Endoscopic Third Ventriculostomy and Choroid Plexus Cauterization for Pediatric Hydrocephalus

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In March of 2000, my family and I moved to Mbale, Uganda, to help Children's United Rehabilitation Effort International (CURE) International develop a neurosurgical hospital for children. It became immediately apparent that hydrocephalus was an enormous problem in this part of the world. Based on the numbers of infants younger than 1 year of age presenting to our hospital with hydrocephalus from the neighboring districts and the known populations and birth rate, it was conservatively estimated that in Uganda, a country with 28 million people, between 1000 and 2000 new cases of hydrocephalus occurred during infancy each year. I established that neonatal infection was the single most common etiology of hydrocephalus in this part of the world.[10]

Although shunting is the standard method of treating hydrocephalus, it is fraught with difficulties. For instance, the North American Shunt Design Trial failure rate was more than 40% within 3 years of the shunt placement.[2] Shunt dependency is even more problematic in the setting of a country such as Uganda, where poverty, poor infrastructure, insecurity, and the scarcity of facilities and personnel prepared to deal with shunt problems create an enormous barrier to accessing appropriate care in the event of a shunt malfunction or infection. With support from CURE International and the International Federation for Spina Bifida and Hydrocephalus, I was able to investigate the efficacy of endoscopic third ventriculostomy (ETV) in this context.

ETV AS PRIMARY TREATMENT IN ALL PATIENTS

Every child presenting with hydrocephalus underwent ventriculoscopy for attempted ETV. In those cases in which the cerebrospinal fluid (CSF) was murky or bloody from previous ventriculitis, a ventricular access device was placed for serial tapping until the CSF was sufficiently clear to allow ventriculoscopy. The technique used has been described,[10,14] but is similar to that of others. A flexible steerable fiberoptic neuroendoscope was used to inspect the ventricular system and, if deemed safe to proceed, an opening was made in the third ventricular floor posterior to the dorsum sellae with a blunt dissection technique with a Bugby wire, and the endoscope was passed into the interpeduncular and prepontine cisterns. The ETV was not considered complete unless all membranes, including that of Liliequist, had been fenestrated to reveal a naked basilar artery complex. In the analysis, patients were stratified according to the etiology of hydrocephalus (postinfectious hydrocephalus [PIH]; nonpostinfectious hydrocephalus [NPIH]; or myelomeningocele [MM]) and age (older or younger than 1 yr). The age groups were further stratified according to whether the aqueduct of Sylvius was open or closed on endoscopic inspection (Type A, open, $<$1 year; Type B, open, 1year; Type C, closed, $<$1year; or Type D, closed, 1year). Our initial experience with attempting ETV in 300 consecutive children showed favorable results among all children older than 1 year of age (80% success for both PIH and NPIH), as well as among those infants younger than 1 year with PIH in whom the aqueduct was obstructed (PIH Type C, 70% success).[10,14] However, for all other infants younger than 1 year old (including those with MM, other congenital forms of hydrocephalus, and PIH with an open aqueduct), shunting was successfully avoided in less than 50%[10,14] (*Tables 13.1*–3). A better treatment alternative for these infants was needed.

ETV COMBINED WITH CHOROID PLEXUS CAUTERIZATION

Possible reasons why ETV was less successful in young infants included deficient CSF absorption. The observation that ETV was very effective in infants with postinflammatory aqueduct obstruction (PIH-C), in contrast to those with congenital aqueduct obstruction (NPIH-C), suggested that infants in whom a congenital obstruction (e.g., aqueductal stenosis) had been bypassed by ETV may not, until that point, have had an opportunity to develop competent CSF circulation and absorption pathways, whereas those with PIH-C would have done so before the time of the infection. It seemed logical, then, to include endoscopic cauterization of the choroid plexus (CP) at the time of the ETV, because obliteration of CP in the lateral ventricles had been demonstrated to decrease CSF production.[8] It was hypothesized that even a temporary

0148-703/07/5401-0078

TABLE 13.1. Successful outcomes with endoscopic third ventriculostomy alone for each etiology of hydrocephalus according to age[a]

	Age	Success
PIH	<1 yr	59%
	>1 yr	81%
NPIH	<1 yr	40%
	>1 yr	90%
MM	<1 yr	40%

[a]PIH, postinfectious hydrocephalus; NPIH, nonpostinfectious hydrocephalus; MM, myelomeningocele.

