Chapter

Ventriculostomy

Gobti Beltus Abongha, Ngeloh Meekness Afunui, Nkenganyi Aka Elvira, Kengo Nathan Ezie and Victor Meza Kyaruzi

Abstract

In neurosurgery, especially in pediatrics, the practice of ventriculostomy or placement of an external ventricular drainage (EVD) is a routine procedure. It consists of the implantation of a catheter in the ventricular system of the brain to temporarily divert cerebrospinal fluid or to measure the intracranial pressure. This method was created and improved during the past century, and it is now regarded as a standard procedure. Despite this standardization, EVD installation can still result in a variety of problems, the most serious of which is infection, which is associated with high rates of morbidity and mortality. The essential points of EVDs in the pediatric population are presented in the current chapter, with an emphasis on the indications for insertion, complications, and measures to prevent poor functional outcomes.

Keywords: CSF, external ventricular drain, intracranial pressure, hydrocephalus, ventriculostomy

1. Introduction

Ventriculostomy is a neurosurgical procedure where a drainage hole (or stoma) is made inside the cerebral ventricle. It is usually carried out on people who have hydrocephalus [1]. The ventricular system of the brain is reached by surgically entering the skull, dura mater, and brain gaining access to the lateral ventricle, usually from the non-dominant lobe (the right frontal lobe in most individuals [2, 3]. An external ventricular drain (EVD) is a typical term used to describe temporary catheter drainage. This is going to be the focus of this chapter.

By diverting the CSF often kept in the ventricular system, a ventriculostomy decompresses the spaces and makes it easier for ICP to return to normal [3]. Many clinical situations could urgently call for the implantation of an EVD. In this regard, the rate of EVD installation in the general population has gradually increased, notably in the industrialized world [4, 5].

CSF draining has been attempted numerous times in the past. Its initial technical description has undergone numerous modifications, and new applications for it have emerged as a result of technological advancement. Congenital hydrocephalus was originally treated with external ventricular drainage in the 18th century [6]. Claude-Nicholas Le Cat (1700–1768) described his technique for performing a ventricular puncture using a trocar and catheter modified for the treatment of ascites. Early attempts, however, were unsuccessful [6]. Later, Robert Whytt (1714–1766) concurred with Benjamin Hill that ventricular drainage should never be done, not even as a last resort, believing it to hasten death [6]. Midway through the 19th century, advancements in the ventricular drainage method were seen, proving its usefulness. Three different developments each helped to achieve this: The use of the aseptic approach, understanding of the effects of excessive ventricular drainage, and determination of the best locations for catheter insertion [7].

Brain trauma, cerebral hemorrhage, and brain tumors are only a few neuropathological diseases that frequently cause issues and changes in CSF dynamics in the pediatric population [5]. EVD insertion has been proposed as the most significant and often lifesaving emergency therapy in neurosurgery in this context. These circumstances may demand an urgent treatment of secondary hydrocephalus or to ICP monitoring. Due of this, residents acquire it as one of their initial surgical skills while undergoing training.

While planning to insert an EVD, it's crucial to take into account both the patient's age and the nature of their illness because different indications and technical considerations may apply.

The management of EVD in the pediatric population is reviewed in this chapter. The discussion of indications and technical factors will follow a quick overview of some ventricular anatomy. Finally, the most significant EVD-related consequences are discussed, along with several evidence-based recommendations for preventing or treating those issues.

2. The ventricular system

The brain's ventricular system is a network of compartments filled with cerebrospinal fluid (CSF), which cushions the brain [8]. The purpose of the cerebral ventricles was unknown, despite the fact that their existence has been recognized since antiquity. In the past, researchers thought that the ventricles were where memory, logic, and emotion were stored.

