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# Management of Post Hemorragic Hydrocephalus in Infants

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**Abstract:** Definitive treatment of progressive PHH is a VP (ventriculoperitoneal) shunt; however, this procedure is rarely used as a first intervention for several reasons: the risk of skin ulceration in very low birth weight infants, the high incidence of shunt malfunction, and frequent need of revision, among others. In many cases, the ventricular dilation will be controlled with the use of temporizing neurosurgical procedures (TNPs): lumbar punctures (LP), external ventricular drainage (EVD), insertion of a ventricular access device (VAD), or a ventriculosubgaleal (VSG) shunt. In cases where PHH is not controlled with these procedures, the placement of a VP shunt is indicated. The lack of conclusive recommendations for the treatment of this pathology makes it very difficult to have a standardized protocol; most centers use institutional guidelines, medical expertise, and available resources to guide their treatment.

**Keywords: Post hemorrhagic, Hydrocephalus, Infants.**

**Introduction:**

Many trials and prevention strategies were based on the general theory that GM-IVH incidence would decrease when optimal resuscitation of the infant could minimize CBF fluctuations, hypoxia, hypercapnia, and increased venous pressure. The perinatal period is the most significant in the prevention of GMH and has been divided into prenatal and postnatal.

Prenatal strategies are focusing on the elimination of any stress condition by optimal obstetric management and smooth delivery, judicious usage of cesarean section, and administration of steroids and vitamin K. Postnatal approaches are almost exclusively pharmacological prevention strategies. Agents designed to modulate CBF to the preterm brain may alter other developing organs or impair neurogenesis and cautious administration of these agents is mandatory.

Phenobarbital was believed to have neuroprotective effect by decreasing the metabolic rate of cerebral tissue, inhibiting seizures, and stabilizing blood pressure and production of free radicals. Antenatal administration failed to reduce GM-IVH, while postnatal administration could not be recommended for the prevention of GMH. Additionally, it was found to increase the risk for requiring mechanical ventilation.

Steroids are used routinely before delivery of premature infants. The main reason is to support respiratory function of the newborn, but it was found that the incidence and severity of GM-IVH were also decreased. Further studies demonstrated that this was not only due to the reduction of perinatal respiratory distress but directly due to potential stabilization of GM microvasculature.

Indomethacin is an anti-inflammatory agent used in preterm infants to close patent ductus arteriosus and prevent GM-IVH. Trials have shown that it decreases the rate and severity of hemorrhage in the newborn by inhibition of COX-1 and COX-2 isoforms and further decrease in prostaglandin synthesis, which possibly result in basement membrane maturation, improvement of autoregulation, and stabilization of the blood– brain barrier. It is associated with increased risk of intestinal perforation, and controversy exists about the long-term effects on neurodevelopmental outcome. Indomethacin protection against GM-IVH has been found more profound in male infants and that finding suggested that gender is an important issue in infantile GMH.

Recombinant activated factor VII (rFVII) is a hemostatic agent used in hemophiliac patients and other bleeding disorders such as major trauma, oral anticoagulation, and liver dysfunction. When administered, it binds to activated platelets and promotes a generous thrombin formation and further hemostasis. Small case series involving the administration of rFVII in neonates showed relevant safety and effectiveness and this deserves further investigation.

Other agents that were investigated are ethamsylate, ibuprofen, vitamin E, and pancuronium with results inadequate to support convincing evidence for the prevention of IVH in neonates and have limited use in current practice.

The basic anatomic structure of the germinal matrix (GM) of the premature infants may predispose them to intraventricular hemorrhage (IVH). The veins in this region make a 180° turn at the caudate nuclei and drain via internal cerebral veins. This anatomical arrangement may predispose to turbulence in blood flow and promotes platelet aggregation and vascular instability

In infants of less than 28 weeks gestation, the hemorrhage tends to occur in the head of the caudate nucleus. In full-term infants, the choroid plexus is more likely to be the location of hemorrhage.

In premature infants, the periventricular capillaries appear as immature vascular rete, and the germinal matrix has both a gelatinous consistency and a high fibrinolytic activity. These vascular natures also play an important role in the development of IVH, which leads to a disruption in the cerebrospinal fluid (CSF) and ventricular dilatation.

It is well known that 40-50% of hydrocephalus cases in premature infants, occur following GM hemorrhage (GMH). Such hemorrhages are reported to arise commonly among infants with <1500 g birth weight and <32 weeks old. Of the premature infants with IVH, 20%-50% will go on to develop ventriculomegaly, either transient or progressive.

