Child's Nerv Syst (1997) 13:369–374

ORIGINAL PAPER

Erwin Cornips
Frank Van Calenbergh
Chris Plets
Hugo Devlieger
Paul Casaer

Use of external drainage for posthemorrhagic hydrocephalus in very low birth weight premature infants

Received: 8 January 1997

E. Cornips · F. Van Calenbergh (✉)
C. Plets
Department of Neurosurgery,
University Hospital Gasthuisberg,
Catholic University of Leuven,
Herestraat 49,
B-3000 Leuven, Belgium
Tel.: (32) 16-34 42 90
Fax: (32) 16-34 42 85
e-mail:
frank.vancalenbergh@uz.kuleuven.ac.be

H. Devlieger · P. Casaer
Department of Pediatrics,
University Hospital Gasthuisberg,
Catholic University of Leuven,
Herestraat 49,
B-3000 Leuven, Belgium

Abstract To treat progressive posthemorrhagic hydrocephalus we used early external ventricular drainage (EVD) in 14 premature infants. We think it is important that the catheters in these critically ill infants be inserted in the neonatal intensive care unit, allowing us to keep the infants in an extremely stable environment. Only after prolonged external ventricular drainage (on average 38.4 days) is a ventriculoperitoneal shunt considered, preferably when the child has reached a body weight of 2000 g. There were no infections or other severe drainage-related problems. We report mean daily EVD volumes (which are related to body weight) and EVD duration. The 14 patients included 9 who required permanent shunting. Comparing the mortality, morbidity and follow-up data to at least 3 months of age in this group with similar data for an earlier cohort treated with lumbar punctures and late permanent shunting, we demonstrate the safety of the policy we have recently adopted.

Key words Prematurity · Periventricular hemorrhage · Intraventricular hemorrhage · Posthemorrhagic hydrocephalus · External ventricular drainage

Introduction

An increasing number of very low birth weight (VLBW) premature infants are surviving owing to the continuing improvements in neonatal intensive care. These same improvements are likely to lower the incidence of peri- and intraventricular hemorrhage (PVH-IVH) [18], but their overall effect is that more of these children are surviving. In recent studies IVH rates have still been greater than 40% [7]. Although in large population studies there may be rates of less than 30% [4], even in an advanced neonatal intensive care unit (ICU) the incidence may indeed remain as high as 40% in VLBW infants [16]. This IVH and the resulting posthemorrhagic hydrocephalus (PHH), occurring in 15–25% of neonates with moderate and 65–100% of those with severe hemorrhage [19], are still among the most serious complications in neonatal ICUs, owing to the difficulties involved in their treatment, to the directly or indirectly related mortality and to the incidence of developmental delay, cerebral palsy, epilepsy and visual impairment in those who survive. Some of these children, however, survive with only minor deficits. Therefore, our efforts to improve existing treatment protocols should continue. Furthermore, it is important to improve the predictive criteria used to decide on the need for intervention for PHH [5], since the intervention itself may actually cause additional brain injury.

Modalities proposed in the literature to treat progressive PHH include: drugs, such as acetazolamide, that reduce cerebrospinal fluid (CSF) production [10], serial lumbar [11] or ventricular taps, external ventricular drainage (EVD) [9], subcutaneous (SC) reservoirs [13], and ventriculoperitoneal (VP) shunts. All of these have significant drawbacks, especially in the VLBW infant. Recently the intraventricular administration of fibrinolytics, such as streptokinase, has been suggested to resolve PHH [21, 22]. Several protocols are being studied, since the efficiency might be related to timing, dosage and duration of fibrinolytic treatment [12].

We present our experience using a protocol of early EVD implemented as soon as a short series of lumbar punc-

tures (LPs) proves to be inefficient or, less frequently, even without preceding LPs. Catheter placement is not carried out in the operating room (OR), but in the most comfortable and safest setting for these critically ill infants, the neonatal ICU, and is supervised by a neonatologist. This obviates the need for transportation to the OR with all its inherent risks [6]. The actual VP shunt (if indicated) is preferably delayed until the baby weighs approximately 2000 g. Finally, we compare this group of patients with an earlier cohort treated with many more LPs without consideration of EVD placement.