The walls of the brain's ventricular system (ependyma) are lined by a special kind of cell called an ependymocyte. This cuboidal or columnar epithelium was developed from the neuroepithelium. A collection of permeable capillaries in a connective tissue matrix makes up the choroid plexus, which generates CSF and is situated right underneath the ependymal layer. A layer of subependymal glial cells lies beneath the ependyma. These cells and the astrocyte processes work together to generate the blood-brain barrier, which is tightly connected [8].

The ventricular system consists of four ventricles, with two of them located in each cerebral hemisphere, one in the diencephalon, and the other in the hindbrain. It is connected inferiorly to the spinal cord's central canal.

Each cerebral hemisphere contains a C-shaped hollow known as the lateral ventricle. Ependyma lines the inside, which is filled with CSF with a capacity of 7 ml to 10 ml. The septum pellucidum, a narrow vertical layer of nerve tissue that divides the two lateral ventricles, is surrounded by ependyma on both sides. The interventricular foramen of Monroe serves as its conduit to the third ventricle. The foramen becomes more rounded as the ventricular size grows. The superior choroidal vein, septal vein, and medial posterior choroidal arteries all travel via this foramen [8–10].

A median slit-like hollow known as the third ventricle sits between the two thalami and a portion of the hypothalamus. Through the cerebral aqueduct of

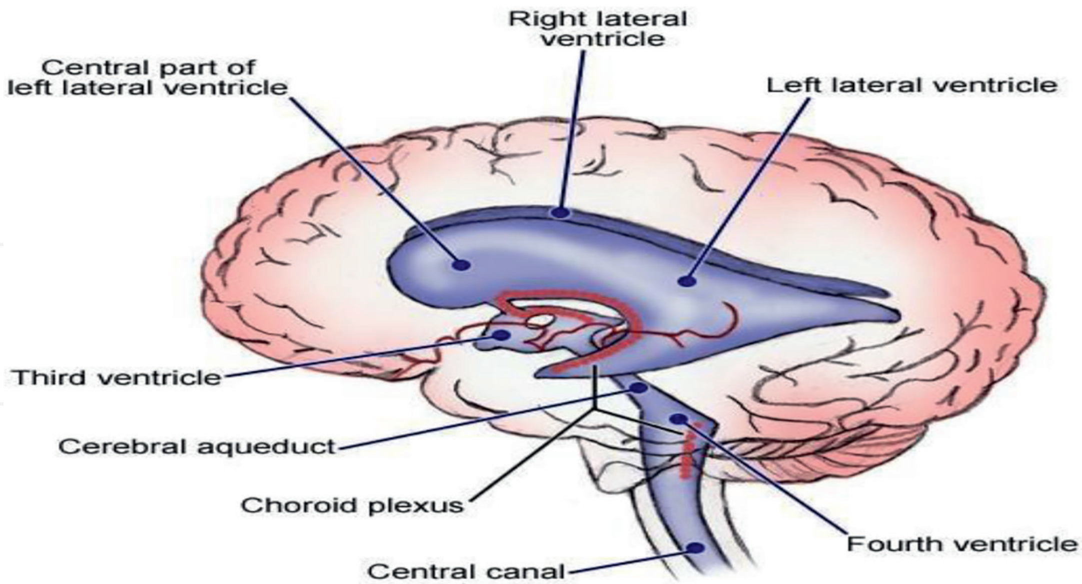

Figure 1.
The ventricular system of the human brain.

Sylvius, it communicates with the lateral ventricles on its anterosuperior aspect and the fourth ventricle on its posteroinferior aspect. Ependyma lines the third ventricle space, and a mass of gray matter known as the interthalamic adhesion or Massa intermedia, which is situated behind the foramen of Monroe and connects the two thalami, passes across it [8, 9].

The Sylvian aqueduct is the brain's ventricular system's thinnest section (as seen in **Figure 1**). It has a diameter of around 18 mm and is where interventricular blockage occurs most frequently. Due to the growth of the surrounding brain tissue, it has been found that the luminal thickness of the aqueduct lowers starting in the second foetal month [8, 9].

