Published in final edited form as:

Curr Neurol Neurosci Rep. 2012 February ; 12(1): 24–33. doi:10.1007/s11910-011-0231-x.

External Ventricular Drainage for Intraventricular Hemorrhage

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Abstract

Hemorrhagic stroke accounts for only 10% to 15% of all strokes; however, it is associated with devastating outcomes. Extension of intracranial hemorrhage (ICH) into the ventricles or intraventricular hemorrhage (IVH) has been consistently demonstrated as an independent predictor of poor outcome. In most circumstances the increased intracranial pressure and acute hydrocephalus caused by ICH is managed by placement of an external ventricular drain (EVD). We present a systematic review of the literature on the topic of EVD in the setting of IVH hemorrhage, articulating the scope of the problem and prognostic factors, clinical indications, surgical adjuncts, and other management issues.

Keywords

External ventricular drain; Ventriculostomy; Intraventricular hemorrhage; IVH; EVD

Introduction

Intraventricular hemorrhage (IVH) is a frequent complication of subarachnoid hemorrhage (SAH) and intracranial hemorrhage (ICH). IVH can range from mild layering of the blood in the posterior horn of the lateral ventricle to complete casting of all the ventricles. Presence of IVH both in the setting of ICH and SAH is associated with poor outcome [1–6]. IVH associated with hemorrhagic stroke causes increased intracranial pressure (ICP) by virtue of mass effect from hemorrhage or associated hydrocephalus due to ventricular outflow obstruction. Increased ICP in the setting of cerebrovascular accident is usually managed both medically and surgically. Arguably the most common neurosurgical procedure done, usually at bedside, is placement of external ventricular drain (EVD) for monitoring and managing ICP, and assisting with clearance of intraventricular blood. We review herein the topic of EVD in the setting of IVH, articulating the scope of the problem and prognostic factors, clinical indications, technical aspects, surgical adjuncts and other management issues, and relevant questions for future research.

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Conflicts of interest: M. Dey: none; J. Jaffe: none; A. Stadnik: none

Epidemiology of EVDs for IVH Associated with Hemorrhagic Stroke and SAH: Scope of the Problem

ICH and SAH account for the majority of hemorrhagic strokes. Although spontaneous ICH with or without intraventricular extension accounts for only 10% to 15% of all strokes, the devastating disease accounts for disproportionate outcomes, at 30-day mortality rates of 35% to 52% and half of those deaths occurring in the first 2 days [7, 8, 9, 10–12]. It has been postulated that rupture of ICH into the ventricles would be beneficial to lessen the mass effect from the large ICH on surrounding structures, but in fact the extension of ICH into the ventricles (Fig. 1a) has been consistently demonstrated as an independent predictor of poor outcome in patients with ICH [13–23]. In a series of patients with supratentorial ICH and IVH, Young et al. [24] demonstrated a strong predictor between ventricular blood volume and poor outcome, and determined that patients with more than 20 cc of interventricular blood in general had poor outcome. Another study examining patients with large IVH found that the etiology of the IVH was more important in predicting outcome than the volume of IVH [25]. Tuhim et al. [14] did a prospective study to determine the prognostic significance and pathophysiologic implication of intraventricular extension of ICH and showed that 30-day mortality was much higher in patients with IVH and there was a direct correlation between IVH volume and poor outcome, and this correlation persisted when controlling for the presence or absence of hydrocephalus and size of associated ICH, thus establishing IVH volume as an independent prognostic factor of poor outcome, independent of the volume of ICH [14].

SAH, most often associated with rupture of intracranial aneurysm, accounts for approximately 5% of all strokes and affects as many as 30,000 Americans each year with 30-day mortality rates as high as 45% [26], and those who survive often have noteworthy morbidity following the event. Predictors of poor outcome in the setting of SAH include severity of initial hemorrhage, older age, longer time to treatment, and size and location of aneurysm. SAH extending into the cerebral ventricles can contribute to obstruction of cerebrospinal fluid (CSF) circulation and acute hydrocephalus (Fig. 1b). Several studies have demonstrated the impact of IVH as an independent poor prognostic indicator after aneurysmal SAH [6, 27, 28].