Although survival for extremely low gestational age newborns has improved in the past three decades, the continued improvements in neonatal intensive care, the survival of infants including those that develop PHH continues to be a challenge to the pediatric neurosurgeons.

**Intraventricular hemorrhage in premature infants**

**Clinical features**

The premature IVH can present as a catastrophic event, saltatory, or as a clinical silent phenomenon. It usually occurs within 48 h of birth and 50% will occur in the first 24 h. A later onset is not uncommon, especially following a secondary hypoxic insult such as pneumothorax.

Catastrophic deterioration evolves in minutes to hours. Aggressive neurosurgical intervention is rarely considered as many of these infants do not survive this event. The salutatory or subacute presentation is seen principally in an infant with a smaller hemorrhage that evolves over hour to days.

There may be a subtle change in the decreased alertness and activity, hypotonia, abnormally tight popliteal angle, abnormal eye movements, and respiratory difficulties. Many IVHs are clinically silent and is one diagnosed by cranial ultrasonography. An unexplained decline in the hematocrit, decreased tone and activity may suggest that an IVH has occurred.

**Management of IVH**

The incidence of IVH in premature infants who weigh less than 1500 g decreased from 35%-70% to 15%-20% in the past three decades. Less than half of these children will develop transient or progressive

ventriculomegaly. Considerable ventriculomegaly can occur before any increase in IICP or head circumference is noted. It seems reasonable to treat IVH aggressively; however, too-aggressive therapy may change a small lesion to a large one. We suggest early consultation with pediatric neurosurgeon as early as possible when premature IVH with more than a subependymal hemorrhage or mild progression of ventricular dilatation is diagnosed.

*Pharmacological treatment:*

In the acute hemorrhage maintaining cerebral perfusion and lowering intracranial pressure (ICP) may be undertaken medically by decreasing the PaCO2, and perhaps using some medicine.

However, a large multicenter randomized trial showed that reduction of CSF production by acetazolamide and furosemide had a worse outcome in the treated arm. Drainage, irrigation, and fibrinolytic therapy (DRIFT) Based on the hypothesis that reducing pressure, free iron, and proinflammatory and profibrotic cytokines may reduce death and severe disability, prevention of PHH in newborn infants by DRIFT has been conducted studied in UK since 2003. A total of 77 premature babies with IVH were studied. Though DRIFT improves cognitive function in the 52 out of the 66 surviving babies after 10-year follow-up, secondary IVH is a major complication that up to 35% of the infants who received DRIFT had secondary IVH compared with 8% of the standard group. In addition, DRIFT did not reduce shunt surgery or death when tested in a multicenter, randomized trial in UK. DRIFT is still not a standard treatment for the prematurity with IVH.

*Neuroendoscopic lavage*

A study demonstrated that neuroendoscopic lavage in 19 neonates with IVH had less shunt, fewer infections, and multiloculated hydrocephalus than the 10 neonates treated with various conventional modalities. A multicenter, prospective study to verify the outcome is warranted.

*Endoscopic ventricular lavage*

Endoscopic ventricular lavage has been proposed as treatment of PHH. The hypothesis of Schulz et al. was based on the 2-year outcome results of DRIFT trial, and the removal of the hematoma would eliminate the proinflammatory cytokines, iron, and free radicals and reduce the risk of progression of the hydrocephalous.

Several studies have shown a decreased conversion to VP shunt in those who undergo an early endoscopic ventricular lavage; however, these studies have potential limitations, including the design of the studies and the small patient sample. This procedure is technically feasible but there is insufficient evidence to recommend its use.

**Management of PHH**

Transient or progressive ventricular dilatation is seen in 20%50% patients with premature IVH. Early ventriculoperitoneal (VP) shunt insertion is associated with a high failure rate and many complications in premature infants with PHH; hence, temporizing measures are always instituted until the infant is mature enough at age and/or weight. Many different approaches have been taken to achieve temporary ventricular decompression in infants with PHH. Therapeutic serial lumbar and ventricular tapping remain temporizing options in the treatment of PHH used by 10% and 30% of the neonatal units.

*Serial lumbar punctures*

Lumbar punctures (LP) is only useful when the ventricles are in communication with the lumbar subarachnoid space. Daily LPs can be used if it is necessary to stabilize the head circumference, and usually up to 10 ml of CSF is removed per LP. It is often difficult to remove sufficient quantities of CSF in these infants, and, again, the child is exposed to contamination each time.

Spinal osteomyelitis has been associated with repeated LPs. It has been suggested that daily LPs need to occur for at least 7 days to be effective whereas the repeated procedures can be traumatic for the premature infants and, therefore, not always the preferred treatment. Randomized controlled trials have failed to demonstrate a significant effect of serial LPs on the rates of morbidity, mortality or conversion to permanent VP shunt in the treatment of PHH.