Patients and methods

EVD group

We studied the 14 preterm infants treated with EVD in the neonatal ICU of our institution in the period of March 1993 to April 1995. Of these newborns, 4 had a low first minute Apgar score (2 or 3), while another 6 had a slightly higher score (5 or 6). The lowest score after 10 min was 6 (1 newborn), the others all scoring ≥8. All newborns developed a grade III or IV PVH-IVH according to Papile [15], confirmed by bedside ultrasonography (US). These infants, who were invariably treated with EVD after a short series of LPs that proved to be inefficient, will be collectively called the 'EVD group' (Table 1). Five of them were delivered per vaginam, and 9 by cesarean section. One baby was one of twins, and another, one of triplets. Five babies were born after premature rupture of the membranes, 2 because of uncontrollable contractions and the others because of fetal distress (Rhesus immunisation with hydrops fetalis), pre-eclampsia or abruptio placentae. All 14 patients developed respiratory problems, most frequently severe hyaline membrane disease, with or without associated open ductus Botalli. All patients were artificially ventilated from day 1 onward for a mean duration of 10.8 days. Five patients received surfactant therapy. The first US examination was performed on day 4 on average. By day 7 all patients had shown US evidence of PVH-IVH, among them 4 on the day of birth and 5 more in the next 2 days. PHH was diagnosed on average 6.2 days after birth.

Table 1 Patient characteristics in both groups (*EVD* external ventricular drainage, *LP* lumbar puncture, *IVH* intraventricular hemorrhage)

	EVD group (*n*=14)	LP group (*n*=15)
Gestational age (weeks)	24–31 5/7	26–32
Gestational age (mean)	29	29 2/7
Birth weight (g)	775–2000	694–1980
Range mean (g)	1273	1244
<800	1	1
800–1200	7	6
1200–2000	6	8
>2000	0	0
IVH grade III	10	11
IVH grade IV	4	4
Sex ratio (M/F)	5/9	7/8

Surgical procedure

According to our protocol the ventricular catheters in these infants with severe respiratory distress and in poor general condition are inserted in the neonatal ICU and not in the OR [6]. No antibiotics other than those already being given for other reasons are administered. Depending on the condition of the child, as judged by the neonatologist, in some cases general anesthesia is preferred (using propofol or fentanyl), while in other cases local anesthesia (with diluted xylocaine 1% without adrenaline) is adequate. A small semicircular incision is made in the right frontal region, slightly anterior to the coronal suture and centered on the midpupillary line. After splitting of the periost, the skull is opened with the point of a standard no. 25 blade rotated like a hand-held drill. A mosquito forceps is used to remove the tiny bone particles from the edges of the hole. To prevent leakage, special care is taken that the hole is not larger than needed to accommodate the catheter. A mini-redon needle is now tunneled subcutaneously starting in the incision and exiting at least 3 cm away from it. After cauterization of the dura and puncturing of the cortex the catheter is inserted in the frontal horn. Tunneling of the ventricular catheter attached to the redon needle minimizes the risk of leakage and infection. The incision is closed with 4/0 sutures and the catheter fixed to the skin with two polyester 3/0 stitches, the first of them being as close as possible to the exit point of the tunneled trajectory. The catheter is connected to a closed-system external drainage set consisting of a graduated cylinder (equipped with a bacterial filter) and a collection bag (Cordis, Miami, Fla.). Postoperatively in these 14 neonates we routinely checked CSF samples taken at the three-way stop-cock distal to the graduated cylinder every other day. Whenever we found a positive gram stain or culture the entire system, including the ventricular catheter, was promptly removed and a new one inserted. Additional antibiotics were given for at least 4 days, as long as it took to exclude a true ventriculitis. We define "ventriculitis" as pleiocytosis and positive cultures of the sample taken directly from the ventricle during insertion of the new catheter, with or without clinical signs. On the other hand we define "colonization" as a positive gram stain and/or culture of the sample taken at the distal three-way stopcock, but with no fever, no other clinical signs, no pleiocytosis and no growth of the culture of the sample taken from the ventricle during insertion of the new catheter.

LP group (control group)

Looking for an (historical) "control" group, we found 15 preterm infants treated in our institution between 1985 and 1991, when we were treating even massive hemorrhages with serial LPs and (if necessary) late permanent shunting. All had a grade III or IV PVH-IVH. These infants, all treated with serial LPs for a prolonged period of time, will be collectively called the 'LP group' (Table 1). All patients had shown US evidence of PVH-IVH by day 19 of life (11 by day 8). PHH was diagnosed on average 7.4 days after birth.