Several recent studies have attempted to grade the extent of IVH in relation to patient outcome [14, 19, 24, 25]. The “Graeb score” (Table 1) considers the extent of involvement of the respective ventricles and associated ventriculomegaly, and has been extensively validated in outcomes studies [1, 19, 29].

Indications for EVD in IVH

Acute obstructive hydrocephalus following IVH and SAH causing high ICP can lead to significant morbidity and mortality. Even though ICP can be managed medically with sedation and osmotic diuretics, such management is often insufficient to reduce ICP and those settings call for EVD placement [30]. An analysis of IVH cohort in a large prospective randomized study of surgery for ICH [31] demonstrated that continuous drainage of CSF contributes to the normalization of ICP. However, the placement of EVD does not eliminate the morbidity and mortality of IVH, perhaps due to underlying damage from the associated

stroke, and the toxic effects of ventricular blood on adjacent periventricular brain tissue, including hippocampus, diencephalon, and brainstem. Catheter occlusions occur frequently in the setting of large IVH volume, with casting and clotting on ventricular blood, and these can result in poor ICP control. Catheter occlusions also require repeated catheter removals and insertions, thus increasing the risks of hemorrhage and infection [32]. The precise thresholds for insertion of EVD after IVH have not been clarified, but it is generally agreed that the presence of hydrocephalus and deteriorating neurologic condition are an indication for placing an EVD [33]. It is unclear whether an EVD is beneficial in anticipation of potential ventricular obstruction in patients with good neurologic condition, or to enhance clearance of obstructive IVH.

EVD and Clearance of IVH

The placement of EVD does not immediately clear the IVH and is sometimes not sufficiently effective by itself due to obstruction of the catheter by blood. Naff et al. [34] showed that blood clot resolution in CSF follows first-order kinetics. And it has been suggested that EVD could even potentially slow the rate of IVH clearance by removing the tissue plasminogen activator released from the clot into the CSF. Conversely, the injection of thrombolytic agents into the ventricular space would increase the rate of clot resolution. Thrombolytic therapy for IVH has evolved in response to the problems of catheter obstruction and slow IVH clearance, and has been shown to be safe and effective in animal studies [22, 35, 36] and in small clinical case series [37–41]. A systematic review comparing indirect observational studies comparing conservative treatment, EVD, and EVD combined with fibrinolysis in the setting of severe IVH due to SAH or ICH found that the fatality rate for conservative treatment was 78%, for EVD 58%, and for EVD with fibrinolytic agents 6%; and the poor outcome rate for conservative treatment was 90%, EVD 89%, and EVD with fibrinolytic agents 34% [42]. This information is obviously limited by retrospective data sets and varying management protocols and the potentially different severity of hemorrhage in cohorts treated with different modalities. In the setting of SAH a prospective observational study by Nieuwkamp et al. [43] showed that massive IVH occurs in 10% of patients with SAH and approximately half of these patients may benefit from intraventricular fibrinolysis.

In the setting of very large IVH (>40 cc) with casting and mass effect, Hinson et al. [44•] showed that use of bilateral simultaneous EVD catheters may increase clot resolution with or without adjunctive thrombolytic therapy. Conversely, Staykov et al. [45] found no difference in clot resolution between the groups treated with one versus two EVDs in the setting of severe IVH; however, they did find a trend toward a longer EVD duration and higher infection rate in the bilateral EVD group. The Staykov study [45] did not include a comparison with single catheter cases, controlling for IVH volume.

