Journal of Clinical Neuroscience 97 (2022) 7–11

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Clinical study

# Freehand frontal external ventricular drain (EVD) placement: Accuracy and complications

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ARTICLE INFO

*Article history:*
Received 7 October 2021
Accepted 29 December 2021

*Keywords:*
EVD
Ventriculostomy
Hemorrhage
Misplacement
Infection
Bicaudate index
Complications

ABSTRACT

Ventriculostomy placement is a life-saving procedure. Our aim was to determine the predictors of inaccurate placement, our infection and hemorrhage rate. This was a retrospective study of EVD placements between January - November 2019. Data related to hemorrhage, infection and catheter misplacement were collected. Univariate and multivariate analyses of predictors of suboptimal catheter placement were performed. 131 consecutive patients underwent freehand EVD placement. The indications were subarachnoid hemorrhage in 36 (27.5%) patients, hemorrhagic stroke in 36 (27.5%), and trauma in 32 (24.4%) patients. Nine patients (6.8%) had culture-proven CSF bacterial infection. Sixteen (12.2%) patients developed small tract hemorrhage, while 8 (6.1%) patients developed large intraparenchymal hemorrhage. There was no correlation between tract hemorrhage or large hemorrhage with the use of antiplatelet or anticoagulation medicines on presentation, diagnosis or Kakarla grade. Trauma diagnosis (odds ratio 2.59, *p*-value 0.05), left side of EVD placement (odds ratio 2.84, *p*-value 0.03), increasing midline shift (odds ratio 1.09, *p*-value 0.03), and lower bicaudate index (odds ratio 0.56, *p*-value 0.02) were all predictors of Kakarla grade 3 suboptimal placement. When Kakarla grade 2 and 3 were combined, similar results were obtained except that midline shift was no longer statistically significant. The multivariable regression model predicting Kakarla 3 suboptimal placement revealed that low bicaudate index and left sided EVD were predictors of misplaced EVD.



## 1. Introduction

Frontal external ventricular drain (EVD) placement is the gold standard for monitoring intracranial pressure and managing acute hydrocephalus. This life-saving procedure is commonly performed by a neurosurgery resident at the bedside without neuronavigation, making it prone to increased complication rate.

EVD placement remains the most common procedure performed in our neurosurgical intensive care unit (ICU). Complications including hemorrhage, infection and misplacement have been followed with interest for decades. Several risk factors for hemorrhage and infection have been recognized and protocols were placed to improve outcomes [1]. In terms of ventriculostomy-related infection, antibiotics-impregnated catheters, pre-procedural dose of antimicrobial agents, EVD duration and manipulation of the closed system were largely debated in retrospective studies. The rates of infection varied from 0% to 40% based on the institutional criteria for diagnosis of device-related cerebrospinal fluid (CSF) infection [2]. Intracranial hemorrhage is another complication that may be associated with EVD placement or withdrawal. In 2009, a *meta*-analysis on hemorrhagic complications of ventriculostomy placement reported an overall hemorrhage risk of 5.7% [3]. This study also reported a 0.61% rate of clinically significant hemorrhage and found that in studies which used routine post-placement CT scans, the hemorrhage rate was 10.06% vs. 1.53% in those that did not utilize post-placement CT scans. Another *meta*-analysis in 2011 demonstrated an overall hemorrhagic complication rate of 7% and a 0.8% of hemorrhages were deemed clinically significant by the authors [4].

The rate of accurate catheter placement ranges from 40% to 80% [5–7]. EVD placement is well recognized as an important skill in

*Abbreviations:* EVD, external ventricular drain; IPH, intraparenchymal hemorrhage; IVH, intraventricular hemorrhage; MLS, midline shift; PGY, post-graduate year; ROC, receiver operating characteristic; SD, standard deviation.

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https://doi.org/10.1016/j.jocn.2021.12.036
0967-5868/

neurosurgical training but less frequently discussed in the literature. Therefore, we designed a study to mainly determine the predictors of catheter misplacement, and report on our hemorrhage and infection rate.

## 2. Methods

Institutional Review Board (IRB protocol number: 53002) approval for viewing images and medical records of patients undergoing external ventricular drain placement was obtained before the initiation of this retrospective study which was compliant with the Health Insurance Portability and Accountability Act (HIPAA). Written informed consent was waived.

Hospital records were searched retrospectively for patients who had undergone external ventricular drain (EVD) placement at the University of Kentucky Albert B. Chandler Hospital between January 1st-November 30th, 2019. Inclusion criteria were: patients with EVD performed at the bedside by a neurosurgery resident. Exclusion criteria were: non-frontal ventriculostomy placement, shunt at the same surgical site, previous EVD or patients without a post-procedure CT scan.

We performed a literature review on EVD complications following PRISMA guidelines to identify the data variables closely related to catheter misplacement, post-procedure hemorrhage and post-procedure infections. Details of the literature review are not reported in this article because it was only intended to help identify the variables for the study. Hospital charts were reviewed for demographics, indication for ventriculostomy placement, pre-and post-procedure platelets anti-aggregation and anti-coagulation medicines, and methamphetamine use. Patients on anti-coagulation medicines were reversed according to hospital pharmacy protocols. Patients on antiplatelets were given one or two units of platelets prior to EVD placement.

Laboratory studies were reviewed for all cerebrospinal fluid (CSF) samples and *peri*-procedural (a day before, the day of and day after the procedure) blood, urine and respiratory cultures. CSF cultures and gram stains, CSF nucleated cells, and CSF glucose levels were studied. Pre-procedural CT scans were reviewed by a PGY-4 neurosurgery resident to calculate the bicaudate index. We chose to have a neurosurgery resident rather than a radiologist calculate this because it is not a standardly reported finding by radiology. Rather, it would be a clinically applicable index used 'at the bedside' by neurosurgery providers. Pre- and post-procedure midline shift (MLS), catheter location, and type of catheter-related hemorrhage (small tract, or large intraparenchymal hemorrhage) were extracted from the radiology reports.