TABLE 13.2. Successful outcomes with endoscopic third ventriculostomy alone for postinfectious hydrocephalus according to age and aqueduct status

Age	Aqueduct	Success
<1 yr	Open	45% (14/31)
	Closed	70% (44/63)
>1 yr	Open	78% (7/9)
	Closed	80% (8/10)

TABLE 13.3. Successful outcomes with endoscopic third ventriculostomy alone for nonpostinfectious hydrocephalus according to age and aqueduct status

Age	Aqueduct	Success
<1 yr	Open	31% (8/26)
	Closed	48% (11/23)
>1 yr	Open	67% (4/6)
	Closed	100% (10/10)

reduction in CSF production might bring it into balance with the existing rate of absorption while the subarachnoid spaces had a chance to adapt to the new CSF influx resulting from the ETV.

The technique of the CP cauterization (CPC) has been described.[14] After the ETV, attention is turned to the CPC. Beginning at the foramen of Monro and gradually moving posteriorly, the CP of the lateral ventricle is thoroughly cauterized using the Bugby wire and low-voltage monopolar coagulating current. In cases of severe ventriculomegaly, a portion of the CP in the anterior roof of the third ventricle is often available for cauterization as well. Care is taken to avoid injury to the thalamostriate and internal cerebral veins or ependymal surfaces. Special attention is paid to the complete coagulation of all vessels within the plexus, including the superior choroidal vein along its entire length. At the level of the atrium, the glomus portion of the CP is thoroughly cauterized. Then, passing the scope posterior to the thalamus, its tip is flexed and turned to direct the procedure along the CP of the temporal horn, which is then cauterized in similar fashion beginning from its anterior extreme and advancing the wire posteriorly along its length. Cautery is continued until all visible CP has been coagulated and shriveled. For cases in which the septum pellucidum is intact, a septostomy is performed superior to the posterior edge of the Foramen of Monro to gain access to the contralateral CP, where the same procedure is performed in the left lateral ventricle. Uncommonly, bleeding (usually venous) may be encountered from the CP. In such cases, I have found it most efficiently controlled by tamponading it with the Bugby wire while gently irrigating for a couple of minutes until the bleeding stops. The bilateral CPC typically adds approximately 20 minutes to the procedure.

Just as the results of ETV alone as the primary treatment had been prospectively evaluated in the initial group of patients, the prospective data collection continued as CPC was unselectively added to the ETV in subsequent patients.[14] Among 550 patients in whom ETV was completed, 284 underwent ETV alone and 266 underwent the combined ETV/CPC procedure. The results of the study are summarized in *Figures 13.1–13.3*. The operative infection and morbidity rates were both less than 1% and the operative

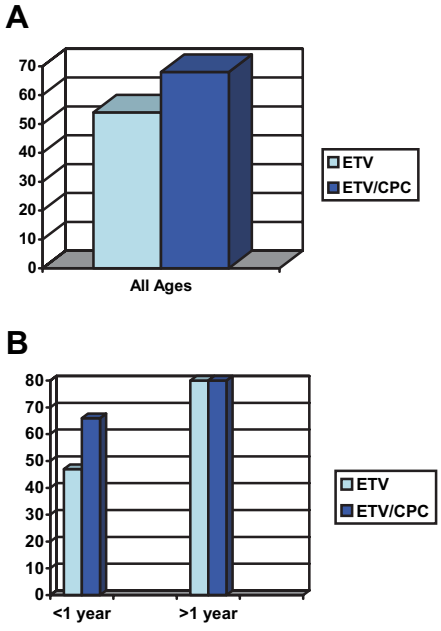

FIGURE 13.1. Percent success for ETV/CPC compared with ETV alone in (*A*) all age groups (n = 523, $P = 0.0006$); and (*B*) ages younger than 1 year and older than 1 year (<1 yr, n = 423, $P < 0.0001$; 1 yr, n = 100, $P = 1.0$).

