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Critical Care Neurology (H Hinson, Section Editor)

Management of External Ventricular Drains and Related Complications: a Narrative Review

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Abstract

Purpose of Review Although external ventricular drains (EVDs) are widely used, there is a lot of variability in how they are managed. This review will provide an update on the management of EVDs, based on the current evidence.

Recent Findings Bundles of care focused on aseptic techniques for EVD insertion, maintenance, and care are likely to prevent EVD-associated infections. EVD management in subarachnoid hemorrhage (SAH) found no clinical advantage to gradual weaning over rapid weaning with an intermittent drainage strategy versus a continuous strategy. Rapid weaning was associated with a shorter length of stay, lower incidence of ventriculostomy-associated infections, and EVD blockages. EVD placements done by mid-level practitioners found no significant differences in accuracy or infection rates when compared to placement by neurosurgeons which could be of value in low resource centers. Intraventricular

fibrinolytics for treatment of intraventricular hemorrhage may not affect functional outcomes but hasten ventricular blood clearance and may lower mortality compared to no treatment.
Summary EVDs are indicated when CSF diversion and intracranial pressure monitoring are needed. There is variability in insertion, management, and removal of EVDs, as well as administration of intraventricular medications. More research is required to standardize EVD-related processes.

Introduction

An external ventricular drain (EVD) insertion or ventriculostomy is one of the most common procedures performed by neurosurgeons with an estimated over 20,000 EVD placements per year in the USA alone [1, 2]. After being first attempted in the eighteenth century, EVD insertion techniques, indications, and materials used have undergone several changes to date particularly with the advancements of technology, knowledge of infection control, and safety [3]. However, there remains significant variability surrounding EVD practices from insertion, infection control measures, and administration of intraventricular medications to strategies for drainage and removal [4••, 5]. This review will provide an overview of the management of EVDs and treatment of some common related complications.

Disease states

There are two primary indications for EVD insertion: drainage of cerebrospinal fluid (CSF) and measurement of intracranial pressure (ICP). The commonly encountered conditions where EVDs are inserted include:

1. Subarachnoid Hemorrhage (SAH)

This is probably the most common indication for EVD placement [6]. Intraventricular hemorrhage (IVH) secondary to high grade SAH can lead to acute obstructive hydrocephalus requiring EVD insertion. Hydrocephalus occurs secondary to obstruction of the arachnoid villi (the natural CSF absorbent system) and the obstruction of the ventricular and cisternal drainage systems [7]. The incidence of hydrocephalus in aneurysmal SAH is around 20–30%, mostly occurring acutely within 48 h after bleed onset, but also can be delayed by weeks or even months after hemorrhage [8]. EVD insertion in patients presenting with SAH-related hydrocephalus is recommended as it provides a temporary diversion of the CSF outside the brain as well as ICP monitoring [9]. Aneurysmal rebleeding is a theoretical risk after inserting an EVD. This may occur because of rapid CSF drainage and fluctuating ICP immediately after EVD insertion in SAH patients with an unsecured aneurysm. One retrospective study found that the volume of CSF drainage was highly correlated with the probability of in-hospital aneurysmal rebleeding [10]. However, other studies

found no increased risk [11, 12]. It is prudent to carefully control the amount of CSF drainage and avoid over-drainage prior to aneurysm obliteration.

2. Traumatic Brain Injury (TBI)

EVDs are one of the commonly used types of ICP monitors in TBI patients along with intraparenchymal devices. As per the 2016 Brain Trauma Foundation (BTF) guidelines, ICP monitoring is indicated in all salvageable TBI patients with abnormal CT scans [13]. It is also indicated with a normal CT scan, if two of the following three risk factors are present: age > 40 years, motor posturing, and SBP < 90 mmHg. An EVD can serve in these conditions both as a diagnostic tool for ICP monitoring as well as for immediate therapy to drain CSF in cases of high ICP with increased ventricular size. An intraparenchymal fiberoptic probe is preferred if the goal is only to measure ICP in the presence of collapsed ventricles secondary to diffuse cerebral edema. One prospective observational study compared EVDs to intraparenchymal fiberoptic probes in TBI patients and found a better 6-month Glasgow Outcome Scale score in the EVD group [14]. It also found less refractory high ICP episodes and better 1-month and 6-month survival rates in the EVD group with similar rates of device-related complications.