A large, tent-like cavity of the hindbrain filled with CSF is known as the fourth ventricle. The pons and cranial half of the medulla form its anterior border, and the cerebellum forms its posterior border. On a sagittal section, it appears triangular, and on a horizontal section, it appears rhomboidal. It connects to the cerebral aqueduct in the superior region and the spinal cord's central canal in the inferior region. The fourth ventricle interacts with the subarachnoid space by two lateral foramina of Lushka and one medial foramen of Magendie [9].

A solitary cavity, or hollow of the neural tube, is where the ventricular system originates. Around the fourth week of pregnancy, the neural tube begins to develop. The amniotic cavity and neural cavity are then segregated shortly after the spinal neurocele closes [8, 9].

Ventricles grow and expand to adult size in the early stages of development. After that, the brain tissue starts to grow in a different directions from the ventricles, from caudal to cephalic, and this difference in growth creates the adult ventricular shape. Any obstruction to the CSF's free passage through the ventricular system causes hydrocephalus [8, 9].

3. Indications and contraindications for ventriculostomy

3.1 Indications

Placement of an EVD is essential for many disorders in neurosurgery;

1. Acute symptomatic hydrocephalus: one of the most frequent indications for a ventriculostomy is for the management of acute symptomatic hydrocephalus. Hydrocephalus is a condition in which excess cerebrospinal fluid (CSF) builds up within the fluid-containing cavities or ventricles of the brain. Other causes of hydrocephalus such as normal pressure hydrocephalus and hydrocephalus ex vacuo which are usually chronic and non-symptomatic are usually not managed by this procedure. It is used in the management of congenital hydrocephalus and acquired hydrocephalus in children and adults usually following subarachnoid hemorrhage (SAH), strokes and meningitis [11]. This procedure is used as management for congenital hydrocephalus only when the baby is >6 weeks of age. For acquired hydrocephalus, it enables drainage of accumulated blood (in SAH), infected CSF (in meningitis) or peritoneal shunting of excess CSF [2, 11–13].

2. Intracranial pressure (ICP) monitoring: the ideal method for monitoring ICP is a ventriculostomy. It can be used to drain CSF or to estimate intracranial compliance and can be introduced by a twist drill craniostomy at the patient's bedside. The catheter can be attached to a filter-protected collection chamber for CSF drainage as well as a pressure transducer to assess intracranial pressure (ICP). To ensure that spontaneous CSF resorption is sufficient and ICP will not rise to unsafe levels, ICP is watched for at least 24 hours [12].

3. Adjunct management for malfunctioning or infected ventriculoperitoneal shunts (VPS): an effective treatment option for CSF shunt infection is endoscopic third ventriculostomy (ETV). It is possible to compare the ETV lifetime to that of reinserted VPSs. Use of ETV during infected CSF shunt removal can be considered a potent alternative or at the very least an adjunct to VPS reinsertion because the reinserted VPS has considerably better lifetime than a VPS reinserted without employing ETV, even in the event that ETV fails [14].

4. As a panacea for brain relaxation during intraoperative brain edema: ventriculostomy performed during intraoperative brain edema is associated with a high level of success in achieving brain relaxation. The use of this technique during pterional approaches for acute aneurysmal surgery in the tight, bulging brain to achieve relaxation and avoid secondary complications such as retraction contusions and resultant cerebral edema is also recommended [15].

5. Planning therapeutic interventions- thrombolytics, antibiotics, for managing vasospasms [2]: this indication is not considered a major indication as there are other conservative and noninvasive methods that can be used. A ventriculostomy in the case of managing vasospasms is considered an ICU intervention.

3.2 Contraindications

The contraindications for ventriculostomy include:

1. Concurrent use of anticoagulant drugs: ventriculostomy is contraindicated during concurrent use of anticoagulant drugs as these may predispose patient to excessive bleeding.

2. Bleeding disorders: ventriculostomy is usually associated with some initial bleeding during placement thus in patients with bleeding disorders this could lead to severe hemorrhage.