Lumbar tappings are also associated with increased risk of CSF infection. Hence, early repeated LPs cannot be recommended as the mainstay treatment for neonates at risk of, or actually developing PHH and spinal taps are increasingly considered a temporizing measure in the management of PPH only for an initial period. If frequent multiple LPs are needed other measures can be used as described below.

*Serial ventricular punctures*

Repeated ventricular taps incur a new injury to the frontal lobe with each pass of a needle ("puncture porencephaly"). Each access exposes the child to the risk of infection. Ventricular taps have fallen out of favor due to the risk of porencephalic cyst formation, infection, and loculated hydrocephalus. In general, ventricular puncture should be reserved for treating infants in extremis.

*Temporary devices*

Most of the temporary devices which include external ventricular drainage (EVD), ventriculosubgaleal shunt (VSGS), and ventricular access device (VAD) can be performed at the bedside with or without anesthesia. However, with the advancement of neonatal neurocritical care, and anesthesiology the role of beside surgery of PHH became less significant considering the higher infection rate in the neonatal unit than in the operation theater.

The three temporary measures involve ventriculostomy. During cannulation of the frontal horn, Kocher's point is landmarked as a point of entry through the frontal bone for an intraventricular catheter to drain CSF. In adult or children, it is located 2.5-3 cm lateral to the midline (at approximately the mid-pupillary line) and approximately 1 cm anterior to the coronal suture.

In premature infants, because of small head size, the Kocher's point is located 1.5-2 cm lateral to the midline and approximately 0.5-1 cm anterior to the coronal suture. The distance and depth can be measured accurately by preoperative bedside ultrasound.

In addition, since the fontanel is widely open in premature infants with PHH, it is suggested to draw an imaginary line between the bilateral edges of the fontanel as the future coronal suture, then the Kocher's point can be properly located. Mostly, the non-dominant, right frontal horn is preferred unless the right side is not suitable to use due to any reason.

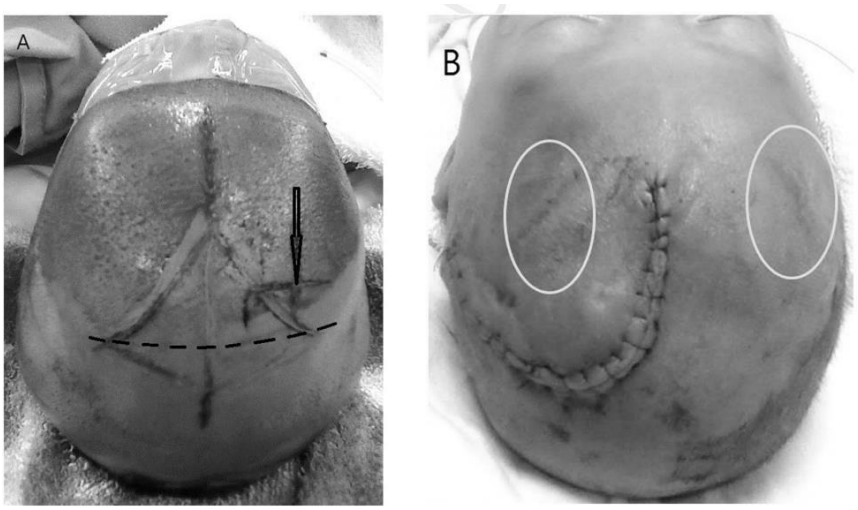


Fig. (1). (A) The Kocher's point for a proper frontal entry of the ventricular catheter is sometimes hard to locate due to the widely open fontanel in premature infant and the inexperienced of the neurosurgeons. In premature infants with PHH, it is suggested to draw an imaginary line between the bilateral edges of the fontanel as the future location of the coronal suture (dotted line), then the Kocher's point can be properly located (bold arrow). The Kocher's point is located 1.5-2 cm lateral to the midline and approximately 0.5-1 cm anterior to the coronal suture. (B) This patient was referred to the author from other institution due to repeated malfunction of the ventricular reservoirs and recurrent hydrocephalus. The old incisions for bilateral ventricular reservoir placement were located too anteriorly to the Kocher's point (circles). The baby just underwent a burr-hole typed ventriculoperitoneal shunt insertion after the body weight was good enough.