Gestational age, birth weight, IVH grade and male-to-female ratio for both groups can be found in Table 1, showing a near-perfect match for gestational age and birth weight.

Data collection

Data were collected concerning the day of PHH diagnosis, age at first LP, total number of LPs, number of patients being submitted to ten or more LPs, volume drawn at each LP. Furthermore, we assessed age and weight at EVD, increase in head circumference during the week before EVD, mean daily EVD volume and weekly evolution of the mean daily EVD volume for the entire group, mean first-week EVD volume as a function of weight at EVD (each patient, regression analysis for the group), EVD duration, number of EVD episodes (number of revisions), complications of EVD (especially infections), and finally, whether a permanent shunt was eventually needed and

how this was decided, the timing of any permanent shunt, and the total hospital stay to first discharge.

Follow-up in these infants is presented for at least 3 months after the EVD procedure. In the EVD group, 6 patients have a minimum follow-up of 1 year, and 1 has been followed up elsewhere (no data available). In the LP group, 9 patients have been followed up for more than 3 years, and 3 patients for more than 1 but less than 3 years; as in the EVD group, 1 has been followed up elsewhere (no data available). As a measure of outcome we assessed psychomotor development and noted focal motor deficits, epileptic seizures and visual impairment. None of the patients in the EVD group has died so far, although 5 had a birth weight of less than 1000 g and 5 were born after a pregnancy of under 28 weeks. Furthermore, all of them went through a period of significant respiratory distress, 5 patients receiving surfactant therapy. In the future we plan to present a second study with long-term follow-up data on these same infants.

For statistical analysis Chi-square analysis, paired *t*-testing and regression analysis were used.

Results

Both groups were initially treated with LPs. The total number of LPs performed as a result of the old and new treatment protocols, however, was clearly different: a mean of 9 (range 0–14) for the EVD group and a mean of 16 (range 7–24) for the LP group ($P<0.0001$). In the EVD group only 6 of the 14 children received more than ten LPs, as against 12 of the 15 in the LP group (not significant). The mean volume evacuated by successful LP was 7.85 and 7.79 ml respectively, with frequent "dry taps" and a rare maximum of 22 ml (Table 2). It has to be noted that 1 EVD was introduced (at age 9 days) without preceding LPs, and that 3 more children, having undergone multiple, unsuccessful LPs, subsequently received their EVD. Thus, in 4 of these 14 children, the first CSF evacuation was through the EVD.

The mean age at the time of the EVD procedure was 22.5 days (ranging from 9 to 53 days), and as many as 10 of the 14 patients received their EVD by the 25th day after birth. Five patients had a weight of <1000 g at that time, another 7 between 1000 and 2000 g, and only 2 weighed over 2000 g (Table 3). A dramatic increase in head circumference was mostly apparent the week before the procedure, illustrating the insufficient evacuation of CSF even by repeated LPs. Duration of EVD is represented in Fig. 1: most frequent was an EVD duration of 20–40 days but in three infants it was in the range of 40–60 days, including one or more revisions. Three patients thus had two EVD episodes of approximately 2–3 weeks' duration each, 2 patients had 3 episodes and 1 even had 4 episodes (3 revisions). Mean duration of EVD was 38.4 days or 5 1/2 weeks. One infant had an EVD for as long as 91 days, but was finally successfully "weaned" and did not require a permanent shunt.

The mean daily EVD volume was 23.4 ml. We did not observe a decline over time (Table 4). Mean daily EVD volume the first postoperative week was 22.8 ml. The mean daily EVD volume the first postoperative week (for individual patients) was statistically analysed in relation to their weight at operation. As shown in Fig. 2, a linear correlation was found by regression analysis (Y=8.364+ 9.663E-3**X*; $R\hat{}2$=0.564). For example, for an infant of 1200 g a daily drainage volume of 20 ml can thus be expected (during the first week).

