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Original Article

Single institution series describing external ventricular drain (EVD) placement and short- and long-term complications related to placement accuracy

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ABSTRACT

Background: The placement of an external ventricular drain (EVD) for the treatment of acute hydrocephalus is one of the most common life-saving procedures that neurosurgeons perform worldwide. There are many well-known complications associated with EVD placement, including tract hemorrhages, intra-parenchymal and subdural hemorrhages, infection, and catheter misplacement. Given the variety of complications associated with EVD placement and the inconsistent findings on the relationship of accuracy to complications, the present study reviewed short- and long-term complications related to EVD placement at our institution.

Methods: A retrospective review was conducted for all consecutive patients who underwent bedside EVD placement for any indication between December 2020 and December 2021. Collected variables included demographic information, etiology of disease state, pre-and post-operative head computed tomography measurements, and post-procedural metrics (immediate and delayed complications).

Results: A total of 124 patients qualified for inclusion in our study. EVDs that were non-functioning/exchanged were not significantly related to age, accuracy, ventriculomegaly, sex, disposition, laterality, type of EVD used, intraventricular hemorrhage (IVH), etiology, or Kakarla Grade (KG) (all $P > 0.17$). The need for a second EVD was similarly not related to age, accuracy, ventriculomegaly, sex, disposition, location, laterality, type of EVD used, IVH, etiology, or KG (all $P > 0.130$). Patients who died, however, were significantly more likely to have a second contralateral EVD placed (18.2% vs. 4.9% $P = 0.029$). We also found that left-sided EVDs were significantly more likely to fail within seven days of placement (29.4% vs 13.3%, $P = 0.037$; relative risk (RR) 1.93, 95% confidence interval: 1.09-3.43), unrelated to age, sex, etiology, type of EVD, IVH, location of the procedure, or accuracy (all $P > 0.07$). This remained significant when using a binary logistic regression to control for ventriculomegaly, accuracy, mortality, age, sex, and etiology ($P = 0.021$, B = 3.43).

Conclusion: In our cohort, although a clear relationship between inaccuracy and complication rates was not found, our data did demonstrate that left-sided EVDs were more likely to fail within the immediate postoperative time point, and patients who died were more likely to have a second, contralateral EVD placed.

Keywords: Accuracy, Complications, External ventricular drain (EVD)

INTRODUCTION

The placement of an external ventricular drain (EVD) for the treatment of acute hydrocephalus or elevated intracranial pressure (ICP) is one of the most common life-saving procedures that neurosurgeons perform worldwide.[7,12] EVDs can be used to both monitor and treat intracranial hypertension through the diversion of cerebrospinal fluid (CSF) in a multitude of disease states, including acute hydrocephalus from aneurysmal subarachnoid hemorrhage (SAH), intraventricular hemorrhage (IVH), severe traumatic brain injury, and obstructive hydrocephalus from certain tumors.[4,9,12] Given the acute and life-threatening nature of acute hydrocephalus and elevated ICP and the time-sensitive need for CSF diversion, it is widely accepted that EVDs can be placed at the bedside, employing a "free-hand" technique using anatomical landmarks to accurately cannulate the frontal horn of the ipsilateral ventricle.[7,9,12]

There are many well-known complications associated with EVD placement, including tract hemorrhages, intraparenchymal and subdural hemorrhages, infection, and catheter misplacement.[3] Complication rates vary but have been reported to be as high as 20–30% for hemorrhagic complications,[8,12] up to 45% for catheter misplacement,[12] and infection rates from 4% to 40%.[7,9,15,16] These complications are associated with an increase in hospital length of stay (LOS) and patient morbidity and mortality.[3,5,16] EVD misplacement may be associated with EVD failure, intracranial hemorrhage, higher reinsertion rates, and drain blockages.[10] Given this, more accurate EVD placement through image guidance techniques may provide better outcomes.