*External ventricular drainage (EVD)*

The chances of infection and the long duration required for EVD make it an unattractive option. The EVD procedures were performed with a ventricular catheter connected to a closed drainage plastic container via subcutaneous tunneling. EVD has the physiological advantage of continuous clearance of bloody CSF. Therefore, EVD reduces the spikes of intracranial hypertension which can occur with intermittent tapping. It also gives an opportunity to titrate the amount of CSF drained in order to prevent problems of underdrainage.

On the contrary, the continuous drain may induce overdrainage and results in trapped and loculated ventricle. Considering the small amount of CSF, 10 mL/kg/day, that needs to be drained in premature infants with PHH, the advantage of continuous drainage of EVD becomes less significant. The disadvantages of EVD include infection, need for repeated CSF studies, and repeated rotation of the EVD site, obstruction and dislodgement of the catheter, and CSF leakage from the exit site of EVD. Though a long-segment of EVD can be performed to reduce infection and to reduce rotation of the EVD site, EVD is not a favored way to manage PHH in pediatric neurosurgery.

*Ventriculosubgaleal shunt (VSGS)*

Since the first VSGS was performed in 1896 by von Mikulicz, VSGS has been used in chronic postoperative CSF fistulas, tumor, recurrent subdural hematoma, acute head trauma, and repeated VP shunt infections.

A VSG shunt consists of a shunt tube with one end in the lateral ventricle while the other end is inserted into the subgaleal space of the scalp. This will allow for the membranes of the scalp to absorb the excess CSF. VSGS is preferred by many institutes because it is a simple and rapid method, precludes the need for repeated aspiration without causing electrolyte and nutritional losses. VSG shunt is associated with lower infection rates than EVD due to the closed system of CSF drainage and lack of external tubes.

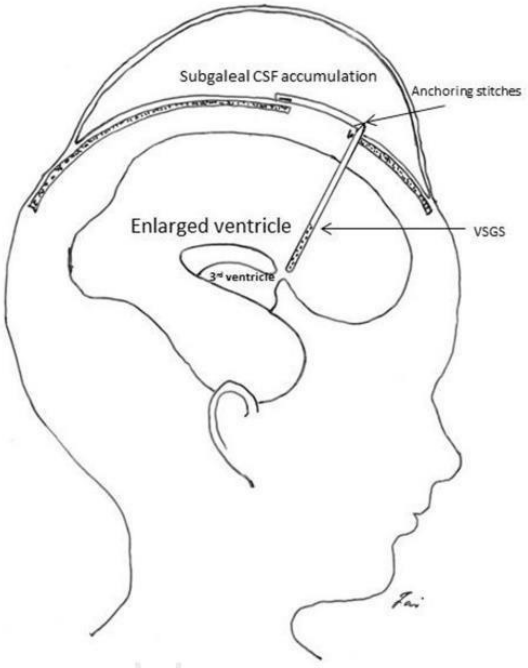


Fig. (2). The cartoon shows the ventriculosubgaleal shunt. The ventricular catheter can be connected to a subgaleal catheter with a right-angle connector or a low-pressure valve (not shown). A one-way mechanism is needed by using a subgaleal catheter with slits or a lowpressure valve.

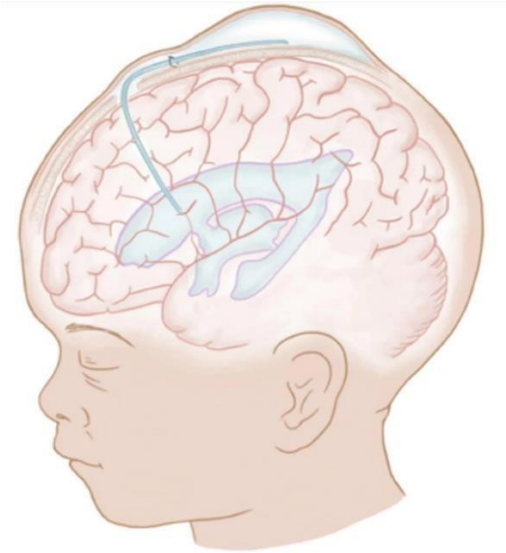

Fig. (3). Ventriculosubgaleal shunt.

Surgical techniques of VSGS. It is important to identify the coronal sutures and locate the Kocher's point for the entrance of ventricular catheter. Other important factor includes not grasping the extremely thin skin of the premature infants during the whole procedure.

In the supine position, the first step is placement of a ventricular catheter into the frontal horn. Next, the ventricular catheter is connected to either a reservoir or via a right angled connector to a short piece of close-end tubing with slits on it in order to establish one-way flow from the ventricle into the subgaleal pocket. If a reservoir is not used, the tubing is secured to the periosteum with suture to prevent catheter migration into or out of the lateral ventricle. To prevent this, the use of a reservoir is suggested.