3. Scalp infection: scalp infections predispose patient to further complications as Ventriculostomy could cause translocation of infection.

4. Brain abscess: a common and often debated concern regarding CSF drainage with a ventriculostomy is that it can cause subfalcine herniation in the presence of a hemispheric mass or upward herniation of the cerebellum in the presence of an infratentorial lesion [13].

4. Ventriculostomy procedure

By diverting the CSF often kept in the ventricular system, a ventriculostomy decompresses the spaces and makes it easier for ICP to return to normal. In this treatment, the ventricle is reached by guiding a flexible silastic catheter through the brain parenchyma using a hard internal stylet [16] (**Figure 2**).

In about 10–40% of cases, there are recorded complications of ventriculostomy such as bleeding and unintentional insertion in brain tissue. In order to increase the precision and effectiveness of placement, technical advancements utilizing computed tomography (CT), ultrasound, endoscopy, and stereotactic neuronavigation have been made [2]. The incidence rate of these complications thus necessities a rigorous procedure for higher efficiency.

Equipment to include in the basic tool set include: Non-sterile gloves, soap, a brush, a towel, a razor, and a marker pen to prepare the components and mark the location where the monitor devices will be placed. A face mask, sterile gloves and

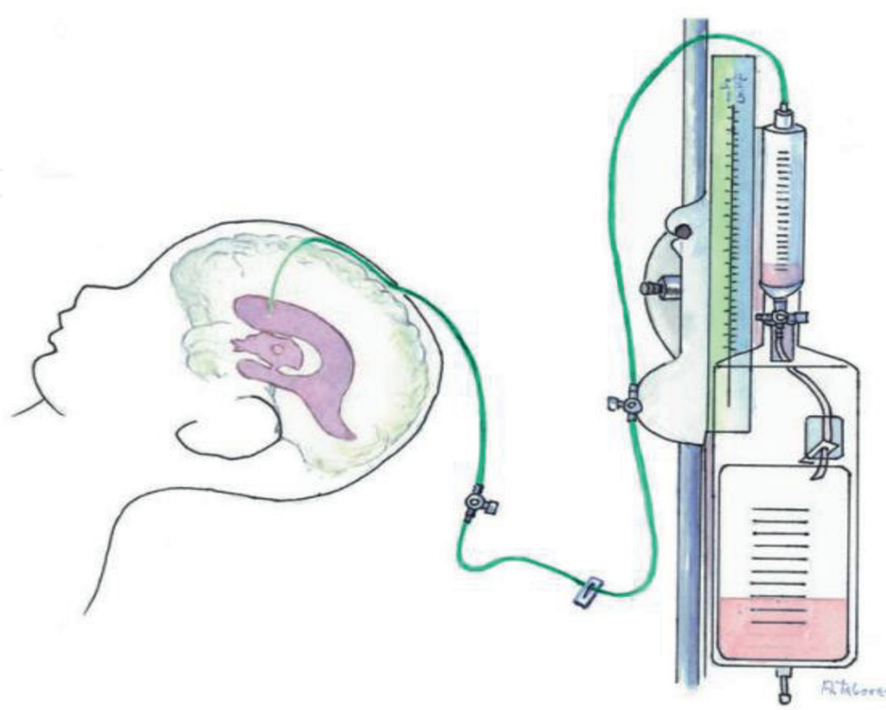

Figure 2.
Closed external ventricular device.

gown, antiseptic solution, drape, local anesthetic, 5-ml syringe, 15- or 11-number surgical blade, and ICP monitoring kit are required for the treatment itself. According to the techniques, a drill with a drill bit, a bolt, an ICP sensor, and a transducer, an aseptic dressing and suture material will be necessary.

A multidisciplinary medical team comprising of:

The brain surgeon (Neurosurgeon),

A competent assistant,

A nurse practitioner,

An anesthetist and.

A general assistance [17].