Kakarla *et al.* first studied the relationship of EVD accuracy to complications with the use of a subjective grading system for EVD placement, with the ideal position being categorized as a catheter tip in the ipsilateral frontal horn or third ventricle (Grade 1) ranging to suboptimal placement in the eloquent cortex (Grade 3).[6] Since this, several studies have highlighted how EVD misplacement can lead to increased complications and revisions.[4,7,8] For example, Toma *et al.* described how inaccurate EVD placement led to higher rates of revisions (40%), which may have led to higher complication rates.[13] Shtaya *et al.* also demonstrated how inaccurate EVD placement led to higher rates of complications and revisions.[11]

Given the variety of complications associated with EVD placement and the inconsistent findings on the relationship of accuracy to complications, the present study reviewed short- and long-term complications related to EVD placement at our institution.

MATERIALS AND METHODS

Patient selection

A retrospective review was conducted for all consecutive patients who underwent bedside EVD placement for any indication between December 2020 and December 2021. All EVDs were placed by members of the neurosurgical team (specifically residents) at the bedside, either in the intensive care unit (ICU) or in the emergency department, using standard procedural protocols, without neuronavigation and secured to the skin by suture. All patients received pre-procedural antibiotics (usually ancef) before receiving the EVD, as per our institution's protocol. Patients who received antibiotic-impregnated EVDs were at the discretion of the neurosurgical team. EVDs that were antibiotic-impregnated included minocycline and rifampin. The tubing for EVDs is barium impregnated, and the dimensions are as follows: 80 cm by 1.5 mm by 0.7 mm. All EVDs at our institution are manufactured by Medtronic (Minneapolis, MN, USA). Inclusion criteria were patients who were 18 years of age or older and indicated a frontal EVD placement. Exclusion criteria were patients under the age of 18, those who received any non-frontal EVDs, and those with EVDs placed in the operating room.

Data collection and variable characteristics

This study was approved by the Institutional Review Board at the home institution, protocol number STUDY20050395. The informed consent process was waived as this was a secondary use of patient data obtained for clinical purposes. All clinical and imaging data were retrospectively collected from the patient's electronic medical record. Collected variables included: (1) pre-procedural metrics such as demographic information, indications for EVD placement, and etiology of disease state; (2) pre- and post-operative head computed tomography (CT) measurements; (3) procedural information; and (4) post-procedural metrics (immediate and delayed complications). Etiology of hemorrhage and hydrocephalus was characterized as traumatic, subarachnoid hemorrhage (SAH), intraparenchymal hemorrhage (IPH), intraventricular hemorrhage (IVH), pseudotumor cerebri, normal pressure hydrocephalus, arteriovenous malformation, or other. Preoperative head CT measurements included the maximum width of the skull, maximum distance of the frontal horns, inter caudate distance, and maximum third ventricle distance. Post-procedural head CT measurements included the vertical distance of the tip of EVD to the foramen of Monro (FOM), the horizontal distance of the tip of EVD to the FOM, and the linear distance of the tip of EVD to the FOM (TTF). All CT measurements were completed by the first author of the manuscript and confirmed by the senior author. Procedural information was characterized by the length of the procedure, laterality of EVD placement, and Kakarla grading scale. Immediate complications were those that occurred within the present hospital stay (within one month of the EVD placement), while delayed complications were those that occurred after discharge (generally after one month). Complications were defined as tract hemorrhage, subdural hematoma, epidural hematoma, or infection. In addition, we collected data on if the EVD was revised, repositioned, removed, or replaced.

Data analysis and statistical testing

Statistical tests conducted for analysis included a Chi-squared test, paired *t*-test, and logistic regression. All statistical analyses were performed using SPSS software (IBM, Armonk, NY). Data are reported as mean (standard deviation) for continuous data, mean (standard deviation) for quantitative data, and *n* (%) for all other values. Statistically significant values were set at $P < 0.05$.

