Shunt removal or replacement based on intraventricular infusion tests

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Abstract In 14 children with indwelling ventriculoatrial or ventriculoperitoneal shunts, the need for continued shunt treatment was judged to be uncertain based on clinical symptoms and signs and CT scans. Ventricular outflow resistance ($R_o$) was determined by implantation of a ventricular catheter and steady state infusion of artificial cerebrospinal fluid (CSF) according to the formula $R_o = (P_p - P_o)/\text{Infusion rate}$, where $P_o$ is the opening pressure in the lateral ventricle and $P_p$ the plateau pressure recorded at that particular infusion rate. $R_o$ was determined during general anesthesia and steady state ventilation was ensured by mechanical ventilator. Ventricular fluid pressure (VFP) and arterial blood pressure (ABP) were recorded by standard fluid pressure transducers. The cerebral perfusion pressure ($\text{CPP} = \text{ABP} - \text{VFP}$) was kept above 30 mmHg by reducing the infusion rate in cases of unacceptable increase in VFP. $R_o$ was determined with the shunt clamped. During steady state infusion at the plateau pressure the shunt was unclamped to test shunt patency. Four children had normal $R_o$ values with the shunt clamped. Their shunts were removed. They have done well clinically, and control CT scans have not demonstrated increased ventricular size. Three children demonstrated pathologic $R_o$ values (above 12 mmHg/ml per min) that normalized after shunt unclamping; i.e. each had a well-functioning shunt. Seven children demonstrated increased $R_o$ values even after shunt unclamping. Their shunts were replaced, and clinical improvement has been observed in 6 of them. Ventricular infusion tests appear useful to evaluate shunt dependence and function in difficult cases.

Key words Intraventricular infusion • Hydrocephalus CSF shunting • Shunt independence

Introduction

The prognosis for hydrocephalic children has improved remarkably during the last 30 years since the introduction of shunt surgery. It is now possible to stop the harmful and even devastating dilatation of the ventricular system by simple and easily performed surgical procedures, such as implantation of ventriculoatrial (VA) or ventriculoperitoneal (VP) shunts.

Few fields of neurosurgery, however, have complication rates such as those of shunt surgery. These complications include shunt infection with potential ventriculitis, septicemia and shunt nephritis and thromboembolic consequences of VA shunting, in addition to shunt failure. The increasing use of VP shunting has led to shunt hyperfunction causing slit-ventricle syndromes or even subdural hematomas in a number of cases.

While an improved general outlook for hydrocephalic children is beyond doubt, the long-term consequences of
ventricular fluid diversion have not been explored. Many neurosurgeons initially believed that ventricular fluid diversion was only necessary to overcome the harmful head enlargement during the first years of life. The term "spontaneously arrested hydrocephalus" or simply "arrested hydrocephalus" was introduced to denote such a state [2]: the shunt was no longer functioning, the child had no clinical signs of shunt malfunction and the need for continued CSF diversion was therefore thought to have resolved spontaneously.

There is, however, increasing evidence that most individuals, once shunted, will be shunt dependent throughout their lives [2]. The obvious corollary to this is that children should not have a shunt implanted unless it is reasonably certain that they really need it. In most children it can be firmly established whether or not a shunt procedure is indicated by clinical evaluation including serial recording of the head circumference and examination by imaging techniques such as ultrasound, computed tomography (CT) or magnetic resonance (MR). Such imaging techniques are also helpful tools in the follow-up of shunted children along with clinical symptoms and signs. In a few individuals, however, both shunt function and shunt dependence are difficult to assess.

In the present study, determination of ventricular fluid outflow resistance was performed in such children (1) to evaluate the need for continued shunting; (2) to evaluate shunt function; and (3) to establish a basis for shunt removal.

### Patients and methods

Fourteen children underwent determination of the ventricular fluid outflow resistance by steady state infusion of artificial cerebrospinal fluid (CSF) through an implanted Holter ventricular catheter in the right lateral ventricle. The test was performed during fentanyl/N₂O anesthesia and steady state moderate hyperventilation (PaCO₂ 3.5-4.2 kPa; capnograph: Datex, Finland).

Ventricular fluid pressure (VFP) and arterial blood pressure (ABP) were recorded at midcranial level by standard fluid pressure transducers (AME, Horten, Norway). The outflow resistance (Rₒ) was determined from the formula [4]:

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Rₒ = (Pₚ - P₀)/\text{Infusion rate}
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where P₀ is the opening pressure and Pₚ is the plateau pressure reached with the particular infusion rate. The standard infusion rate was 1.5 ml/min, but 1.0 or 0.5 ml/min was sometimes used to avoid an unacceptable increase in VFP. The cerebral perfusion pressure (CPP = mean VFP - mean ABP) was kept above 30 mmHg throughout the test. There were 7 male and 7 female patients, aged 3-19 (median 6) years.

### Results

The need for continued shunting was assessed by an intraventricular infusion test with the indwelling shunt closed, and the patency of the old shunt was tested by opening the shunt during steady state infusion into the lateral ventricle. The results are summarized in Table 1. In children tested at 3-5 years of age a Rₒ value above 10 mmHg/ml per min was considered the threshold indication for continued shunting. In children aged 6 or more, the adults Rₒ threshold value of 12 mmHg/ml per min was used [1, 3]. Four children were judged to be shunt independent and the old shunt was removed. Ten children were judged to be dependent on continued shunting. Three of these had well-functioning Pudenz VA shunts that had been inserted in early infancy and had remained in place without revision during the subsequent 12-17 years. The other 7 had their malfunctioning VA or VP shunts replaced by a new Holter or Sophysa VP shunt during the same procedure.

All children who underwent combined testing and implantation of a new shunt were given Keflin 10 mg/kg i.v. intraoperatively, followed by the same dose i.v. every 6 h for 24 h. We have not seen adverse effects of combined outflow resistance testing and shunting procedures performed at the same time.

All 4 children who had their shunt removed after testing have had an uneventful clinical development during follow up (1-4 years). Control CT scans have demonstrated unchanged ventricular size and preserved subarachnoid space over the hemispheres after 1 and 2 years.

### Discussion

Implantation of VA or VP shunts is now the most common procedure in pediatric neurosurgery. The results of CSF diversion are generally good in terms of improved clinical development, normalization of the head circumference and reduced ventricular size demonstrated by CT scans. As long-term experience with VA and VP shunts accumulates, a number of problems related to shunt...