The safety and feasibility of intraventricular thrombolysis was recently tested in phase 2 clinical trial [34], and the dose of intraventricular thrombolysis has been optimized, with 1 mg every 8 h achieving the most enhanced clearance without increasing hemorrhage risk. The data from the CLEAR II trial show that low-dose recombinant tissue-plasminogen activator (rt-PA) for the treatment of ICH with IVH has an acceptable safety profile

compared with placebo and prior historical controls. The effect of intraventricular thrombolysis on survival and functional outcome compared to EVD alone with placebo irrigation is being tested in an ongoing phase 3 clinical trial (CLEAR III [Clot Lysis: Evaluating Accelerated Resolution of Intraventricular Hemorrhage Phase III]; www.cleariii.org).

Techniques of EVD Insertion

In 1890, Keen [46] first reportedly used skull landmarks to cannulate the lateral ventricle and in 1918 Dandy [47] published a technique involving anterior and occipital ventricular horn punctures for air ventriculography. The standard neurosurgical technique for bedside EVD insertion has gradually evolved in subsequent decades using preassembled kits, and ultimately the introduction of disposable instruments and drills and tunneling of the catheter [48]. Ghajar [49] introduced the principle of cannulating the cerebral ventricle by precise perpendicular trajectory to the skull surface, and he developed a tool to facilitate this approach. Roitberg et al. [50] reported minimal complications and successful EVD placement and maintenance for duration of required drainage in a retrospective series of 103 consecutive cases of bedside EVD placement in the intensive care unit (ICU), with sterile technique and short subcutaneous tunneling of the catheter. Kakarla et al. [51] confirmed the safety and accuracy of EVD placement by neurosurgical trainees by bedside ventriculostomy for ICP monitoring and CSF drainage.

Due to occasional complications associated with bedside EVD placement some have recommended placement of the EVD in the operating room, with a rationale of better sterile technique, and more optimal visualization and hemostasis of burr hole exposure and brain surface cannulation [50]. However, the acute nature of increased ICP and the added time involved with operating room access and patient transport have continued to favor the emergent use of bedside technique.

Standard Technique of EVD Insertion—Usually right frontal EVD at the Kocher's point is preferred unless specific contraindications are present such as right lateral ventricle hematoma, arteriovenous malformation/lesion in the trajectory of the EVD, etc. Insertion of the EVD is a technical procedure and thus is operator dependent. Very few studies have been done to assess the precision of EVD placement, and these have not used standardized or adjudicated criteria [51–59]. Successful cannulation of the ventricle (subjective, and series dependent), number of catheter passes, and inadvertent EVD placement in brain tissue or subarachnoid space varied vastly depending on the study (and what was assessed and reported). There are very few studies reported in the literature that primarily look at the safety and accuracy of EVD placement (Table 2).

Technical Adjuncts—Given that the body of the lateral ventricle lies in the midpupillary line and the curve of the superior aspect of the anterior horn parallels the curve of the overlying cranium, a catheter directed at a right angle to the cranial surface in the midpupillary line will enter the ventricle. Based on this principle, Ghajar [49] designed a device that, when placed over a burr hole at Kocher's point, guides a catheter perpendicular to the skull surface. The efficacy of the guide was studied in 17 patients who required

ventriculostomy. CSF was obtained in all patients on the first pass of the catheter at an approximate intracranial distance of 5 cm. Eleven patients had confirmation of correct catheter placement in the ipsilateral anterior horn of the lateral ventricle by intraoperative fluoroscopy or postoperative CT [49]. However, this technique is useful only when a mass lesion has not distorted the patient's brain anatomy. A study comparing the freehand technique of catheter placement using external landmarks with the use of the Ghajar guide showed that successful cannulation was achieved using either technique; however, the catheters placed using the Ghajar guide were closer to the target [59].