Permanent shunting was inevitable in 9 of the 14 infants in the EVD group and in 7 of the 15 in the LP group (not significant). The latter group was operated on much later: on average on day 162 (LP group) as against day 85 (not significant). Even after an EVD time ranging from 21 to as much as 91 days, a permanent shunt was avoided in 5 children (at a daily CSF evacuation rate of 25–40 ml during the last EVD week). Whenever the CSF analysis had normalized (protein content <200 mg/100 ml) and the

Table 2 Lumbar punctures (in both groups)

	EVD group (*n*=14)	LP group (*n*=15)
Age at 1st LP (days)	10.4	11.3
Total no. of LPs	9.1	15.5
Patients >10 LPs	7 (50%)	13 (87%)
Volume/LP		
Mean (ml)	7.85	7.79
Min.	0	0
Max.	22	22

Table 3 Patient characteristics by the day the EVD was inserted (EVD group, *n*=14; *HC* head circumference)

Age (days)	22.5
Weight (g)	
<1000	5
1000 –2000	7
>2000	2
Increase in HC in last week (cm)	
0–1	3
1–2	5
>2	6

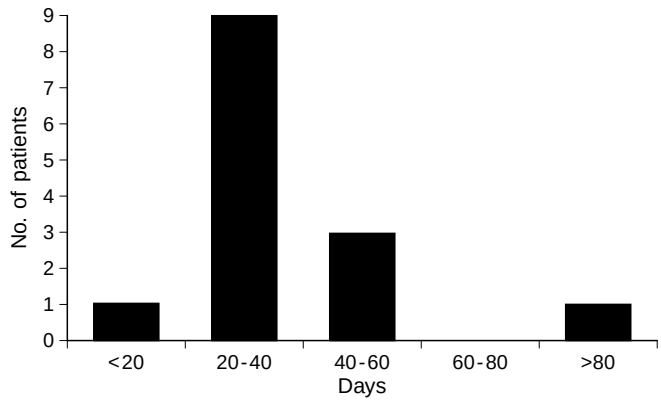

Fig. 1 Graph illustrating the duration of external ventricular drainage in the EVD (external ventricular drainage) group

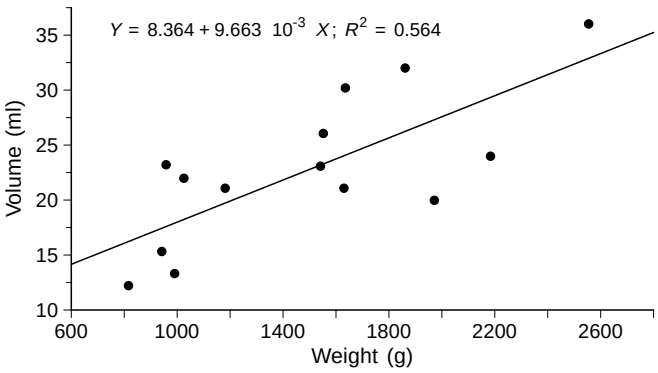

Fig. 2 Regression plot comparing the average daily volume of CSF (in ml) evacuated by EVD during the first week, with the weight of the infant at EVD placement (g)

Table 4 Mean daily EVD volume for the entire group, as a function of time. Overall mean daily EVD volume was 23.4 ml and mean EVD duration, 38.4 days

Mean daily EVD volume (ml)		No. of patients[a]
Week 1	22.8	14
Week 2	22.9	14
Week 3	20.35	13
Week 4	25.13	9
Week 5	26.6	8
Week 6	31.8	4

[a] No. of patients (total=14) with EVD for as many weeks as indicated

Table 5 Outcome measures (*VPS* ventriculoperitoneal shunting)

	EVD group (*n*=14)	LP group (*n*=15)
Infection (ventriculitis) before VPS	0	1
Permanent shunt dependence	9	7
Days after birth at VPS operation	85	162
Days after birth at 1st discharge	96.5	86
Development		
Normal	4	5
Mild retardation	3	5
Moderate retardation	4	1
Severe retardation	3	3
Focal motor deficit		
Mild	1	2
Moderate	2	1
Severe	0	3
Total	3	6
Epilepsy	1	3
Visual impairment	3	2

child was doing well so that successful weaning was possible, the EVD was removed. If weaning was unsuccessful a VP shunt was implanted, preferably when the child had reached a weight of over 2000 g (6 out of 9 shunted infants).

We recorded all complications we encountered using the EVD protocol in these 14 neonates. There were no CSF infections ("ventriculitis," defined as above). In contrast there were three episodes of "colonization," all with coagulase-negative *Staphylococci*, while the CSF aspirated directly out of the ventricles immediately after changing the catheter showed no inflammatory signs, a negative gram stain and no bacterial growth. Leakage occasionally occurred but could always be controlled at the bedside by an additional stitch. Hyponatremia was usually prevented by routine NaCl substitution and was never a major problem. In 1 patient a subdural effusion was diagnosed on CT scan. It resolved spontaneously without any additional treatment.