RESULTS

Demographics, clinical information, and operative techniques

A total of 124 patients qualified for inclusion in our study. The average age was 56.1 (±15.3) years with a slight preponderance toward male patients (55.6%; *n* = 69) [Tables 1 and 2]. The majority of EVDs were placed for aneurysmal SAH (41.9%, *n* = 52), followed by IPH (22.6%; *n* = 28), trauma (19.4%; *n* = 24), tumor (9.7%; *n* = 12), and other (including stroke and postoperative complications; 6.5%; *n* = 8) [Table 2]. Most patients had IVH present (*n* = 81, 65.9%) and did not have ventriculomegaly by either third ventricular width (>10 mm; 9.1 ± 5.2 mm) or Evan's Index (>0.30; 0.28 ± 0.05) [Table 2]. The average midline shift (MLS) was 3.8 mm (±2.5 mm) [Table 2].

Most EVDs were placed in the ICU (*n* = 69, 55.6%), on the right side (*n* = 90, 72.6%), and using regular bore catheters (*n* = 82, 66.1%) [Table 1]. EVDs had an average duration of 10.2 (± 6.4) days with a total of 1024 EVD days in the dataset [Table 2]. The average overall LOS was 24.1 (±17.9) days and average ICU LOS was 18.8 (±14.1) days. The duration of EVD placement was significantly longer in SAH than in all other groups (13.4 ± 6.1 vs. 7.88 ± 5.6 days, $P < 0.001$) and significantly shorter in trauma patients (7.83 ± 5.9 vs. 10.76 ± 6.5, $P = 0.045$).

Accuracy

Overall, most EVDs were placed in Kakarla Grade (KG-1, *n* = 86, 69.4%;) [Table 1] accurately with an average Euclidean TTF distance of just over 1 cm (10.3 ± 7.9 mm); [Table 2]. Linear accuracy was not impacted by the location of procedure, laterality, age, or sex (all $P > 0.078$). Accuracy by TTF distance was not related to ventricular caliber as determined by third ventricle width ($P = 0.994$) or Evans Index ($P = 0.462$) and similarly was not affected by MLS ($P = 0.117$) or presence of IVH ($P = 0.926$).

We did find that patients without hydrocephalus (14.8% vs. 2.3%, $P = 0.031$) and without IVH (15.7% vs. 0%, $P = 0.041$) were significantly more likely to have mispositioned catheters.

Table 1: Demographics.

	Count	Percentage
Sex		
Female	55	44.4
Male	69	55.6
Indication for EVD		
SAH	52	41.9
IPH	28	22.6
Trauma	24	19.4
Tumor	12	9.7
Other	8	6.5
IVH present?		
No	42	34.1
Yes	81	65.9
Location of procedure		
ED	55	44.4
ICU	69	55.6
Laterality		
Left	34	27.4
Right	90	72.6
Type of catheter		
Regular	82	66.1
Large bore	22	17.7
Antibiotic coated	20	16.1
Kakarla grade		
1	86	69.4
2	25	20.2
3	13	10.5

EVD: External ventricular drain, IVH: Intraventricular hemorrhage, SAH: Subarachnoid hemorrhage, IPH: Intraparenchymal hemorrhage, ED: Emergency department, ICU: Intensive care unit

Table 2: Patient characteristics.

	Mean	Std. dev.	Min.	Max.
Age (years)	56.1	15.3	12.0	93.0
EVD duration (days)	10.2	6.4	0.0	26.0
Hospital LOS (days)	24.1	17.9	1.0	129.0
ICU LOS (days)	18.8	14.1	0.0	83.0
Midline shift (mm)	3.8	2.5	0.0	15.1
Third ventricle width (mm)	9.1	5.2	1.4	32.6
Evans index	0.28	0.05	0.09	0.47
Linear distance TTF (mm)	10.3	7.9	1.4	63.7

EVD: External ventricular drain, LOS: Length of stay, ICU: Intensive care unit, mm: Millimeters, TTF: Tip of EVD to Foreman of Monro, Std. dev.: Standard deviation, Min.: Minimum, Max.: Maximum

Patients with a misplaced EVD had significantly smaller third ventricle width (6.3 ± 3.8 vs. 9.5 ± 5.7, $P = 0.037$). While we thought this subset of patients might represent the trauma population, EVDs placed in traumas were not significantly more likely to have malpositioned EVDs ($P = 0.271$). Catheter malposition was also not related to age ($P = 0.183$) or sex ($P = 0.467$). Etiology findings related to Kakarla grade is demonstrated in figure 1.