A subgaleal pocket is formed with blunt dissection with finger sweep or blunt tipped Metz scissors with curved ends. In the latter case, care must be given to dissecting the subgaleal space and not a more superficial or deeper layer. Since larger subgaleal pockets can prolong the longevity of the VSG shunt, always try to dissect out laterally toward each ear, posteriorly over the occiput, not onto the forehead taking care when crossing the midline and avoid button holing the skin. The subgaleal catheter is situated to drain in the direction of the pocket. The wound is closed in two layers.

Longevity (survival duration) and evaluation of the effectiveness of VSGS. The average longevity of the primary VSG shunt was 35.1 and 37.4 days, respectively in two studies. Some of the infants may need two VSG shunts. The survival duration of the VSG shunt is variable depending on several factors that include the absorptive capacity of the subgaleal space and the creation of an ample space during dissection. However, in some cases the ventricles might re-enlarge due to the large collection of CSF exceeding the absorptive capacity of the subgaleal space. This is an indication for a shunt conversion.

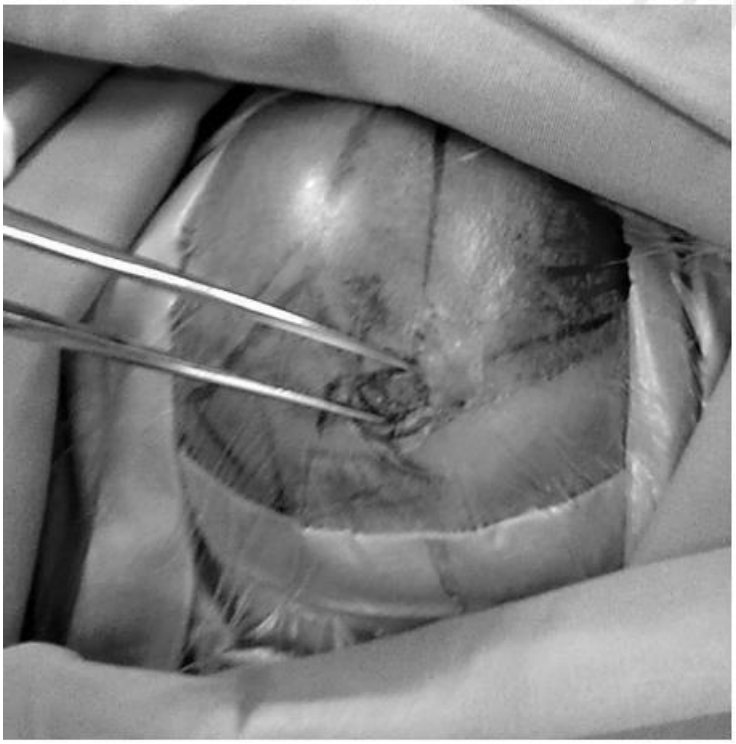

Fig. (4). A non-grasping technique is used during the whole shunting procedure in premature infants to prevent skin injury. The two arms of a forceps can be used as retractor to separate the incision and prevent injury to the thin skin.

The effectiveness of VSG shunt is judged by reduction of head circumference, softening of the anterior fontanel, and reduction of ventricular size as seen on cranial ultrasound or other neuroimaging studies.

In cases of VSG shunt failure, either the previously soft, fluctuant subgaleal pocket became tense with fluid, or the subgaleal space became obliterated without the presence of subgaleal fluid. Cranial imaging confirm ventricular enlargement with either scenario.

Complications of VSGS. The drawback of VSGS is the cosmetically unappealing swelling caused by the CSF collection in the subgaleal space. Most of the parents accept the transient cosmetic problem if they are made aware of the significant scalp swelling. The complications of VSGS include wound leakage before or when sutures were removed, kinking and blockage of the catheter, migration of the catheter from the ventricle or its

slippage into the lateral ventricle, VSG shuntrelated death due to intraoperative rapid decompression of a poorly myelinated neonatal brain under high pressure, resulting in numerous intracerebral hemorrhages.

In a study of Willis et al., a unacceptably high infection rate of VSGS was noted that even made VSGS no longer performed at their institution. The infection includes infection of VSGS per se, and 3/4 of the infections occurred after the VSGS were converted to a VP shunt. They proposed the cause of infection as below: the formation of pseudomeningocele in the subgaleal space causes further thinning of the extremely thin skin of the premature infants promoting colonization by skin flora. They suggested CSF sampling before conversion VSGS to a permanent shunt and changes in the proximal hardware (ventricular catheter and the valve) of VSGS at the time of insertion of the VP shunt, as the VSG shunts have been in situ for a prolonged period in contact with potentially colonized CSF, may decrease the infection rates.

