr>
<td>HD-3</td>
<td>0.58</td>
<td>severe</td>
<td>fistula†</td>
<td>2</td>
</tr>
<tr>
<td>HD-4</td>
<td>0.56</td>
<td>severe</td>
<td>fistula</td>
<td>4</td>
</tr>
<tr>
<td>HD-5</td>
<td>0.40</td>
<td>moderate</td>
<td>fistula</td>
<td>1</td>
</tr>
<tr>
<td>HD-6</td>
<td>0.28</td>
<td>mild</td>
<td>control</td>
<td>0</td>
</tr>
<tr>
<td>HD-7</td>
<td>0.40</td>
<td>moderate</td>
<td>fistula†</td>
<td>2</td>
</tr>
<tr>
<td>HD-8</td>
<td>0.47</td>
<td>moderate</td>
<td>fistula</td>
<td>3</td>
</tr>
</tbody>
</table>

* Premature kaolin death: ventriculitis.
† Treated lateral ventricle smaller than contralateral ventricle.
The brains with Evans ratios of at least 0.50:1 (pronounced ventriculomegaly) had well defined, unobstructed fistula tracts to the subarachnoid space. In four of five brains, a clearly delineated, open fistula was present from the ventricle to the subarachnoid space. In one brain, the fistula was poorly defined.

**Discussion**

Current shunt systems are not basic biological systems and are a crude though effective method of treatment for hydrocephalus. Shunting procedures do not mimic the normal CSF dynamic state, especially as related to intermittent CSF pressure elevations and depressions over 24 hours. The shunts notoriously require repeated evaluation and revision for years. The type of hydrocephalus can be changed by shunting, such as aqueduct stenosis developing when a ventricular shunt is placed to control communicating hydrocephalus. Theoretically, treatment of hydrocephalus should be by a system that does not require implanted artifacts in the body. 5,24-26

Completely biological procedures have been used to treat hydrocephalus, such as third ventriculostomy. The Torkildsen internal shunt, while using a tube, did conduct CSF from a point proximal to CSF bulk flow obstruction to basal cistern areas of the posterior fossa. Both procedures conduct CSF from the ventricle to the subarachnoid space and use natural absorption systems for CSF. The procedure connecting the lateral ventricle to the convexity subarachnoid space is simpler than either of these techniques; it conducts CSF from the ventricle to subarachnoid spaces, it depends on natural brain CSF absorption systems; and it can be completely biological.

For such procedures to be effective in hydrocephalus treatment, the absorptive system into which the CSF from the occluded ventricle is transmitted must have sufficient bulk flow capacity to absorb the ventricular CSF. The convexity subarachnoid space and pacchionian system can be compressed by the hydrocephalus pressure of aqueduct stenosis to the extent that such CSF flow absorption cannot occur. However, such flow absorption can be reestablished if the system was functional prior to the hydrocephalus (M Sayers, personal communication, 1980). Some types of hydrocephalus have never had normal flow absorption in this system. This is especially true in certain pediatric hydrocephalus problems, such as those with aqueduct stenosis, Arnold-Chiari malformations, and associated spina bifida. No fistula from an obstructed ventricle to the subarachnoid space can work properly if the distal space is also obstructed to CSF flow. In general, clinical observations indicate that acquired hydrocephalus (obstructive or communicating) can develop adequate distal CSF flow, or "open up" again, several days after the compression by the hydrocephalic ventricle is released (M Sayers, personal communication, 1980). This appears to be the case in the animal study reported here.

Persisting patency of the fistula for CSF flow in the dog is now reasonably reliable with the techniques described due to satisfactory arachnoid sealing (healing over the fistula by use of Gelfilm) and adequate distal flow absorption of CSF. The fistula is made in a convexity sulcus through a pool of CSF. This allows arachnoid regeneration with minimal pia-arachnoid scarring which might plug the fistula. The Gelfilm patch holds the arachnoid flaps in position to allow regeneration and healing without pial or dural contact. This technique minimizes cicatrix. The benign low-grade inflammatory healing of arachnoid is basic to a successful fistula. Absolute control of bleeding at operation is essential. The disappearance of Gelfilm in 60 to 90 days with minimal inflammatory response is a great advantage of this therapy.