For the **procedure**, the patient is kept in the supine position with the head of the bed elevated at a 45-degree angle. It could be necessary to shave some hair with the

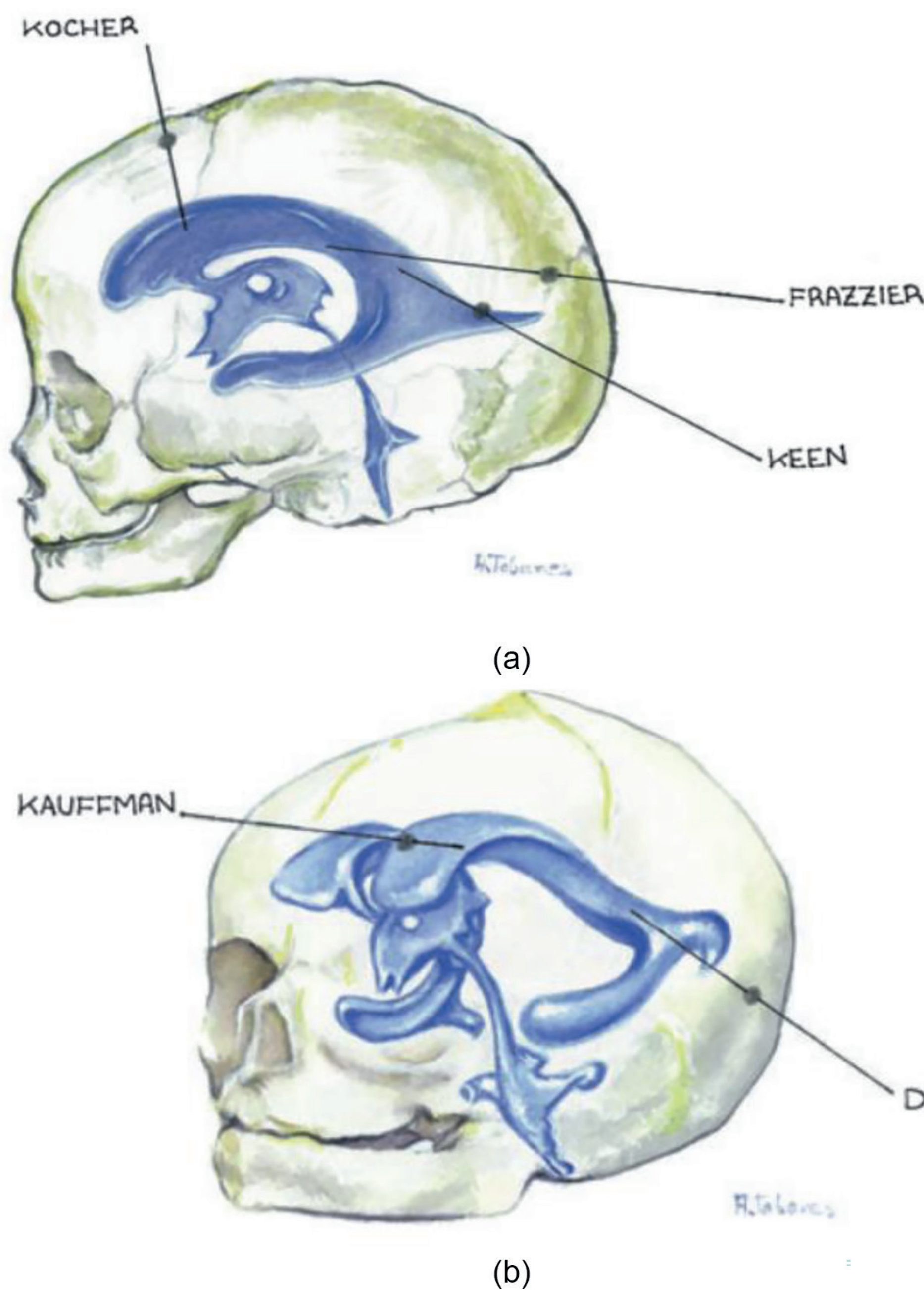

Figure 3.
(a and b) Main approaches and their trajectories for ventriculostomy.