3. Intraventricular Hemorrhage (IVH)

Extension of the hemorrhage into the ventricular system, i.e., IVH, is an independent risk factor for poor prognosis [15, 16]. IVH following ICH or SAH can be limited to a small layer of blood in the lateral ventricles, or a large extension casting the entire ventricular system. An IVH amount of more than 20 mL has been demonstrated as a strong predictor of poor outcome [17]. Elevated ICP and obstructive hydrocephalus are commonly associated with ICH and IVH which would require emergent EVD insertion to prevent worse outcomes [16]. The outcomes remain poor in many patients with high-grade hemorrhages despite EVD insertion. This may be due to the primary etiology of the bleed, its location, and the toxic effects of IVH on the adjacent brain structures and vasculature leading to cell ischemia and fibrosis [18, 19]. CSF drainage may not clear the blood from the ventricles. Therefore, injection of fibrinolytic agents such as alteplase through the EVD, intraventricular fibrinolysis, has been studied with the expectation that faster clearance of intraventricular blood will lead to improved outcomes. Despite the promising safety profile and results from the CLEAR II trial (Thrombolytic Removal of Intraventricular Hemorrhage in Treatment of Severe Stroke), the larger randomized, placebo-controlled phase 3 trial (CLEAR III) showed that routine irrigation with alteplase did not substantially improve functional outcomes at the modified Ranking Scale (mRS) score of 3 cutoff compared with irrigation with saline alone [20]. Numerous systematic reviews and meta-analyses have been conducted reviewing the role of intraventricular fibrinolysis in patients with IVH. The most recent one by van Solinge et al. showed a lower risk of EVD obstruction, faster clearance of blood from the 3rd and 4th ventricles,

and reduction in mortality rates in patients receiving intraventricular fibrinolytics compared to EVD alone. There was no significant difference in functional outcomes and rates of ventriculitis [21••].

4. Acute Ischemic Stroke

EVDs can also be used for ICP monitoring and CSF drainage in severe ischemic strokes associated with cerebral edema, mass effect, and midline shift. Insertion can be either prior to or after decompressive craniectomy, if ICP elevation remains a concern. EVD use in this situation remains controversial secondary to a lack of randomized controlled studies. A small prospective study suggested that ICP monitoring of large hemispheric ischemic strokes can predict clinical deterioration and final outcomes [22]. However, a later study showed that severe brainstem herniation and pupillary changes can occur despite normal ICP readings [23]. Thus, ICP monitoring should not be a substitute to frequent bedside clinical exam and radiographic monitoring. EVDs can also be used for temporary relief of obstructive hydrocephalus secondary to posterior fossa large cerebellar ischemic strokes. Cautious CSF drainage should be applied to prevent upward brainstem herniation which is frequently encountered on imaging prior to EVD insertion due to posterior fossa space occupying lesion; however, this remains safe upon EVD insertion in one study by Braksick et al. [24]. It should be considered as a temporizing measure until definitive surgical treatment is achieved. The American Stroke Association recommends surgical management with posterior fossa decompression in favor of EVD placement alone [25].

5. Central Nervous System Infections

In the neurological critical care unit (NCCU), ventriculostomy-associated infection is a well-known complication after EVD placement [26]. The mainstay of treatment for such infections is intravenous antibiotics. However, in certain cases, refractory to standard intravenous treatment, intraventricular or intrathecal antibiotics can be considered. This is discussed in more detail in a subsequent section. Another indication for intraventricular antibiotics is a severe nosocomial meningitis with obstructive hydrocephalus refractory to intravenous antibiotics. EVD placement and intrathecal antibiotics would be next best therapeutic step in such cases [27].