The postmortem asymmetry of the ventricles in these dogs with fistulas showed a smaller ventricle on the side of the fistula (Fig. 6 and Table 3). This is highly suggestive that better hydrocephalus recovery occurs on the side of the fistula. It is conceivable that bilateral fistulas would be a better treatment; however, more precise and longer-term study of this point is needed.

The loss of compliance present in progressing hydrocephalus is reversed by placement of the fistula since there is considerable recovery from the high CSF pulse pressure postoperatively in these dogs (Fig. 2 and Table 1). This means that damping mechanisms affecting CSF pulse pressure waves are reactivated by the fistula. Such mechanisms were lost during progressing hydrocephalus. A nearly normal dynamic CSF state is achieved with this treatment. Clinical studies show that CSF shunting often does not change the high-amplitude undamped CSF pulse pressure waves, on the other hand. 11-13 The fistula treatment of hydrocephalus may, therefore, restore normal intracranial CSF dynamics better than external shunting, although comparisons are still tenuous.

In dogs, CSF rhinorrhea is a normal phenomenon. In our study, disappearance of CSF rhinorrhea was associated with kaolin-induced hydrocephalus, and appears to be a valid indicator of that type of hydrocephalus. Other studies have found that CSF rhinorrhea was increased in naturally occurring obstructive hydrocephalus. However, all isotope injections in our studies were made into the ventricle, whereas injections of isotope were made into the cisterna magna in the study of Di Chiro, et al. 8 This difference in technique is critical to resultant CSF rhinorrhea in the animal with hydrocephalus. Therefore, the data from these two studies are not directly comparable.

This study emphasizes the natural role of perineural olfactory flow of CSF. Studies of this route of CSF absorption indicate that such CSF flow is returned to the blood system by the lymphatic system. 2,15,20

The simultaneous dual radionuclide tracer technique used here does not necessarily prove that different sizes of molecules in the CSF are subject to different bulk flow routes and/or different reabsorption sites. The
study does show again, however, that small molecules in the CSF are less reliable tracers to diagnose hydrocephalus than the large-molecule tracers (Table 2). In hydrocephalus, the small-molecule tracer (\(^{111}\)In DTPA) did appear in all five animals in the nasal area, although markedly reduced from normal. The larger molecule (labeled albumin; MW 68,000) did not appear in nasal flow during hydrocephalus and is presumably a more reliable indicator of hydrocephalus in these conditions.

Conclusions

In eight dogs, CSF pressure and CSF nasal rhinorrhea (radionuclide studies) were studied in the normal state, in kaolin-induced progressing hydrocephalus, and in hydrocephalus arrested (or compensated) by a fistula created between the lateral ventricle and the convexity subarachnoid space. The results indicate that CSF rhinorrhea is a natural, reliable phenomenon which is prevented by kaolin-induced hydrocephalus. Such flow was measured reliably by both large- and small-molecule radionuclide tracers (\(^{125}\)I, \(^{131}\)I, and \(^{99m}\)Tc albumin and fibrinogen, and \(^{111}\)In DTPA), using nasal pledget radionuclide measurement and radionuclide ventriculography with the gamma camera.

Treatment of kaolin-induced hydrocephalus by this surgical transcerebral fistula reestablished CSF rhinorrhea. Thus, CSF rhinorrhea is a good indicator of patency of the fistula up to at least 4 months after placement.

The mean CSF pressure and pulse CSF pressure gave reliable evidence that significant loss of compliance occurred with kaolin hydrocephalus. This was reversed to nearly normal by the transcerebral fistula (that is, cerebral compliance was recovered).

The transcerebral fistula can now be reliably achieved by the new technique of using a Gelfilm patch to achieve arachnoid seal over the cerebral fistula. Continued patency of the fistula, seen up to 4 months after placement, is apparently favored by continued CSF flow through the fistula which is, presumably, also dependent on the adequate CSF flow absorption capacity of the distal CSF spaces and pacchionian granulations.

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FIG. 7. Photomicrograph of a coronal brain section demonstrating the fistula pathway (4 months postoperatively) connecting the subarachnoid space to a lateral ventricle. A = arachnoid, F = fistula, LV = lateral ventricle, S = non-occlusive synechia, SS = sagittal sinus, III = third ventricle. H & E, × 3.5.

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