Lollis and Roberts [60] proposed the use of robotic technique, and reported a small prospective series with safe, highly accurate, and reliable EVD placement with robot-guided trajectory even in patients with very small ventricles. Image-guided frameless stereotaxy is increasingly being used for ventricular catheter placement in shunt procedures for hydrocephalus, demonstrating greater accuracy and better placement of catheter in even difficult cases such as slit ventricles, and shift due to mass lesion or cysts, etc. [61]. Although this practice has not translated into routine use for emergent EVD placement because of time constraints and the life-threatening nature of acute hydrocephalus, it may be most appropriate for catheter replacements after initial poor placement, or for second catheters targeted at trapped or casted ventricles (Fig. 2a). In selected situations, EVD placement may be accomplished with real-time image guidance in the CT scanner under sterile technique, as per procedures of real-time CT-guided biopsy (Fig. 2b).

Special Surgical Considerations

Despite the technical ease of their placement, misplacement of the ventricular catheter can lead to a range of complications including hemorrhage and infection [62]. In a meta-analysis performed by Binz et al. [9•], they reported 5.7% new bleeding on CT scan after EVD placements, with less than 1% risk of clinically significant hemorrhage. Even though hemorrhage associated with ventriculostomy placement is a known risk, it is very poorly studied and quantified. Complication rate may be influenced by many factors such as the institutional and individual practitioner's practice patterns, timing of the CT scan, the thresholds on coagulation studies to indicate safety, use of platelet infusion for patients treated with antiplatelet agents, access site, drill bit size and thread distance, aggressive drilling, use of saline to irrigate the twist drill hole, removal of all bone fragments prior to dural opening, sharp or blunt dural penetration, sharp or blunt pial opening, slow or quick access of the frontal horn, removal of the stylet at ventricular entry or after advancement to the foramen of Monroe, or even tightness of scalp closure [9•]. Gardner et al. [63] noted a possible trend, but no statistically significant reduction of hemorrhage risks when EVDs are placed in the operating room compared with the ICU. Other authors have reported modified techniques in an attempt to lower the risk of EVD-associated hemorrhage. In a retrospective study of 50 patients using a modified spinal needle for ventricular access, Hassler and Zentner [64] demonstrated a 0% "symptomatic" hemorrhage rate. Using a stainless steel blunt-tip needle for percutaneous ventriculostomy, Meyer et al. [65] reported an ICH rate of 1% with only 0.5% caused by the actual ventricular puncture in 200 patients. Careful well-designed studies are needed to objectively define and estimate the risk of EVD-associated

hemorrhage. Adjudicated data in this regard will emerge from ongoing trials of thrombolysis versus placebo in EVD for IVH [34, 66, 67•, 68••].

Management of EVD

Measuring Opening Pressure—One of the most important facts obtained from the EVD is the opening ICP measurement. This value has significant prognostic implications, and it influences the subsequent strategy and threshold of CSF drainage through the EVD. In all but cases of impending cerebral herniation, special attention is paid so as not to allow significant CSF escape from the EVD before documenting pressure, and this can be accomplished with a manometer or transducer. Once the pressure is measured, the EVD catheter is secured and connected with the drainage bag system and pressure transducer.

Opening Level, Intermittent Versus Continuous Drainage—There are several options of managing EVD drainage, depending on the opening pressure and the underlying pathology. In the setting of SAH and untreated aneurysm, the conventional wisdom is to not lower the ICP too drastically. The rationale is to avoid changing the transmural pressure across the wall of recently ruptured aneurysm, predisposing to rebleeding [69]. Although some studies did not confirm an increased risk of rebleeding with EVD after aneurysmal SAH [70], current best practice aims not to drain too much CSF too fast. There has been no comparison of intermittent drainage strategies (regularly scheduled intermittent volume, or as needed in response to ICP elevations), versus continuous drainage with the drip chamber set a particular level (drainage as needed when ICP exceeds that level). Continuous drainage may allow more rapid clearance of ventricular blood, and presumably spasmogenic and irritative contents of bloody CSF, but may also be vulnerable to overdrainage during patient suctioning and mobilization (experienced units protocolize temporary clamping of the EVD during those maneuvers). Others have cautioned that overdrainage of CSF could predispose to cerebral vasospasm as well as hydrocephalus [71].