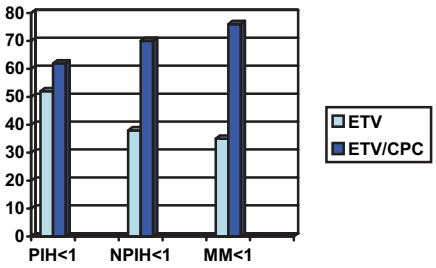

FIGURE 13.2. Percent success for ETV/CPC compared with ETV alone in infants younger than 1 year of age according to the etiology of hydrocephalus (PIH, n = 251, $P = 0.1607$; NPIH, n = 101, $P = 0.0025$; MM, n = 65, $P = 0.0045$).

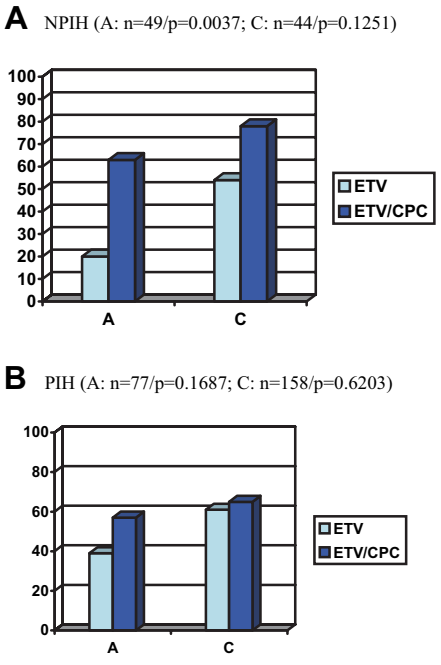

FIGURE 13.3. Percent success for ETV/CPC compared with ETV alone for Type A (<1 year of age with open aqueduct) and Type C (<1 year of age with closed aqueduct) patients with NPIH (*A*) and PIH (*B*). *A*, NPIH (Type A, n = 49, $P = 0.0037$; Type C, n = 44, $P = 0.1251$). *B*, PIH (Type A, n = 77, $P = 0.1687$; Type C, n = 158, $P = 0.6203$).

mortality rate (death from any cause within 30 d of surgery) was 1.3% (<1% for ETV/CPC). Failure was defined as the ultimate requirement for a shunt as determined by a continued abnormally rapid rate of head growth, tense anterior fontanel, increasing ventricular size, and/or continued or progressive symptoms of elevated intracranial pressure. Mean follow-up times were 19 months for the ETV group and 9.2 months for the ETV/CPC group; and 3.8% of patients were lost to follow-up at less than 1 month and were excluded from further analysis.

ETV/CPC was significantly more successful in avoiding shunting than ETV alone in infants younger than 1 year of age ($P < 0.0001$). There was no advantage in children older than 1 year of age ($P = 1.0$). When stratified by etiology of hydrocephalus, the differences in outcome between ETV/CPC and ETV alone for the subgroups of NPIH and MM were statistically significant ($P = 0.0025$ and 0.0045, respectively) and, although there seemed to be an apparent advantage in the PIH group, this was not statistically significant ($P = 0.16$). Stratifying the patients into even smaller groups according to whether the aqueduct ostium was open or closed on direct endoscopic inspection demonstrated that the addition of CPC maintained a statistically significant advantage in the smaller group of NPIH-A, an apparent but not significant advantage for the NPIH-C and PIH-A groups, and no apparent advantage among patients with PIH-C.

Although the results for ETV alone among infants younger than 1 year of age had been best overall in the PIH group, with the addition of CPC to the procedure, the NPIH and MM groups demonstrated the best success rates. When the PIH infants were stratified according to whether the cistern was scarred or clear, as noted at the time of the ETV, there was a very strong correlation between cisternal scarring and ultimate failure (*Table 13.4*). Infants with PIH (Types A and C) and no cisternal scarring had a success rate of almost 80%, whereas only 40% of those with cisternal scar succeed in remaining shunt free ($P = 0.0001$) (BC Warf, unpublished data).