aid of the razor and the area sterilized before the procedure. Given that it is not the dominant hemisphere for language function in >90% of patients, the right frontal cerebral hemisphere is the recommended site of entry. The reference point is that of Kocher which is located at 1–2 cm in front of the mid pupillary line's coronal suture, 11 cm behind the glabella, 3–4 cm to the side of the midline ipsilateral medial canthus, and a line going coronally from the ipsilateral tragus. The superior sagittal sinus and the motor strip of the frontal brain are avoided at this point. Other points include Keen's point which is 2.5–3 cm above the ear pinna and 2.5–3 cm posterior, Dandy's point: 2 cm laterally and 3 cm above the inion, Frazier's point: 4 cm laterally and 6 cm above the inion, Paine's point: the point of an isosceles triangle, whose two limbs each measure 2.5 cm and whose base is located along the Sylvian veins, and Tubbs' point: The trajectory points 45 degrees away from a horizontal line and 15–20 degrees medial to a vertical line, passing through the top of the orbit at a location just medial to the mid papillary point [2–4].

On the scalp, a 2 cm-tall incision is made that may be straight or horseshoe-shaped after local anesthetic has been given (**Figure 3**).

The twist drill is used to enter the skull along the path chosen for ventricular cannulation. The ventricular catheter is primed and advanced no further than 7 cm, aiming in the anteroposterior plane at a spot 1.5 cm anterior to the ipsilateral tragus, toward the ipsilateral Foramen of Monro, and in the coronal plane toward the medial canthus of the contralateral eye. After the catheter stylet has been removed, CSF flow may be seen, and it can then be transduced to determine the opening intracranial pressure. It is then connected to an external drainage system after being tunneled

Approach	Description
Keen	Entry point: 2.5–3 cm behind and 2.5–3 cm above the earpinna. For roughly 4–5 cm, the catheter is positioned perpendicular to the cortex with a small cephalic inclination.
Kocher	11 cm behind the glabella and 3–4 cm lateral to the midline or 1–2 cm anterior to the coronal suture at the middle pupillary line. When treating very young patients, it is recommended that the catheter be advanced no further than 6 cm. To guide catheter insertion, use the ipsilateral medial canthus in the coronal plane and the external acoustic meatus in the sagittal plane.
Dandy	3 cm above and 2 cm lateral to inion. The catheter is placed perpendicular to the cortex with a slight cephalic direction for about 4–5 cm
Frazier	3–4 cm lateral from the midline and 6–7 cm superior to the inion (depending on age and head size). For roughly 4 cm, the catheter is advanced perpendicular to the cortex, in the direction of the contralateral medial canthus.
Kauffman	3 cm from the midline and 4 cm above the nasion. The catheter is aimed for 6–7 cm at a point 3 cm above the external occipital protuberance.
Menovsky	Following an eyebrow incision, a catheter is angled 45 degrees toward the midline and 20 degrees away from an imaginary line parallel to the orbito-meatal line during a supraorbital craniotomy. About 5 cm of the cortex are passed through the catheter.
Hyun	The catheter is placed approximately 5 cm posterior along the anterior limb of Paine's triangle.
Park	It is 2 cm anterior to the posterior limb of Paine's triangle and 2.5 cm superior to the lateral orbital roof and 4.5 cm anterior to the Sylvian fissure. Inserting the catheter around 3.5 cm below the surface

Table 1.
Approaches for ventriculostomy and EVD insertion.

through the skin by a different incision away from the point of entry. Dissolvable stitches, which will gradually fall out over the following 7–14 days, will be used to sew the scalp back together [18] (**Table 1**).