Placement of EVD

The technique of placing EVDs is beyond the scope of this review. Due to the urgent nature of this procedure, EVDs are often placed at the bedside in the intensive care unit (ICU) or in the emergency departments. Timely ventriculostomy placement is critical to avoid secondary brain tissue damage from prolonged elevations of ICP. Alert protocols including team members across the patient's pathway within the hospital have been demonstrated

to reduce delays [28••]. EVDs are typically placed by neurosurgeons or neurosurgery residents. There is no significant difference in EVD placement accuracy based on operator experience or the location of EVD insertion (operating room or bedside) [29••]. More recently, neurointensivists and even advanced practice providers (APPs) such as nurse practitioners (NPs) and physicians assistants (PAs) have taken up this role after undergoing appropriate training [30]. Simulation using virtual reality and smartphone devices is aimed to reduce learning curves and improve placement in emergency situations [31••, 32]. In one retrospective analysis, EVDs placed by NPs and PAs were compared with EVDs placed by neurosurgeons at the same center [33••]. The rates of hemorrhage, infection, and placement accuracy were similar between the two groups. Having non-neurosurgeons be able to place EVDs has many advantages. It may allow for more prompt intervention as intensivists and APPs are often situated on-site and can place the EVDs at the bedside without any delay.

The use of prophylactic systemic antibiotics peri-procedurally during EVD placement is a common practice in many institutions. The results of studies that looked at the effect of prophylactic antibiotic use have been inconclusive. Older studies suggested that prophylactic antibiotics resulted in a reduction of ventriculostomy-related infections (VRI), recently termed ventriculostomy-associated infections (VAI), at the expense of selecting for resistant bacteria [34]. However, subsequent studies did not find any reduction in VAI rates among patients who received antibiotics throughout the duration of EVD treatment compared to those who did not, with increased rates of nosocomial infections and cost in the group receiving antibiotics [35]. According to a recent systematic review by Lord et al. those who received a prolonged duration of intravenous antibiotics throughout the EVD use were at an increased risk of developing resistant organisms, *C. difficile* colitis, and increased healthcare cost with mixed results in reduction of VAI [36••]. The Neurocritical Care Society suggests one dose of prophylactic antibiotics prior to insertion of EVDs [37]. An additional step that has now become standard is tunneling of EVD catheters as a means of reducing infection risk. A recent meta-analysis showed that tunnel lengths of 5 to 10 cm were associated with the lowest rate of VAI [38••]. An important consideration before placing an EVD is whether to place a standard silicone catheter or an antimicrobial-impregnated one [40]. Antibiotic-impregnated EVDs were first introduced about two decades ago, followed soon after by silver-impregnated catheters. Both have shown a decreased rate of catheter-related infections compared to standard EVDs alone in multiple studies and meta-analyses [39–41]. In an RCT where 288 patients were randomized to get antibiotic-impregnated catheters versus standard silicone catheters, the VAI rate was significantly reduced in patients with antibiotic-impregnated catheters compared to the control group (1.3% compared with 9.4%, respectively, $p = 0.002$) [42]. Another study showed that the combination of antibiotic-impregnated catheters and an evidence-based EVD insertion and management bundle decreased VAI rates from 8.2 to 1% ($p = 0.0005$) [40]. The mean duration to onset of infection has also been found to be significantly prolonged with antibiotic-impregnated catheter use compared to standard catheters (8.8 days and 4.6 days, respectively, $p = 0.002$) [43]. In a large meta-analysis pooling 4399 patients from 4 randomized clinical trials and 7 observational