Outcomes

The overall rate of mortality (death or hospice) in our cohort was 17.7% ($n = 22$), with an average time to death of 10.45 (±8.3) days. Patients with IPH accounted for 54.5% of all deaths, which was significantly higher than any other etiology ($P < 0.001$), and 42.9% ($n = 12$) of IPH patients died [Figure 2]. Most patients were discharged to rehab (55.6%, $n = 71$), with 15.3% being discharged home ($n = 19$). Patients who died were significantly older (64.5 ± 12.7 vs 54.3 ± 15.3, $P = 0.004$), were more likely to be male (81.8% vs 50.0%, $P = 0.006$), had significantly greater midline shift (3.6 ± 1.8 vs. 5.2 ±4.1, $P = 0.003$), and had significantly higher rates of hydrocephalus by third ventricle width (59.1% vs. 35.3%, $P = 0.038$). Patients who died did not differ in rate of IVH ($P = 0.213$), location of EVD placement ($P = 0.557$), or laterality of EVD ($P = 0.284$). Patients who died did not differ in the accuracy of EVD placement by any metric.

Complications

The most common complication in our cohort was an EVD that was non-functioning or exchanged (20.2%, $n = 25$) followed by an EVD that required placement of a second, contralateral EVD (7.3%, $n = 9$) [Table 3]. Our infection rate was low with only one confirmed case of ventriculitis (0.8%). Hemorrhagic complications occurred in 12.9% of patients with the most common such complication being tract hemorrhage >1 cm (9.7%, $n = 12$) followed by subdural hemorrhage (3.2%, $n = 4$). Hemorrhagic complications were not associated with age, ventriculomegaly, sex, disposition, location, laterality, type of EVD used, IVH, etiology, or KG (all $P > 0.09$). Hemorrhagic complications were not a significant predictor of EVD failure/exchange ($P = 0.333$) or the need for a second EVD ($P = 0.231$).

Overall, EVDs that were non-functioning/exchanged were not significantly related to age, accuracy, ventriculomegaly, sex, disposition, laterality, type of EVD used, IVH, etiology, or KG (all $P > 0.17$). The need for a second EVD was similarly not related to age, accuracy, ventriculomegaly, sex, disposition, location, laterality, type of EVD used, IVH, etiology, or KG (all $P > 0.130$). These comparisons all held when grouping non-functioning/exchanged EVDs with EVDs that required placement of a second, contralateral EVD. We did, however, find that patients who died were significantly more likely to have a second contralateral EVD placed (18.2% vs. 4.9% $P = 0.029$) but had similar rates of EVD revision ($P = 0.799$).

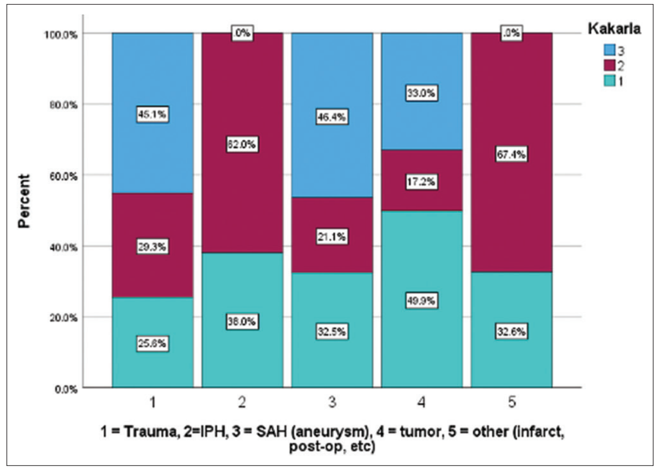

Figure 1: How Kakarla grade functioned based on etiology. Etiologies: 1: trauma; 2: Intraparenchymal hemorrhage (IPH); 3: Subarachnoid hemorrhage (SAH) (aneurysm); 4: tumor; and 5: other (infarct, postoperative, etc.).