The conclusion from these data is that infants younger than 1 year of age in the hydrocephalus etiology categories of NPIH, MM, and PIH-A (the poor outcome groups for treatment with ETV alone) benefited from the combined ETV/CPC procedure.[13,14] Furthermore, if those with cisternal scarring are excluded, nearly 80% of infants with PIH were able to successfully remain shunt independent. The protocol that developed from this was to proceed with shunt placement in those infants with PIH who had significant cisternal scarring (which accounted for approximately one-third of those with PIH). Among all other infants, shunting was avoided in more than 70% overall. ETV/CPC was performed in those with NPIH (70% success), MM (76% success), and PIH-A (71%

TABLE 13.4. Effect of cisternal scarring on success of endoscopic third ventriculostomy (±choroid plexus cauterization) among infants with postinfectious hydrocephalus

Cistern	Good	Fail
Clean	79 (79%)	21
Scarred	22 (36%)	39

$P = 0.0001$

success), whereas those with PIH-C did just as well with ETV alone (83% success).

APPLICATION TO THE DEVELOPED WORLD

Congenital Hydrocephalus

The overall results of ETV/CPC for infants with congenital forms of hydrocephalus (NPIH and MM) should not vary with race or geographic region. ETV/CPC was safe (<1% infection, morbidity, and mortality) and significantly more effective (70% and 76% success, respectively) than ETV alone (<40% success for both).[13,14]

However, any new technique should be compared regarding safety and efficacy with the current standard of care and *Table 13.5* demonstrates an initial comparison of the technique to shunting in a historical control group. Seventy-eight infants with hydrocephalus associated with MM, a homogenous population, were identified who had a minimum of 1-year postoperative follow-up. Placement of a ventriculoperitoneal shunt (VPS) was the primary treatment in 44 of these patients and ETV/CPC was the primary treatment in 34. This is a comparison of two similar populations (MM < 1 yr of age), representing the time periods before and after our institution of ETV/CPC as the primary treatment in these infants. The two primary treatment groups were compared in terms of infection, number of patients requiring additional hydrocephalus-related surgery within the first year (including VPS placement in those who failed ETV/CPC), and death from any cause within the first year. There was a lower primary infection rate with ETV/CPC, and there was no difference in the percentage of patients requiring additional surgery or mortality within the first year. This suggests no disadvantage to treating all infants with MM primarily by ETV/CPC instead of shunting, even though some will require conversion to a shunt (75% of failures occurring within 2 months and 95% within 6 months). Beyond 1 year, those in whom ETV/CPC has been successful subsequently avoid the known ongoing lifetime risk of shunt failure.

Together, these data support the broad application of the ETV/CPC technique to this patient population. However, there are at least two potential objections. First, the risk of late ETV/CPC failure is unknown. There is, however, literature to suggest that late failure of ETV can occur, but this seems to be rare.[3] That it occurs at all, however, is cause to admonish parents and patients that a shunt-free treatment of hydrocephalus should not be considered a "cure" and continued clinical vigilance is to be advised. The second objection is that shunting leads to smaller ventricles. My observation of ventricular volume changes after ETV/CPC in infants with MM is similar to that reported by others regarding ETV alone. *Figure 13.4* demonstrates the change in frontooccipital horn ratios (as a reflection of ventricular volume) among 18 MM infants treated successfully by ETV/CPC. It can be seen that, although the ventricles deflate or stabilize during the first 3 to 6 months, they do not achieve a normal size (frontooccipital horn ratios < 0.3). There is, however, no evidence that normal-sized ventricles are essential to normal neurocognitive development. In fact, evidence suggests that psychomotor development and the progress of myelination correlate well with one another and (negatively) with elevated intracranial pressure, but do not correlate with ventricular volume.[4,5,9] Furthermore, the chronic and difficult problems of children with slit-like ventricles from shunting are far from insignificant, and this problem is avoided when the hydrocephalus is treated without a shunt.