Table 1 Practical suggestions to minimize risk of VAI

1. Adopt bundles-of-care
2. One dose of pre-procedural antibiotics
3. Consider antimicrobial-impregnated catheters
4. Tunneling of catheters 5–10 cm
5. Chlorhexidine dressings
6. CSF sampling when indicated, avoid routine sampling
7. Avoid routine catheter exchanges
8. Consider rapid weaning and early clamp trials when indicated

studies, there was a 62% relative reduction in infection rates when using antibiotic-impregnated devices [39]. The Neurocritical Society in their evidence-based consensus statement recommends usage of antimicrobial-impregnated catheters as part of a bundle to minimize infection risk associated with EVDs [37]. Finally, chlorhexidine-impregnated dressings, which are widely utilized to reduce central line colonization and catheter-related bloodstream infection, have also been used with EVDs to reduce rates of VAI. A recent meta-analysis that included 5 studies found a significant reduction of EVD-associated infections with chlorhexidine use (7.9% vs 1.7%, $p = 0.04$) [44••]. However, the authors reported a significant risk of bias in all the included studies.

Table 1 offers a practical suggestion on how to minimize ventricular-associated infections.

Setting up and managing an EVD

After placing the EVD, it is standard practice to raise the patient's head of bed to an angle of 30°, keep the neck in a neutral position, and attach the EVD CSF collection system to a pole near the head end of the bed (Fig. 1). The EVD collection system is zeroed at the level of the foramen of Monroe. This corresponds to the external auditory meatus in the supine position and the midsagittal line in the lateral position [45••]. The height of the EVD collection system is determined by the indication for the procedure. If placed for treating SAH, the level is initially set high, often at 20 cm H2O, to prevent over-drainage and possible rebleeding of the unsecured aneurysm. In surgical cases, it is usually set at a lower level and then gradually increased. While it is common practice to have an open drainage system, this practice has been called into question by newer studies in aneurysmal SAH [46••, 47]. With an open drainage system, CSF is allowed to drain continuously and ICPs are checked periodically, typically once an hour. While this does facilitate ease of use, it does not allow for continuous ICP monitoring. In patients with SAH, a continuous drainage strategy has been associated with more complications compared to an intermittent drainage strategy, wherein CSF is only drained when ICP reaches a certain predetermined threshold. Single center studies have shown associations with decreased length of stay, lower

Fig. 1 Standard EVD set up, zeroed at the level of the tragus. 1: 3-way patient stopcock; 2: ICP transducer; 3: chamber height (green: cmH_2O; blue: mmHg); 4: graduated drip collection chamber; 5: drainage collection bag.

ventriculo-peritoneal shunt (VPS) rates, and decreased risk of malfunctioning catheters with closed drainage systems [48–50]. A prospective study by Olson et al. reported a higher rate of nonpatent EVDs in the continuous group versus the intermittent group (44.1% vs 11.5%, respectively; *OR* 4.35, 95% *CI* 1.18–16.10) along with a higher rate of ventriculitis as well (17.6% vs 3.8%, respectively; *OR* 5.36, 95% *CI* 0.60–47.57) [49]. They also found a strong association (alpha = 0.01) between loss of patency and infection, regardless of group assignment (*OR* 7.96). They felt that the higher rate of infection was probably due to higher rates of EVD manipulation due to loss of patency. A retrospective study by Rao et al. observed higher rates of VP shunt placement (35% vs 13%, $p = 0.001$) and ICU length of stay (16.9 days vs 14.2 days, $p = 0.001$) and double the rates of non-functioning EVD in the continuous group versus the intermittent group (30% vs 15%, respectively; *OR* 0.29, *CI* 0.12–0.71, $p = 0.006$) [48]. A recent meta-analysis that included 1549 patients concluded that intermittent CSF drainage was associated with lower EVD

infection rates (2% vs 12%; *RR* = 0.20, 95% *CI* 0.05–0.72, *I*-squared = 0%) and EVD blockages (15% vs 36%; *RR* = 0.45, 95% *CI* 0.27–0.74) compared to continuous strategies [46••]. Interestingly, they also observed that the amount of CSF drainage per day was similar in both groups (129.6 mL/day with continuous drainage versus 119.5 mL/day with intermittent drainage). Various explanations have been put forth to explain these findings. Rao et al. theorize that a closed EVD "…might involve early recruitment of CSF outflow pathways. A closed EVD and relatively higher CSF compartment pressures could facilitate CSF resorption through arachnoid granulations." They also suggest that an open system might augment CSF production due to lower CSF pressures and increase the risk of blockage.