5. Complications of ventriculostomy

It has been noted that with technological advancement and improvement of medica knowledge the management of hydrocephalus and ventricular pathologies has greatly improved. However, it is worth noting that despite these advancement in management we still have a lot of complications from ventriculostomy. These complications range from infection to death. Intraoperative, early (1 month), and late postoperative (>1 month) complications are all possible. Hemorrhage (cortical, ventricular, and cisternal vessels), neural injury (fornix, third cranial nerve, hypothalamus, and middle brain), subdural collections, pneumoventricle, hyponatremia, seizures, delayed awakening, bradycardia, hypothalamic dysfunction (diabetes insipidus, lack of thirst, amenorrhea), and hyperthermia are among the intraoperative and early complications. Reclosure of the stoma, weight increase, and premature puberty are examples of late problems.

The following paragraphs discuss these complications detailly;

1. Neurocognitive decline: to begin, most of these patients usually present with cognitive decline in the initial stages especially memory and executive function impairment [19]. They could be attributed to the fact that some neurocognitive complications attributed to surgery are often either underestimated or underdiagnosed [20]. Furthermore, lesions of important ventricular structures caused by surgical procedures are rarely assessed for and seldom described within reports in the literature, although such lesions potentially lead to incriminating neurocognitive morbidity. Other neurocognitive complications include severe personality changes as was recorded in a patient who underwent an endoscopic ventriculostomy for the treatment of slit ventricle syndrome; this was characterized by impulsiveness, physical hetero aggressiveness, binge eating, hypersomnia, and impairment of memory and frontal executive functions [21]. These symptoms referred to frontal lobe lesions and damage to the fornix and its connection to the hippocampus and mamillary bodies, which was confirmed by postoperative MRI. Also, an additional report of a woman undergoing surgery showing severe psychotic depression, occurring gradually within 3 weeks after surgery [22]. These clinical reports in essence go to highlight the cognitive damages which could be attributed to surgery or the disease in itself.

2. Pneumencephaly: often considered a minor or insignificant complication, this is described as air in the epidural, subdural or subarachnoid space within the brain parenchyma [23]. Pneumocephalus (pneumatocele or intracranial aerocele) can delay postoperative recovery and is often associated with headache, nausea, and vomiting (signs of increased intracranial pressure). Entrapment of air at the time of surgery can interfere with direct visualization of the anatomic landmarks that are essential to performing a third ventriculostomy safely. This can be minimized by carefully flushing all irrigation lines of air bubbles but not too fast nor rapid rate as this could lead to bradycardia [23]. Decompression of the ventricular system too rapidly can contribute to the formation of a subdural hematoma.

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3. Infection (ventriculitis): ventriculitis is inflammation of the ependymal lining of the cerebral ventricles, usually secondary to infection. It has other names such as; ventricular empyema and pyogenic ventriculitis. It is an indolent but lethal infection and a source of persistent infection [24] Early diagnosis is essential for appropriate treatment. It is of particular concern in patients post ventriculostomy and has been associated with increased morbidity, mortality and financial costs [25]. This could be associated to either the asepsis intra op, introduction of foreign material, presence of stoma blockage or persistent leak which are often result in delayed wound healing.

6. Others

6.1 Blocked stoma

In cases of infective or post haemorrhagic pathologies there is often the presence of blood clot formation which favors the stoma closure. Also, in cases of rapid tumor progression or the presence of secondary membranes (liliquist) [26]; there is a high risk for the formations of plugs which block the stoma.