Infection Prophylaxis

Incidence of ventriculostomy-related infections has been reported from 0% to 22% [72–76]. This frequently necessitates replacement of EVD, prolonged hospital stay, antibiotic-associated cost and morbidities, and occasionally life-threatening sequelae. Risk factors that have been suggested in association with EVD-related infections include previous craniotomy, systemic infection, depressed cranial fracture, lack of tunneling of the catheter, IVH, duration of EVD, catheter irrigation, site leaks, and frequency of CSF sampling [77]. Yet many of these factors have not been carefully adjudicated in controlled studies, or even in multivariate analyses. Factors suggested to reduce infectious complications include strict sterile insertion technique with tunneling of the EVD catheter, wound care, closed system devices, and minimum interruption of the closed systems [78]. Most of these suggestions have attributed particular interventions to a low infection rate, or have compared sequential periods or different series with various protocols, but there have not been careful controlled studies addressing these adjuncts. Some studies showed an associated risk of infection if the catheter is left more than 5 days [79], and a linear correlation between infection rates and duration of catheter and CSF leakage [80]. Other studies have shown that length of EVD duration has no effect on the rate of infection [81].

Antibiotic Use—To reduce infections associated with EVD, a common practice is to administer intravenous antibiotics to cover common skin flora [79]. However, antibiotic prophylaxis may contribute to the development of resistant organisms, or much more morbid gram-negative ventriculitis [82]. Protocols of antibiotic use have varied widely, including perioperative use at and for short period after EVD insertion, or continued for the duration of drainage [79, 83]. A meta-analysis of randomized clinical trials and observational studies concluded that the use of prophylactic systemic antibiotics throughout the duration of EVD and use of antibiotic-coated EVD appears beneficial in preventing ventriculostomy-related infection [83–87]; however, the absolute and relative risk reduction of EVD infections, if any, with antibiotic use has not been carefully assessed and requires further carefully controlled trials. In the setting of CSF infection with indwelling EVD, it is commonly advised to remove the presumably colonized EVD, and replace it with a clean EVD, preferentially at a different “clean” site. The new EVD allows resumption of CSF drainage, may enhance clearance of ventriculitis, allows CSF sampling to monitor response to treatment, and provides a route for intraventricular antibiotic administration. The latter may be lifesaving in fulminant ventriculitis. In addition to changing the EVD, intravenous antibiotics should be started or adjusted in response to the specific offending agent, and intraventricular antibiotic instillation should be considered for more fulminant or recalcitrant infections. Protocols of managing bacterial ventriculitis in association with EVD have varied widely, with a number of protocols resulting in successful eradication of infection [86, 88, 89].

CSF Surveillance—To proactively monitor development of infection in the setting of EVD, regular CSF samples may be collected under sterile conditions and examined for organisms, cells, glucose, and protein and sent for microbiological culture. Infection may be gleaned from CSF white blood cell pleocytosis, relative CSF hypoglycemia, positive gram stain, or positive polymerase chain reaction (PCR) for bacterial DNA, but positive CSF culture is the ultimate proof of infection [90]. There is wide variation in current practices regarding CSF surveillance, ranging from routine CSF monitoring on a daily basis or other regular intervals, to CSF sampling only when there is clinical concern for infection, and in documenting clearance of infection. Gram stain and newer PCR techniques may allow rapid identification of colonization or early infections, and the initiation of treatment before the serious sequelae of intraventricular purulence.