The data is less clear in non-SAH patients. In a matched cohort study of severe TBI patients treated with continuous versus intermittent EVD draining approaches, the mean ICP was lower in the continuous group, with better overall ICP control [51]. When evaluating for infection, EVD systems are frequently used to collect CSF samples. Care must be taken during these maneuvers as frequent CSF sampling has been associated with an increased risk of EVD-related infections [52, 53]. CSF sampling should only be done when infection is suspected or to gauge treatment response.

External ventricular drain complications and their management

Given the invasive nature of EVDs and despite appropriate care and maintenance, EVDs can be complicated by malfunction due to malposition, dislodgment, obstruction, hemorrhage, and infection, all of which can result in increasing ICU length of stay and contribute to significant morbidity and mortality as discussed in the following section.

Ventriculostomy-associated infection

Ventriculostomy-associated infection is a major concern after catheter placement. Infection rates have been reported in the range of 0 to 22%, but mostly around 10% or less [54–56]. In a large scale surveillance study in a neurological ICU of a major tertiary care center, the incidence rate (per 1000 device days) of VAI was 4.0 [26]. Coagulase negative *Staphylococcus* is usually the most common pathogen isolated. Other common organisms include *Staphylococcus aureus*, Klebsiella species, and *Pseudomonas* species [57••]. The diagnosis of VAI can be challenging due to the lack of a consistent definition in the literature. CSF inflammation and inflammatory ventriculitis can be seen with IVH and following neurosurgery and not only with infection. Many studies have used the definition of VAI set by the CDC which is based on a combination of a positive CSF culture, typical laboratory findings, and clinical symptoms. Risk

factors associated with VAI include SAH, IVH, craniotomy, depressed skull fracture, and history of diabetes mellitus [55, 56, 58••]. In a subarachnoid hemorrhage study using Bayesian Model Averaging, only higher-grade Hunt and Hess, and diabetes mellitus were associated with the probability of developing VAI; craniotomy did not increase the probability [59]. VAI can result from inoculation of pathogens during EVD placement or due to contamination of EVD postoperatively by migration of organisms along the cutaneous tract. It may also be introduced secondary to frequent EVD manipulation [56]. Many studies have shown a direct correlation between the risk of VAI and the duration of EVD placement. Most studies have reported a lower VAI rate in the first 5 days of EVD drainage and that the infection rate increases significantly after 5 to 10 days of EVD placement [60–62]. Prophylactic or regular exchange of EVD catheters after 5 days of EVD placement has not been shown to decrease VAI risk. On the other hand, the number of EVD placements has been found to be a strong predictor of VAI [63]. Hence, it is recommended to remove the EVD as early as the clinical situation allows and to avoid routine changes of EVD [37]. As discussed earlier, antibiotic-impregnated catheters have been shown to potentially reduce VAI rates. VAI should be considered in the differential diagnosis of any patient with an EVD who has signs and symptoms suggestive of an infection. Initial VAI treatment involves removal or exchange of the catheter and administration of broad-spectrum intravenous antibiotics with activity against gram-positive as well as gram-negative pathogens. Subsequent targeted antibiotic therapy can be tailored to CSF culture and susceptibility results and continued for 10 to 14 days following last positive CSF culture [27]. Brain MRI with contrast-enhanced or DWI sequences can help guide the antimicrobial course particularly in cases poorly responsive to treatment by identifying loculated infections or abscess formation. Intraventricular antibiotic administration should be considered in patients who do not respond to intravenous antibiotics alone or in infections caused by multi-drug-resistant organisms. They have also been used to treat infections with organisms with high MIC to intravenous antibiotics that do not achieve adequate CSF concentrations. Most of the studies done in this area are small, retrospective in design, and not sufficiently powered to detect significant differences in meaningful clinical outcomes [57••, 64, 65]. However, many of them have demonstrated faster achievement of CSF sterility and improvement of CSF parameters with the use of intrathecal antibiotics. In a multicenter retrospective cohort study that included 105 patients who received intraventricular antibiotics, CSF sterilization occurred in 88% of patients with recurrence of positive cultures in about 10% [57••]. In another study of 34 post-neurosurgical patients with persistently positive CSF cultures despite appropriate intravenous antibiotics, the addition of intraventricular antibiotics resulted in CSF sterilization at an average of 2.9 days [65]. Interestingly, within 24 h of initiating intraventricular antibiotics, 50% of these patients had negative CSF cultures. It is to be noted that no specific antibiotic has been approved for intrathecal use by the FDA. The antibiotics most ordered are vancomycin and aminoglycosides [57••]. Intrathecal antifungal treatment can also be considered for special fungal infections such as coccidial meningitis and cryptococcal meningitis. It is