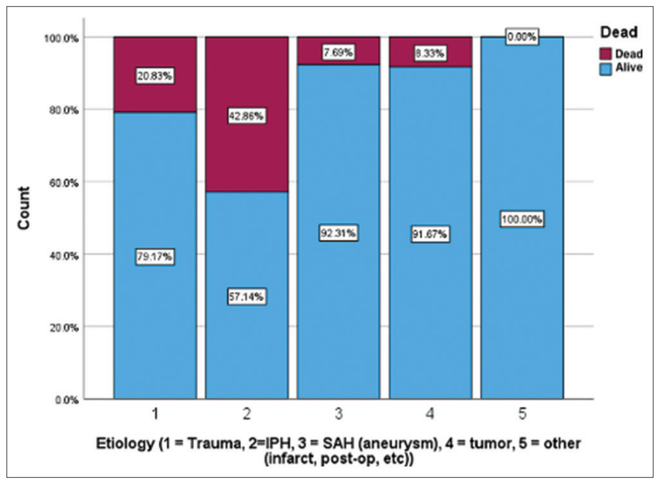

Figure 2: Death based on etiology. Etiologies: 1: trauma; 2: Intraparenchymal hemorrhage (IPH); 3: Subarachnoid hemorrhage (SAH) (aneurysm); 4: tumor; and 5: other (infarct, postoperative, etc.).

When looking at all EVD failures (non-functioning, exchanges, and second EVDs together), we found the average time to EVD failure to be 6.59 ± 5.9 days (median = 4.5 days). Therefore, we sought to analyze this subset of immediate EVD failures as defined by all EVDs that failed within the first seven days of placement. We found that left-sided EVDs were significantly more likely to fail within seven days of placement (29.4% vs 13.3%, $P = 0.037$; RR 1.93, 95% confidence interval: 1.09–3.43), unrelated to age, sex, etiology, type of EVD, IVH, location of the procedure, or accuracy (all $P > 0.07$). This remained significant when using a binary logistic regression

Table 3: Complications.

	Count	Column *n* %
Disposition		
Home	19	15.3
Rehab	71	57.3
SNF	8	6.5
Hospice	4	3.2
Death	22	17.7
Complications		
None	89	71.8
Infection	1	0.8
Non-functioning EVD requiring exchange or removal	25	20.2
Placement of contralateral EVD	9	7.3
Hemorrhagic complications		
None	108	87.1
Tract hemorrhage	12	9.7
Subdural	4	3.2
Preoperative antibiotics		
No	34	27.4
Yes	90	72.6

SNF: Skilled nursing facility, EVD: External ventricular drain

to control for ventriculomegaly, accuracy, mortality, age, sex, and etiology (P = 0.021, B = 3.43).

DISCUSSION

Despite being one of the most common neurosurgical procedures performed worldwide, the relationship between accurate EVD placements and outcomes is not well understood in the literature. Given the ambiguity surrounding outcomes, complications, and the overall relationship to accurate EVD placements, this study sought to quantify institution-wide outcomes from free-hand EVD placements. As our institution and others investigate bedside image guidance of EVDs through augmented reality or other techniques, there is a demonstrated need to aggregate baseline data from free-hand placements for future comparisons. Despite this being an overall negative study, we did find evidence that patients who died were significantly more likely to have a second, contralateral EVD placed (18.2% vs. 4.9% P = 0.029) and left-sided EVDs were more likely to have failure rates in the immediate postoperative time point, regardless of other characteristics.