In most of the VSG shunt complications, the shunts needed to be removed. Another rare, potential complication of VSGS is the secondary subgaleal encephaloceles that resulted in seizure, meningitis, abscess formation, and infarction of herniated brain parenchyma.

The other unique complications of VSGS include the requirement of CSF taps shortly before a permanent VP shunt is placed when CSF absorption from the subgaleal pocket is no longer adequate to control the hydrocephalus and severe skull deformity. It should be noted that infants should have their head turned every couple of hours in order to avoid skull deformation, which can be severe.

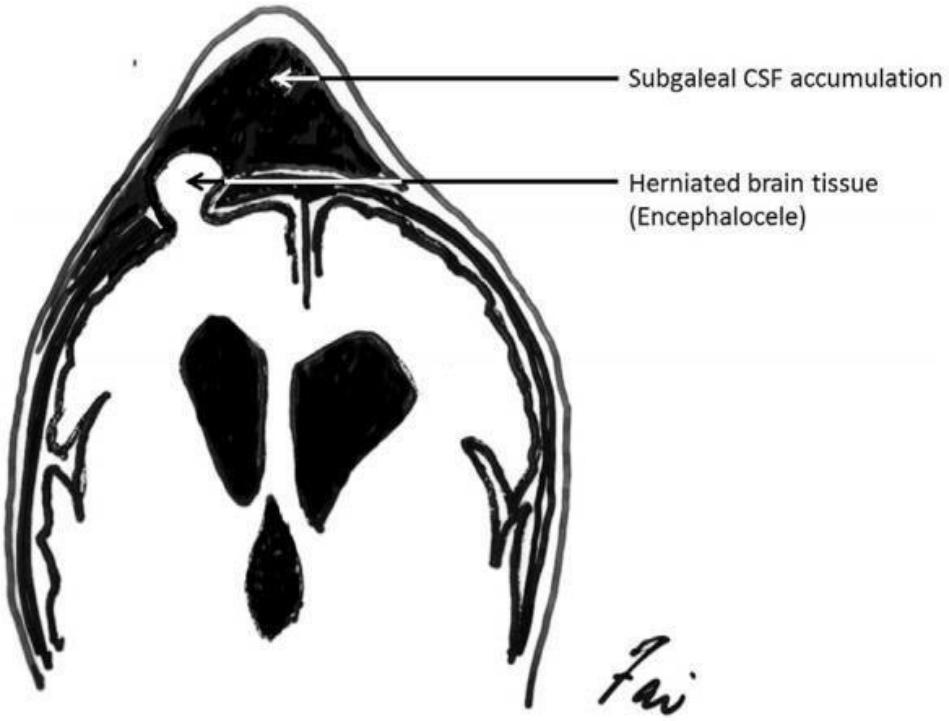


Fig. (5). A rare but unique complication of VSGS, the secondary subgaleal encephaloceles that has to recognized, especially when the patient has unusual presentation of seizure, meningitis, abscess formation, and infarction of herniated brain parenchyma.

Ventricular access device (VAD), subcutaneous ventricular reservoir, neonatal reservoir, Ommaya reservoir.

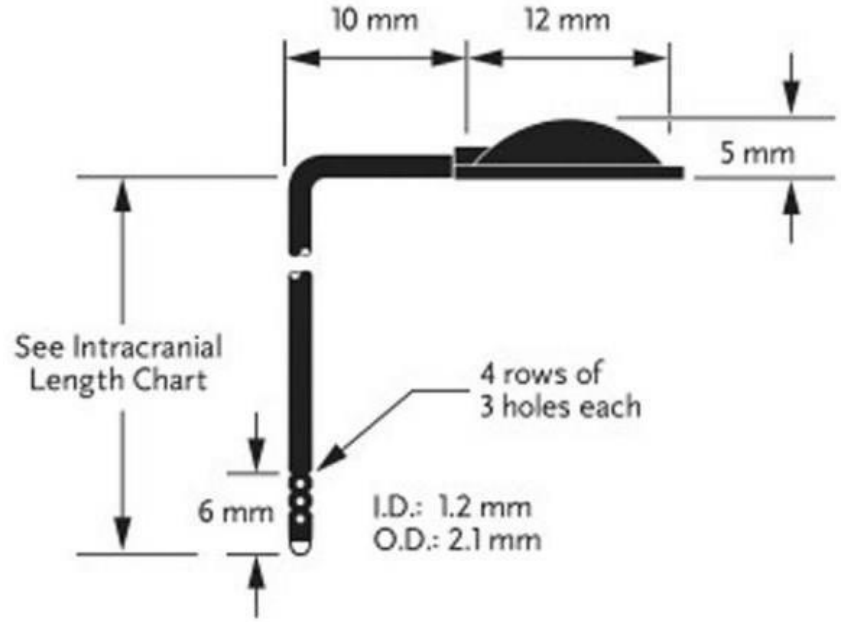


Fig. (6). A ventricular catheter with integrated reservoir (CSF ventricular reservoir, Medtronic Inc.) from one of the many manufactures. The intracranial length of 3.5 cm is most commonly used in premature infants.