prudent to involve infectious disease specialists in these situations and remain vigilant regarding possible increase in ICP with such treatment secondary to the introduction of exogenous therapy into the ventricular system.

Hemorrhage

The incidence of ICH after EVD placement varies widely in the literature. While single center studies have reported hemorrhage rates as high as 56% [66••], three meta-analyses reported incidence rates between 5.7 and 8.4% [67–69]. The definition of EVD-related hemorrhages is important in this context—new catheter tract hemorrhage vs spontaneous new or enlargement of existing ICH/IVH—as most hemorrhages are asymptomatic. Clinically significant hemorrhage rates range from 0.6 to 0.8% with significantly increased risk if they have received anti-platelet agents within 96 h of EVD insertion [70]. Coagulopathy, therapeutic anticoagulation, and antiplatelet use are all known to be associated with increased risk of hemorrhage [71, 72]. The precise value of the coagulation parameters that make it safe to insert EVDs is not clear. One small retrospective study involving 71 patients with TBI compared bleeding risk in 3 groups of patients—those with an INR < 1.2, between 1.2 and 1.4, and between 1.4 and 1.6 [73]. They found no difference in hemorrhage rates between these groups and concluded that the insertion of an EVD was safe in this INR range. A good practice statement from the Neurocritical Care Society recommends correcting coagulopathy prior to EVD insertion, unless it is a dire emergency [37].

Catheter misplacement

EVD malposition rates can range from 4 to 20% [1, 74, 75]. EVD catheters are usually placed using free hand techniques by neurosurgeons in most centers worldwide. The accuracy of placement is graded by the Kakarla methodology, with optimal position (grade 1) being the catheter tip in the frontal horn of the ipsilateral lateral ventricle or third ventricle [1]. Based on these criteria, Kakarla et al. found that optimal catheter position was achieved in about 77% of the cases in their retrospective review of 346 cases. Newer techniques using image guidance are available but not yet popular in usage. A recent meta-analysis of studies including more than 3000 patients comparing free hand technique to image guidance methodology reported higher accuracy and reduced rates of drain failure with image guidance, despite similar number of attempts [76••]. The added time needed for set up and the bulkiness of the equipment make them less useful in emergency situations. Newer devices using holograms and smartphone applications show promise in overcoming some of these limitations [77, 78]. Ultrasound-guided insertion is also gaining popularity especially in certain countries like UK [79••]. Newer probes can transduce via burr holes making real-time image acquisition possible. However, more scalable research and evidence are needed.