Situation	Action
Preoperative patient preparation	Wash the entire scalp with povidone-iodine or chlorhexidine the day before surgery
Operating room	1. Depending on the patient's features, surgery may be performed in the operating room (OR) or the pediatric critical care unit. 2. Reduce the necessary attendance in the OR 3. Sterile protocol: following proper hand hygiene procedures, surgeons and the assisting nurse should wear a cup and mask, sterile gowns, and gloves. 4. Taking a single dosage of preventative antibiotics 60 minutes before making an incision to protect the skin's flora 5. Before and after donning, wash your scalp with povidone-iodine or chlorhexidine. 6. If coated catheters are available and therapeutically necessary, use them. 7. Inserting the catheter as deeply as possible under the skin 8. Dress the wounds in sterile material. The dressing must always be dry.
Postoperative maintenance	1. When managing the system, handle it aseptically and try to avoid manipulating it. 2. During the drainage phase, do not administer preventive antibiotics 3. Avoid CSF sampling until an infection is clinically suspected 4. You should not routinely replace your clothes; just do so if they are jeopardized. 5. No routine EVD exchange if there is not an accompanying infection (option to periodic replacement in situations of meningitis or ventriculitis). Inspect the wounds if there is any possibility of a CSF leak.

Table 2.
Protocol for prevention of EVD-related infections.

6.2 Hypothalamic damage

This could be caused by ventriculostomy done away from the midline or thick wall perforation by blunt instrument. This could be manifested by endocrine disorders such as hypothyroidism, precocious puberty etc.

6.3 CSF leak

Which could be precipitated by persistent increased intracranial pressure or early suture removal. In infants with ventriculomegaly it has been noted that a thin cortical mental is associated with cerebrospinal fluid leakage. Moreover, this can delay wound healing, hence increasing risk for infection; and has been shown to be a sign of failure of the third ventriculostomy [27] (**Table 2**).

7. Clinical relevance of ventriculostomy

Subarachnoid hemorrhage (SAH) and Intracranial hemorrhage (ICH) are common complications which occur secondary to stroke and traumatic brain injury (TBI). These conundrums can cause massive intraventricular hemorrhage resulting into acute obstructive hydrocephalus and elevated intracranial pressure which may cause critical morbidity and mortality. Despite the management of ICP with medications such as sedatives and osmotic diuretics, always it is not effective to reduce the ICP thus necessitating the institution of external ventriculostomy also known as external ventricular drain (EVD). The existing body of evidence has revealed a significant difference of outcomes, the arm treated with conservative management had higher fatality rate compared to the arm subjected to the EVD management [28, 29].

Despite the feasibility of EVD placement it is not without flaws when misplaced, this can cause serious complications such as EVD associated hemorrhage and infections. Numerous factors contribute to increased risk of EVD associated hemorrhage including institutional and individual's practice pattern, timing of the CT scan, coagulation indices thresholds, platelet infusion practice for patient subjected to antiplatelet therapy or blood thinners, access site, drill bit size and thread distance, aggressive drilling, the use of irrigation saline. Removal of bone fragments prior to dura opening, sharp or blunt dura penetration, sharp or blunt pia opening, slow or fast access of frontal horn, removal of stylet at ventricular entry or upon advancement to the foramen of Monro and tightness of scalp closure [28–30].

The incidence of EVD related infections have been reported ranging from 0 to 22%, this has opened the mandatory use of prophylactic antibiotic regimen through the entire course of the EVD period. The contemporary use of antibiotic impregnated catheters has dramatically reduced the risk of ventriculostomy associated infections.

8. Conclusion

One of the most significant and often used techniques in pediatric neurosurgery is EVD implantation. Many pathological disorders, including those that pose a threat to life, are treated with it.

Since infection appears to be the most significant and well-researched issue with this procedure, EVD insertion and care protocols are required to prevent the difficulties that are connected with it.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Gobti Beltus Abongha[1*], Ngeloh Meekness Afunui[1], Nkenganyi Aka Elvira[2], Kengo Nathan Ezie[3] and Victor Meza Kyaruzi[4]

1 Faculty of Health Sciences, University of Bamenda, Bamenda, Cameroon

2 Faculty of Health Sciences, University of Buea, Buea, Cameroon

3 Faculty of Medicine and Biomedical Sciences of Garoua, University of Garoua, Garoua, Cameroon

4 Department of Surgery, Muhimbili University of Health and Allied Sciences, Dar es Salam, Tanzania

*Address all correspondence to: beltusgobti@gmail.com

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