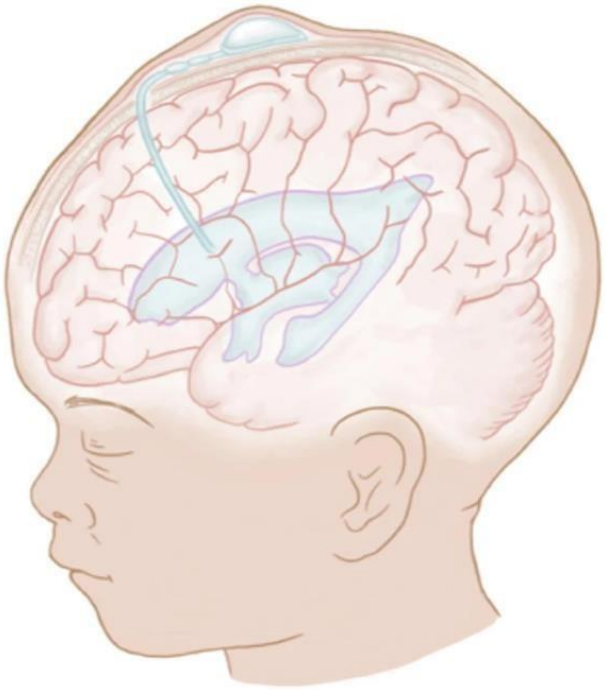

Fig. (7). Ventricular access device.

One of the most acceptable forms of temporized drainage for the prematurity is the implantation of VADs, which located in subgaleal space are repeatedly tapped for decompression of intracranial hypertension and antibiotic and fibrinolytic agents are administered via the reservoir if needed. It also allows easy conversion to a permanent shunt as the suitable proximal hardware is already in place.

The drawback of VAD is the need for repeated punctures of the reservoir with an additional risk of infection though it is much less than that of EVD. Other drawbacks include labor-intensive, wound problems, occlusion, not providing constant decompression of the ventricles, and the loss of proteinand electrolyte-laden CSF. In the author's institute, a tertiary medical center, VAD is routinely used as the first choice in PHH with minimal complications.

Surgical techniques of neonatal reservoir. The right frontal and parietal regions are shaved and prepped. The skin just anterior to the coronal suture and over the parietal bone is infiltrated with normal saline. The frontal part is for the entrance of ventricular catheter and the parietal part is for the placement of the subcutaneous reservoir.

A linear or semi-lunar incision is made anterior to the Kocher's entry point, so that the ventricular catheter later placed does not erode through the incision line. The coronal suture is confirmed again then the dura over the Kocher's point is coagulated with a bipolar unit and incised.

The subgaleal space over the parietal bone is dissected bluntly, then the reservoir dome is placed underneath the skin. The ventricular catheter is inserted into the right lateral ventricle, the incision is then closed in two layers. A 27-gauge needle is used to confirm the function of the reservoir by aspiration of the CSF smoothly.