There are, then, compelling reasons to prefer ETV/CPC in infants with NPIH and MM as an alternative to shunting in the developed world. Long-term outcome studies that include neurocognitive development, survival, and cost are needed. Because the hazards of life-long shunt dependency are well known, many would argue that a procedure that offers a more than 70% chance of avoiding a shunt and has a demonstrated infection, morbidity, and mortality rate of less than 1% should be offered as a reasonable—and probably, desirable—option to families.

Postinfectious and Posthemorrhagic Hydrocephalus

The most important difference between the Ugandan experience and the developed world is, of course, the fact that PIH is common in Uganda and rare in developed countries, whereas the converse is true for posthemorrhagic hydrocephalus (PHH) resulting from intraventricular hemorrhage (IVH) of prematurity. There is, however, reason to suspect that ETV/CPC will be a useful treatment alternative in this population as well. As is the case with PIH,[10] PHH is often marked by internal (e.g., aqueduct obstruction) or external

TABLE 13.5. One-year outcome among myelomeningocele patients treated primarily with ventriculoperitoneal shunt or endoscopic third ventriculostomy/choroid plexus cauterization[a]

	Cerebrospinal fluid infection	No. of patients reoperated <1 yr	Death <1 hr (any cause)	n
VPS	4 (9%)	9 (20%)	11 (25%)	44
ETV/CPC	0 (0%)	6 (17.6%)	7 (21%)	34

[a]VPS, ventriculoperitoneal shunt; ETV, endoscopic third ventriculostomy; CPC, choroid plexus cauterization.

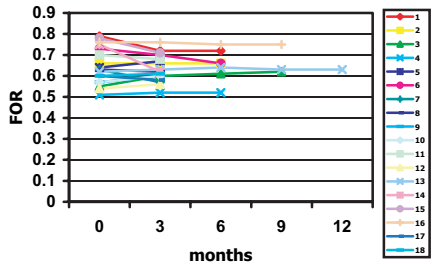

FIGURE 13.4. Frontooccipital horn ratios (FOR) over time among 18 MM infants treated by ETV/CPC.

(posterior fossa scarring) obstruction.[7] Furthermore, interference with CSF absorption at the level of the subarachnoid spaces and arachnoid granulations by blood and particulate matter has also been implicated in the pathogenesis of hydrocephalus after IVH.[1,6,7] ETV could be expected to bypass sites of obstruction, and the addition of CPC could potentially bring production and absorption into sufficient balance to avoid shunt dependency. There is reason to suspect that the response to treatment by ETV/CPC for aqueductal obstruction in PHH might be similar to that in PIH-C, whereas that for PHH without aqueductal obstruction might resemble that in patients with PIH-A. Thus, investigating the outcome of ETV/CPC in these patients as an alternative to shunting (with its known complications and failures) seems warranted.

CONCLUSIONS

A new treatment would be recommended if it were more effective, safer, and less costly than the existing treatment. There is reasonable data regarding safety and efficacy to support ETV/CPC as the primary treatment of hydrocephalus in infants, and the unanswered questions of long-term outcome and neurocognitive development, as well as its efficacy in PHH, need to be investigated. It should be recalled, however, that ETV in older patients with aqueductal obstruction has come into favor as the preferred treatment based on reported outcomes and without the benefit of a prospective randomized trial comparing the procedure to shunting. In addition, it is good to place these considerations in the perspective of the history of the use of shunts, which came into widespread use based on clinical series demonstrating their usefulness, despite high failure rates. Furthermore, a burgeoning array of new, and costly, shunt valve designs has continually been brought into use without any requirement for demonstrating their superiority over existing technology.[11,12] That shunting is familiar and technically easy should not unduly influence its choice as the "best" treatment. Compared with the neuroendoscopic management of hydrocephalus as the primary treatment, there is no evidence that shunting is superior, and the present evidence would suggest the contrary.

A definitive answer to the question of which treatment is best could be determined by a prospective randomized controlled trial of VPS placement versus ETV/CPC in hydrocephalic infants with MM and NPIH. There is, in my opinion, a problem of sufficient equipoise in this case, given the known disadvantages and dangers of shunt dependency. The ethics of creating shunt dependency in the face of a procedure with less than 1% mortality, morbidity, and infection that offers a 70% or greater chance of shunt independence should be questioned.

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