Antibiotic-Impregnated Catheters—Drawing from the success of antibiotic-impregnated central venous catheter in decreasing central line-associated sepsis, antibiotic-impregnated EVD catheters have been developed with the aim of decreasing infection risk. One prospective randomized study found that catheters impregnated with minocycline and rifampin were one half as likely to become colonized as the control catheters, and positive CSF cultures were seven times less frequent in patients with antibiotic-impregnated catheters compared with those in the control group [91]. However, another similar study found no reduction of infection using the hydrogel-coated catheters when presoaked in low concentration bacitracin solution when compared with regular catheter [92]. One of the biggest concerns for using antibiotic-impregnated catheter is that surveillance specimens obtained from antibiotic-impregnated catheter may be less likely to demonstrate bacterial

growth and thus potentially delay the detection of infection until more advanced ventriculitis. A recent study confirms that the risk of a false-negative culture result may be increased when a CSF sample is drawn through an antibiotic-impregnated catheter [93].

Removal of EVD

With IVH and SAH, there is often obstruction of arachnoid villi and the ventricular and cisternal drainage pathways causing acute hydrocephalus and thus the need for EVD. However, CSF flow dynamics may recover in some cases after clearance of ventricular blood, allowing the EVD to be discontinued. In other cases, chronic hydrocephalus develops requiring the need for long-term CSF diversion by shunt placement. The decision of EVD removal or conversion to shunt is based on EVD weaning and clamping trials.

Weaning and Clamping Trials—Extrapolating from other medical devices such as chest or endotracheal tubes, the conventional way of EVD removal is a multiday stepwise weaning by progressive height elevation of the drainage system leading to clamping of the EVD. During this multiday process the size of the ventricles are usually monitored with serial imaging, along with the patient's neurologic condition and the volume of CSF drained at various thresholds. If the size of the ventricles increases during this process, or significant ICP elevations or persistent need of drainage are otherwise documented, those patients are deemed to be in need for permanent CSF diversion strategy such as a shunt. However, a study looking at the gradual versus rapid weaning of the EVD in the setting of SAH found that multistep gradual EVD weaning may have provided no definite advantage, only delaying the ultimate shunt procedure, and contributed to more prolonged ICU and hospital stays [94]. However, it is clear that different patients recover from EVD dependency at varying rates, and many would not require a shunt after a longer period of EVD drainage, which could best be gauged through repeated clamping trials, if not gradual weaning.

Indication and Timing of Ventriculoperitoneal Shunt Placement—In the setting of aneurysmal SAH, older studies have shown many factors loosely associated with increased risk for needing ventriculoperitoneal shunt such as advanced age [95–97], more extensive SAH with higher Fisher grade [95, 98, 99], poorer neurologic condition with higher Hunt and Hess grade [95, 99–101], presence of acute hydrocephalus [98, 100, 102], increased CSF drainage time [102, 103], continuous CSF drainage [71], and female sex [95, 99, 100]. Chan et al. [104] studied the clinical factors predisposing a patient to long-term shunt dependency and tried to formulate a Failure Risk Index that strongly and linearly correlated with the risk of EVD challenge failure. They also found that CSF protein level at the time of challenge was the single most predictive factor. However, this index has not been validated with prospective study. A very recent study suggests that permanent CSF diversion after aneurysmal SAH may be independently predicted by hyperglycemia at admission, findings on the admission CT scan (Fisher grade 4, fourth ventricle IVH, and bicaudate index > 0.20), and development of nosocomial meningitis [105].

Special Consideration

EVD and Thromboprophylaxis—EVD is associated with a 0% to 33% risk of hemorrhagic complications [9•] and many patients requiring EVD are coagulopathic due to

their underlying brain illness or previous therapies. Coagulation parameters are measured before starting the procedure, and in all but life-threatening impending herniation, the conventional practice is to measure coagulation parameters and platelet counts, and to correct the coagulopathy (if International Normalized Ratio >1.2–1.4) or administer platelets (if platelet counts are <100,000) before or during insertion of EVD. In case of previous antiplatelet therapies, it is common to administer platelets for emergent EVD placement, or to document normal platelet aggregation assays if time permits. Although most practitioners advocate platelet transfusion for clopidogrel (Plavix; Sanofi Aventis, Bridgewater, NJ) effect, there is controversy whether aspirin use alone should preclude safe EVD placement. Exact thresholds of coagulopathy for safe EVD placement have largely been derived from empiric experience, rather than carefully controlled studies. Similarly, normal coagulation parameters must be insured for any catheter manipulations, catheter removal, or during thrombolytic administration through the EVD.