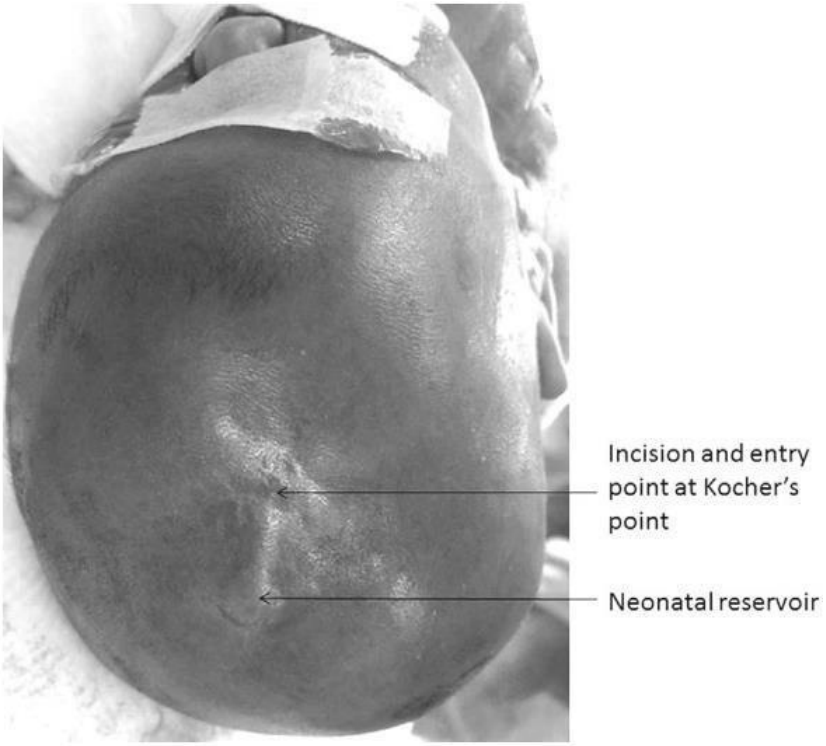


Fig. (8). The photo shows the proper setting of the ventricular access device (VAD). The patient is being receiving the conversion of a temporizing VAD to a ventriculoperitoneal shunt.

Treatment protocol of VAD. The reservoir is tapped through the scalp on a regular basis to remove CSF and maintain a stable clinical condition which includes normal increase of head circumference, soft fontanel, and sonogram.

In the supine position, a scalp needle of 25-gauge or a smaller one is used to tap the reservoir. The frequency and amount of CSF aspiration is tailored for each infant and is determined by the opening and closing pressures, respectively. When the infant lies in supine position, the water-level of the scalp needle at the forehead level is

about 3 cm of intraventricular pressure. Since the normal intraventricular pressure of the premature infant is subatmospheric, we aspirate the CSF of an amount till the closing pressure is just below the level of the forehead. While we like to keep the opening pressure lower than 8 cm, which is the upper limit of the normal ICP of full-term infants. If the opening pressure is higher than 8 cm, the frequency of tapping is increased, for example from twice daily to once daily. It is better to keep the ventricle system mild dilated than collapsed and anterior fontanel soft than marked depressed.

Sonograms can be used to confirm the ventricular size. If the frequency of tapping can be tapered according to the lowering of opening pressure, decreasing amount of CSF in each tap, and the symptomatic hydrocephalus dissipates, the reservoir may be no longer needed. In this situation, we do not routinely remove the VAD or we will wait for at least four years if the parents insist to have it removed. If it becomes evident that permanent CSF diversion is necessary, the VAD will be converted to VP shunt when the baby's weight or age is good enough.

Comparison between the temporary measures. The rates of VP shunt requirement and device infection were similar between patients treated with VAD versus the VSGS. The VSGS requires less labor-intensive management by ventricular tapping; the VSGS patients also attained higher weights and more optimal surgical candidacy at the time of VP shunt insertion.

However, some complications are unique to VSGS, it is thus important for the treating physicians to be aware of these rare, potential complications while using VSGS in the management of PHH. Finally, the potential differences in long-term developmental and neurological outcomes between VSGS and VAD warrant further study.

**Permanent surgical management**

*VP shunt*

Early VP shunt insertion is associated with a high failure rate and many complications; hence, temporizing measures are always instituted until the infant is mature (age and/or weight) enough. VP shunting is indicated when the ventricles continue to enlarge at a body weight exceeds 2 kg and CSF protein levels are below 1-1.5 g/L, then VP shunt insertion is appropriate. Though these minimal requirements are subjective, they indicate fewer complications.

*Endoscopic third ventriculostomy (ETV)*

ETV offers an alternative to a shunt in selected patients with obstructive hydrocephalus; however, ETV alone has low success rate for premature infants with PHH because the age and cause of hydrocephalus of these infants are unfavorable factors of a successful ETV. Combined ETV and choroid plexus cauterization may be effective on the treatment of a selected subsets of premature infants with PHH though further study is warranted.

**Conclusion:** The definitive treatment for progressive post-hemorrhagic hydrocephalus (PHH) is a ventriculoperitoneal (VP) shunt, but it is rarely the first intervention due to risks like skin ulceration in low birth weight infants and high shunt malfunction rates. Instead, temporizing neurosurgical procedures (TNPs) such as lumbar punctures, external ventricular drainage, ventricular access devices, or ventriculosubgaleal shunts are often used initially. If these fail to control PHH, a VP shunt is placed. Due to the lack of conclusive treatment guidelines, most centers rely on institutional protocols, medical expertise, and available resources.

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