The length of hospital stay was not significantly different in the two groups: 96.5 vs 86 days after birth (Table 5).

A summary of psychomotor function testing results is given in Table 5. There seems to be a tendency towards more focal deficits and more epilepsy in the LP group, although these data are difficult to interpret because of the small number of patients and the unequal follow-up periods. No significant differences were observed in the vision tests, with 3 and 2 patients, respectively, having serious visual impairment (more than strabismus only).

Discussion

The use of EVD as a treatment modality for PHH in the newborn has long been reported [2, 9, 17, 20], but even recently some authors found "an unacceptable infection rate when using external drainage devices as temporizing measures" [8]. We changed our protocol to early EVD in 1992 and wanted to demonstrate its safety and efficiency compared with the previous protocol. We compared 14 infants treated with early EVD with 15 infants treated with repeated LPs. The two groups were matched for gestational age, birthweight and grade of bleeding. All children survived. It is believed that the extent of IVH is a predictor of PHH, whereas the localization and extent of major intraparenchymatous hemorrhage is a predictor of neurological deficit at follow-up. Ischemic injury might be the major source of later neurodevelopmental problems [1]. The most important questions now are how (and what) treatment can influence this outcome, and how the risks of iatrogenic complications following these therapeutic interventions can be minimalized.

It seems to be important that the EVD insertion in these critically ill infants be carried out in the neonatal ICU instead of the OR. Finer et al. [6] were the first to demonstrate that the unstable neonate can undergo surgery in the neonatal ICU with a surgical morbidity and mortality comparable to that seen in the OR. Furthermore, these authors reflected on all the possible benefits: avoidance of the transport process, continued care by people who are familiar with the infant, its vascular access and ventilation, and

ease of planning independently of a busy OR schedule. Transportation does indeed destabilize the already critically ill neonate, because it predisposes to hypothermia, frequently results in dislodgement of intravascular catheters, and is likely to increase postoperative pain. Our experience of surgery in the ICU in the present study has been equally positive, as has also that of others in the past [9].

Apart from the location, a sterile and skillful surgical technique is important. Although the more frequently used general anesthesia was uneventful, for some infants it is even possible to use local anesthesia only. To prevent leakage and/or infection, special care is taken to see that the hole just fits the catheter, which is then tunneled with a mini-redon needle to a site distant from the incision. The catheter is connected to a low-pressure Hakim valve and an external drainage set. The CSF is checked routinely every other day.

EVD appears to be much more effective than LPs in evacuating sufficient volumes of CSF. In our series the mean CSF volume evacuated by successful LP was 7.8 ml. Not infrequently, however, little or no CSF was obtained (3 children had multiple, unsuccessful LPs only and 1 had his EVD without preceding LPs), or the ventricles further enlarged in spite of the removal of some CSF. Similar findings have been reported previously [14]. In contrast, the mean daily CSF volume evacuated by EVD, with constant adaptation of the drainage level to the clinical and radiological findings and thus to the apparent needs of the infant, was 23.4 ml, exactly 3 times as much as with a successful LP. In view of this, for treatment of a high-grade bleeding LPs seem to be insufficient. This was also concluded in a randomized study by Anwar et al. [3] and in a study on serial LPs by Kreusser et al. [11]. They believe that daily CSF volumes between 10 and 20 ml are most often necessary. Another major drawback of LPs, as of SC reservoirs, is that the removal of CSF is intermittent. The fluid build-up and resulting rise of ICP between two LPs might be detrimental, even if the overall effect is a reduction in the size of the ventricles. In our series, however, we observed a dramatic increase in head circumference the week before the EVD procedure (when serial LPs were still being done), by 1 cm or more in 11 of the 14 patients. This again proves the inefficiency of serial LPs in most of these children.

The mean age at EVD was 22.5 days. McComb et al. [14], in their study on SC reservoirs, reported a mean age of 12 days for the whole group and 17 days for survivors only. Five of our patients weighed under 1000 g at EVD placement and only 2 weighed more than 2000 g. To the best of our knowledge, the present study is the first publication to detail the CSF volumes evacuated by LP and EVD, the age and weight at EVD, and the duration of EVD. All but 1 infant had an EVD for at least 20 days, and 1 for as long as 91 days, with a mean of 38.4 days (Fig. 1). This is long compared with previously reported series: Harbaugh et al. [9] report a mean of 20.7 days without revisions. In fact we did not find any report mentioning revision of the EVD, which is another important feature of our protocol, as described above. With regression analysis we found a linear correlation between the weight at EVD and the mean daily CSF volume evacuated during the 1st week (Fig. 2). This regression plot can thus be used to guide clinicians. Apparently, a few hundred grams more in these newborns is associated with a significant increase in CSF production in response to massive IVH.