Accuracy

The rates of accuracy in this study are comparable to previous studies using the Kakarla grading scale. Within this cohort, the majority of EVDs were placed accurately (KG-1, n = 86, 69.4%); [Table 1]. A 2021 meta-analysis reported a mean of 74% (±7% standard deviation) rate of ideal EVD placement.[4] While Maher Hulou *et al*. (72.5% accuracy for KG-1) found a statistically significant impact of trauma diagnosis, low bicaudate index, high midline shift, and left-sided placement on rates of accuracy, our present study isolated the size of ventricles as the only significant variable affecting accurate EVD placement.[7] However, despite accuracy being an important measure, within our cohort, there was no significant relationship between accuracy and outcomes. The low rate of malpositioned catheters in the study likely contributed to the lack of a significant relationship between accuracy and outcomes. Patients who died did not differ in rates of EVD accuracy. The previous studies have also reported no clinical morbidity associated with malpositioned catheters, complicating our understanding of the relationships between complications, morbidity, and EVD placements.[3,12] The consequences of a malpositioned EVD are challenging to differentiate from the main pathology.

Outcomes

Patients with IPH experienced the highest rates of mortality. It is important to note that the placement of an EVD does not eliminate the underlying damage from the IPH event.[7] Given that the rates of mortality are not associated with accurate catheter placement but rather the severity of the presenting condition, it is reasonable to conclude that EVD placement was not the primary cause of mortality. More so in our cohort, rates of mortality did not differ due to presenting symptoms of IVH (P = 0.213), location of EVD (P = 0.557), or laterality (P = 0.284). Contrary to our cohort, Tuhrim *et al.* demonstrated that the presence of IVH was an important prognostic factor in the 30-day mortality rate, regardless of the size of the IVH.[14] Although this is different from our data, it could be due to the outcomes that were specifically being measured.

Complications

The infection rate in this cohort (n = 1, 0.8%), [Table 3] is lower than previously published metrics that estimate post-EVD infection rates at 23.2%.[11] The low rates of infection in this cohort can be attributed to the high rate of prophylactic antibiotics (n = 90, 72.6%), [Table 3] and low rates of malpositioned catheters requiring revisions.

Hemorrhagic complications happened more frequently in this cohort (n = 16, 12.9%), [Table 3] than with previously established rates in the literature. A 2011 meta-analysis reported the overall hemorrhage risk associated with ventriculostomy placement based on the existing literature at 7.0% and a rate of significant hemorrhage at 0.8%.[1] Concordant with the previous studies, routine post-placement CT scans can explain higher rates of identified hemorrhagic complications.[2] Regarding immediate failure rates, we did not find any data in the literature focusing on failure rates within seven days. Finally, Maher Hulou *et al*. demonstrated similar results in that left-sided EVD placement was a predictor for suboptimal position (KG-3) (odds ratio 2.84, $P = 0.03$).[7] Our reasoning for the left-sided EVDs being more likely to fail is multifaceted. First, we are trained to insert EVDs on the right side. Most residents are right-handed, and we believe most pathology for EVDs does not significantly localize to one side or the other; thus, baseline preference is the right. The failure rate might be due to less frequent placement and possibly the ergonomics of left- versus right-sided placements. Resident motor memory is for the right; thus, the reflected anatomy probably does not translate as well, and they are off more or require more passes.

Limitations

Despite statistically significant results, there are limitations to our study. The most important being the nature of a single-institution and retrospective review, which limits our ability to control for certain variables, such as number of passes and time of placement as well as limits the patient population to what is seen at our institution. More so, to help overcome this selection bias, we enrolled all patients during a specific period to limit these biases.

CONCLUSION

The rates of complications due to inaccurately placed EVDs are hard to distinguish from the natural course of the disease for which EVD placement is required. In our cohort, although a clear relationship between inaccuracy and complication rates was not found, our data did demonstrate that left-sided EVDs were more likely to fail within the immediate postoperative time point, and patients who died were more likely to have a second, contralateral EVD placed. In future studies, our institution will be utilizing augmented reality image guidance to place EVDs to understand further how accuracy can impact complication rates.

Ethical approval

The research/study was approved by the Institutional Review Board at the University of Pittsburgh Medical Center, number STUDY20050395, dated 11/13/2023.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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