Catheter malfunction

EVD catheter malfunction secondary to catheter obstruction results from misplacement or migration of the EVD catheter tip into the brain parenchyma. Occlusion of the EVD catheter lumen by blood clots and cellular debris will lead to under-drainage or cessation of CSF drainage and may result in a rapid rise in ICP [80, 81]. The incidence rate of EVD malposition is in the range of 4 to 20%, the majority of which do not result in significant clinical complications, but about 4% require EVD replacement [1, 74]. Measures to resolve obstruction include distal EVD tube flushing. If this fails, the proximal EVD tubing can be flushed with a small amount of sterile saline by experienced medical professionals under strict aseptic conditions. We sometimes use intraventricular alteplase if we suspect a blood clot occluding the EVD with no contraindication to its use. If this is not successful, then EVD replacement may be necessary. Removing and reintroducing an EVD carry its own risk of secondary hemorrhage and CSF infection.

Removal of EVD

There are two well-described approaches to removing an EVD. The more popular one is the gradual weaning approach, which is done by raising the level of the EVD everyday by an average of 5 cm H_20 at a time and then doing a clamp trial when the level has reached a predetermined target, usually 20–25 cm H_20. The other approach is immediate clamping and monitoring for 24 h. During the weaning period and clamp trial, the patient is closely monitored for the development of any neurological or radiologic worsening. If this occurs, the EVD is opened, and patient stabilized. The options are then to either repeat a clamp trial or proceed with shunt placement. The superiority of one approach over the other has been a matter of great debate. The only prospective randomized controlled clinical trial (RCT) comparing gradual weaning versus rapid weaning found that a rapid wean with immediate clamping was safe and led to shorter duration of EVD use and shorter lengths of stay in the ICU and hospital [50]. There was no difference in ventriculoperitoneal shunt placement rates in this study. In contrast, in a prospective multicenter observational study, a rapid wean protocol was associated with a lower rate of VPS, 2.1 fewer EVD days, and decrease ICU length of stay [82••]. A recent meta-analysis compared the two weaning methods and found no significant benefits with gradual weaning but a significant reduction in hospital length of stay in the rapid weaning group (30.2 days versus 26.7 days, respectively, 95% *CI* 0.22–0.47, *I*-squared = 0%) [46••]. Again, there was no significant difference in rates of shunt placement between the groups. While the decision to choose one approach over the other depends mainly on the individual situation of each patient, considering the length of EVD placement, the ability for meaningful clinical assessment during the weaning, and

the amount of initial IVH and its clearance, the American Stroke Association recommends a rapid wean approach in patients with SAH [83]. So too does the Neurocritical Care Society, which advises to wean EVDs as quickly as clinically feasible, ostensibly to reduce the risk of VAI [37].

Conclusion

EVDs remain an important part of managing certain neurological emergencies in the NCCU, both for diagnostic and therapeutic purposes. Although there is an accumulating body of evidence favoring practices such as continuous ICP monitoring over continuous CSF drainage and rapid weaning versus gradual weaning, the neurosurgical community has not widely adopted these changes in its practice. New technical modalities that can help in improving accuracy of EVD placements are available, including holographic technology and smartphone apps. More research in several areas of EVD usage is needed, including larger multicenter RCTs on continuous versus intermittent CSF drainage, more data on effectiveness of intraventricular antibiotics, optimal methods of weaning/removal of EVDs, and further refinement of image guidance technology with RCTs comparing them to free hand techniques. With the expansion of the field of neurocritical care, more focused training programs on EVD insertion and management for neurointensivists and advanced practice providers (NPs/PAs) are mandated, as the available evidence seems to suggest that this is feasible.

Compliance with Ethical Standards

Conflict of Interest

Haamid H. Siddique declares no conflict of interest. Hussam Elkambergy declares no conflict of interest. Ahmad Bayrlee declares no conflict of interest. Yasser B. Abulhasan declares no conflict of interest. Florian Roser declares no conflict of interest. Jamil Dibu declares no conflict of interest.

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•• Of major importance

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