Most patients with stroke, including those requiring EVD, are unconscious or immobile, with demonstrated higher risk of developing deep venous thrombosis. Sequential stockings should be used from the time of patient admission, and the literature does not justify any rationale for delaying administration of mini-dose anticoagulation for thromboprophylaxis after placement of EVD, as long as the hemorrhagic stroke has stabilized and the underlying aneurysm or vascular malformation has been secured. Patients are closely monitored clinically, and if needed radiographically, after removal of EVD.

Conclusions and Future Directions

Much controversy persists regarding various facets of EVD management, and these should be clarified in controlled studies. The precise clinical and imaging thresholds for placing an EVD after IVH have not been clarified, nor the precise impact on outcome with and without thrombolysis. There is much variability in EVD placement, including whether anatomical landmarks should be used, placing the EVD in a freehand manner, or using image guidance to place the catheter. Suboptimal placement is more likely when using anatomical landmarks for insertion, but this is often the most efficient technique in emergent situations, and image guidance is not always readily available. Other variability exists in terms of target placement, whether to place the catheter through the lateral ventricle with greater or lesser blood, or how far from the foramen of Monroe the catheter should be placed. Analyses of ICP control, catheter obstructions, and clot resolution rates in relation to various catheter placement strategies will require further clarification in ongoing and future studies.

Acknowledgments

Disclosure I.A. Awad: has received grant support from the National Institutes of Health and the National Institute of Neurological Disorders and Stroke; and has received honoraria and also travel/ accommodations expenses covered or reimbursed from invited lectures, grand rounds, and visiting professorships.

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Fig. 1.
a, CT scan of a typical intracerebral hemorrhage with extension into the ventricles. **b,** CT scan of a typical subarachnoid hemorrhage with intraventricular hemorrhage

Fig. 2.
a, Image-guided external ventricular drain (EVD) placement using frameless stereotaxy. **b,** Image-guided placement of EVD in CT scanner

Table 1

The Graeb score Modified from Graeb et al. [1]

Location	Score
Lateral ventricles (each lateral ventricle is scored separately)	
	0 = no blood
	1 = trace of blood or mild bleeding
	2 = less than half of the ventricle is filled with blood
	3 = more than half of the ventricle is filled with blood
	4 = ventricle is filled with blood and expanded
Third and fourth ventricles	
	0 = no blood
	1 = blood present, ventricle size normal
	2 = ventricle filled with blood and expanded
Total	Range: 0–12

Table 2

Studies looking at the accuracy of EVD placement

Study	Setting	# of EVDs	Misplacement rate	Reference
Retrospective	SAH, IVH	183 (with postoperative CT scan)	50% (other than frontal horn of the lateral ventricle)	Toma et al. [52]
Retrospective	Trauma, ICH, SAH	98	22.4% (extraventricular spaces)	Huyette et al. [53]
Retrospective chart review	Pediatric traumatic brain injury	68	8.8% (outside ventricular system)	Anderson et al. [56]
Observational	Acute obstructive hydrocephalus	100	11%	Bogdahn et al. [55]
Retrospective		104	20.1%	Khan et al. [58]
Prospective	Increased ICP	212	7%	Stangl et al. [57]
Retrospective	SAH, trauma, ICH, IVH	346	13% (eloquent tissue)	Kakarla et al. [51]

EVD external ventricular drain; *ICH* intracranial hemorrhage; *ICP* intracranial pressure; *IVH* intraventricular hemorrhage; *SAH* subarachnoid hemorrhage