On the subject of complications that are believed to be frequent and difficult to avoid when EVD is used in these fragile newborns, the present study confirms our impression of the safety of this procedure when performed according to the proposed protocol. Obstruction of the ventricular catheter by blood clots did not prove to be a problem. Leakage at the catheter exit site was encountered infrequently and was easily controlled at the bedside. Obstruction of the external drainage set was encountered only 5 times. One subdural effusion was noted, which resolved spontaneously. Whereas we encountered a colonization of the external drainage set at routine sampling on three occasions, we did not document 1 single case of real infection (ventriculitis). We believe this has to be attributed to the technique of catheter tunneling, the quality of the nursing in the neonatal ICU and, not least, the regular routine sampling of CSF. Whenever the system was revised because of a positive CSF sample taken from the EVD set, additional antibiotics were given for a few days only, as it seems logical to stop the antibiotics as soon as the peroperative cultures remain sterile after a few days.

Even those infants with prolonged EVD (according to our protocol implicating revision of the entire system every ±3 weeks) did not necessarily require a permanent VP shunt. Whenever the CSF analysis has become normal (protein <200 mg/100 ml) and the child is doing well and has been successfully weaned, the EVD is removed. Otherwise, we wait with the VP shunt procedure until an approximate weight of over 2000 g has been reached, as was the case in 6 of the 9 shunted infants in our series. Indeed, the effect of EVD on permanent shunt dependence is still not known: does the continuous removal of bloody and protein-rich CSF reduce the requirement for permanent shunting or does long-standing EVD, on the contrary, cause the natural CSF resorption to decrease, thus predisposing to the need for a permanent shunt? In the EVD group in our study 9 of the 14 had a VP shunt implanted (64%), as against 7/15 in the LP group (47%). Harbaugh et al. [9], in their series of 11 externally shunted children, report 7 shunt-dependent children in the 9 survivors (78%) after a mean EVD duration of 20.7 days, as compared with 38.4 days in our series. We also noted a remarkable difference in the timing of VP shunt placement between the two groups: a mean of 85 days after birth in the EVD group, as against 162 days in the LP group, almost twice as long after birth. This probably reflects an evolution towards a more aggressive therapeutic approach, part of which actu-

ally is the use of EVD instead of LPs. Although there seems to be a slight increase in permanent shunt dependence with our latest protocol, the difference did not reach statistical significance. To date we can only speculate that EVD and "early" and more frequent VP shunting are not only a reflection of this more aggressive therapeutic approach, but indeed improve the overall outcome of these unfortunate infants. If so, maybe even earlier EVD placement should be considered, avoiding the stress (and inefficiency) of multiple LPs. The number of patients in both groups is too small and the follow-up too short, however, to allow any conclusions on the subject of neurological outcome. The fact that on psychomotor function scales during follow-up 33% of the EVD group had normal scores should encourage further research on the treatment of this condition.

We conclude that early EVD as a treatment for progressive hydrocephalus secondary to massive intraventricular hemorrhage in the preterm infant is both safe and efficient. The operation can be done in the neonatal ICU under local or general anesthesia, thus avoiding the hazards of transportation to the OR and keeping the infant closely monitored by the neonatologists and nursing staff. Combining correct surgical technique and quality nursing with routine CSF sampling and regular EVD revisions serious complications can be efficiently avoided. EVD daily volume was 23.4 ml on average, as compared to only 7.8 ml by "successful" LP. EVD proved to be safe for prolonged periodes of time (mean EVD duration was 38.4 days) and did not invariably make these children shunt dependent. Finally to the best of our knowledge we are the first to demonstrate a linear correlation between EVD volume and weight at EVD placement. We suggest that this equation can be used to guide clinicians at the bedside.

References

1. Allen WC, Volpe JJ (1986) Periventricular-intraventricular hemorrhage. Pediatr Clin North Am 36:47–63
2. Allen WC, Holt PJ, Sawyer LR, et al (1982) Ventricular dilatation after neonatal periventricular-intraventricular hemorrhage: natural history and therapeutic implications. Am J Dis Child 136:589–593
3. Anwar M, Hiatt IM, Kadam S, Hegyi T (1985) Serial lumbar punctures in prevention of posthemorrhagic hydrocephalus in preterm infants. J Pediatr 107:446–450
4. Bor M van de, Verloove-Vanhorick SP, Brand R, Keirse MJNC, Ruys JH (1987) Incidence and prediction of periventricular-intraventricular hemorrhage in very preterm infants. J Perinat Med 15:333–339
5. Brann BS IV, Qualls C, Papile LA, Wells L, Werner S (1990) Measurement of progressive cerebral ventriculomegaly in infants after grades III and IV intraventricular hemorrhages. J Pediatr 117:615–621
6. Finer NN, Woo Bing-Chung, Hayashi A, Hayes B (1993) Neonatal surgery: intensive care unit versus operating room. J Pediatr Surg 28:645–649
7. Gunkel JH , Banks PLC (1993) Surfactant therapy and intracranial hemorrhage: a review of the literature and results of new analyses. Pediatrics 92:775–786
8. Gurtner P, Bass T, Gudeman SK, Penix JO, Philput CB, Schinco FP (1992) Surgical management of posthemorrhagic hydrocephalus in 22 low-birthweight infants. Child's Nerv Syst 8:198–202
9. Harbaugh RE, Saunders RL, Edwards WH (1981) External ventricular drainage for control of posthemorrhagic hydrocephalus in premature infants. J Neurosurg 55:766–770
10. Hill A (1983) Ventricular dilatation following intraventricular hemorrhage in the premature infant. Can J Neurol Sci 10:81–85
11. Kreusser KL, Tarby TJ, Kovnar E, Taylor DA, Hill A, Volpe JJ (1985) Serial LPs for at least temporary amelioration of neonatal posthemorrhagic hydrocephalus. Pediatrics 75:719–724
12. Luciano R, Velardi F, Romagnoli C (1995) Case-control trial of low-dose intraventricular fibrinolytic treatment in neonatal post-hemorrhagic hydrocephalus. Paper presented at the XXIII Annual Meeting of the International Society for Pediatric Neurosurgery, Santiago, Chile, 26–29 September 1995
13. Marlin AE, Rivera S, Gaskill SJ (1988) Treatment of posthemorrhagic ventriculomegaly in the preterm infant: use of the subcutaneous ventricular reservoir. Concepts Pediatr Neurosurg 8: 15–22
14. McComb JG, Ramos AD, Platzker ACG, Henderson DJ, Segall HD (1983) Management of hydrocephalus secondary to intraventricular hemorrhage in the preterm infant with a subcutaneous ventricular catheter reservoir. Neurosurgery 13:295–300
15. Papile LA, Burstein J, Burstein R, Koffler H (1980) Incidence and evolution of subependymal and intraventricular hemorrhage: a study of infants with birth weights less than 1500 gm. J Pediatr 92:529–534
16. Perlman JM, Rollins N, Burns D, Risser R (1993) Relationship between periventricular intraparenchymal echodensities and germinal matrix-intraventricular hemorrhage in the very low birth weight neonate. Pediatrics 91:474–480
17. Pezzotta S, Locatelli D, Banfanti N, Sfogliarini R, Bruschi L, Rondini G (1987) Shunt in high-risk newborns. Child's Nerv Syst 3:114–116
18. Philip AGS, Allan WA, Tito AM, Wheeler LR (1989) Intraventricular hemorrhage in the preterm infant: declining incidence in the 1980s. Pediatrics 84:797–801
19. Volpe JJ (1981) Neonatal intraventricular hemorrhage. N Engl J Med 303: 886–890
20. Weninger M, Salzer HR, Pollak A, Rosenkranz M, Vorkapic P, Korn A, Lesigang C (1992) External ventricular drainage for treatment of rapidly progressive posthemorrhagic hydrocephalus. Neurosurgery 31:52–58
21. Whitelaw A, Rivers RP, Creighton L, Gaffney P (1992) Low dose intraventricular fibrinolytic treatment to prevent posthaemorrhagic hydrocephalus. Arch Dis Child 67:12–14
22. Whitelaw A, Mowinckel MC, Larsen ML, Rokas E, Abilgaard U (1994) Intraventricular streptokinase increases cerebrospinal fluid D dimer in preterm children with posthaemorrhagic ventricular dilatation. Acta Paediatr 83:270–272