At our medical center, ventriculostomies are typically placed by junior neurosurgical residents (PGY 1, 2, 3) under direct supervision. When EVD placement does not result in reliable CSF drainage, a CT scan is obtained to evaluate the location of the catheter and rule out hemorrhage. EVDs are typically placed at Kocher's point without Ghajar guide or image guidance. Kocher's point is identified by measuring 10–11 cm from nasion in the sagittal plane and then measuring 3–4 cm from midline in the coronal plane. The insertion site is shaved with a clipper, prepared and draped in a sterile fashion. The catheter exits the scalp at a depth of approximately 5 cm. Patients do not receive antibiotics specifically for EVD placement, and the catheters are not impregnated with antibiotics. Catheter-related infection was defined with a positive CSF culture only. Post-procedure CT scans are not routinely performed in our department unless clinically indicated.

A series of univariate and multivariate logistic regression analyses were performed to investigate the relationship between clinical characteristics and suboptimal EVD placement. We used Kakarla grading system to analyze our data [6]: Grade 1, optimal placement in the ipsilateral frontal horn; Grade 2, functional placement in the contralateral lateral ventricle; and Grade 3, placement in eloquent cortex or cerebrospinal fluid cisterns, with or without functional drainage. For one set of analyses, suboptimal placement was defined as a Kakarla grade 3. Next, a sensitivity analysis was performed to determine how changing the definition of suboptimal placement impacted findings by including Kakarla grade 2 and Kakarla grade 3 together. Multivariable logistic with regression was performed to predict suboptimal placement (Kakarla 3). All variables that were statistically significant in the univariate analysis were included in the multivariable model. For continuous predictors of suboptimal placement (e.g., MLS and bicaudate index), a receiver operating characteristic (ROC) analysis was performed to determine optimal cut off points for maximizing sensitivity and specificity. All analyses were performed with SAS version 9.4 (SAS Institute, INC). Statistical significance was defined as $p \leq 0.05$.

## 3. Results

Table 1 presents the descriptive statistics for the 131 consecutive patients who underwent freehand frontal EVD placement at a virgin surgical site. The average age was 47.9 (SD = 20.1; range 1 – 87), and 56 (42.7%) patients were female. The indications for the procedure were: subarachnoid hemorrhage in 36 (27.5%) patients, hemorrhagic stroke in 36 (27.5%) patients, trauma in 32 (24.4%) patients and other diagnoses in 27 (20.6%) patients.

### 3.1. Accuracy of EVD placement

#### 3.1.1. Kakarla Grade 3

Of the 131 EVD placements, the majority received a Kakarla grade 1 (n = 95; 72.5%). Fourteen (20.7%) patients received a Kakarla grade 2, and 22 (16.8%) patients received a Kakarla grade 3. The first portion of Table 2 presents the clinical variables related to suboptimal EVD placement, where suboptimal placement is defined as a Kakarla grade 3. All EVDs with Kakarla grade 3 were functional. Trauma diagnosis, side of EVD placement, midline shift,

**Table 1**
Characteristics of patients who underwent EVD placement.

| | |
|---|---|
| *Age, mean (SD)* | 47.9 (20.1) |
| *Sex* | |
| Male | 75 (57.3%) |
| Female | 56 (42.7%) |
| *Diagnosis (Main Groups)* | |
| Trauma | 32 (24.4%) |
| SAH | 36 (27.5%) |
| Hemorrhagic Stroke | 36 (27.5%) |
| Other diagnoses | 27 (20.6%) |
| *Diagnosis (including subgroups)* | |
| 1a: Trauma-cerebral edema | 14 (10.7%) |
| 1b: Trauma + IPH | 16 (12.2%) |
| 1c: Trauma + IPH + IVH | 2 (1.5%) |
| 2a: SAH Only | 24 (18.3%) |
| 2b: SAH + IVH | 9 (6.9%) |
| 2c: SAH + IVH + IPH | 3 (2.3%) |
| 3a: Hemorrhagic stroke only | 4 (3.1%) |
| 3b: Hemorrhagic stroke + IVH | 32 (24.4%) |
| 4: Tumor | 12 (9.2%) |
| 5: Infection | 7 (5.3%) |
| 6: External hydrocephalus | 1 (0.8%) |
| 7: CSF leak | 1 (0.8%) |
| 8: Posterior fossa stroke | 4 (3.1%) |
| 9: shunt failure | 2 (1.5%) |
| *Kakarla Score* | |
| 1 | 95 (72.5%) |
| 2 | 14 (10.7%) |
| 3 | 22 (16.8%) |

**Table 2**
Univariate predictors of suboptimal placement.

| Predictor | Kakarla grade 3 | | Kakarla grade 2 and 3 | |
|---|---|---|---|---|
| | Odds Ratio | *p*-value | Odds Ratio | *p*-value |
| Trauma Diagnosis | 2.59 (0.99–6.80) | 0.054 | 2.72 (1.17–6.33) | 0.020 |
| Left-Side EVD Placement | 2.84 (1.07–7.57) | 0.037 | 2.54 (1.07–6.07) | 0.035 |
| Midline shift[1] | 1.09 (1.01–1.19) | 0.038 | 1.07 (0.99–1.16) | 0.092 |
| Bicaudate Index[2] | 0.56 (0.34–0.92) | 0.022 | 0.65 (0.44–0.98) | 0.041 |

[1] Per 1 unit increase
[2] Per 0.07 unit increase

and bicaudate index were all related to suboptimal EVD placement, though trauma diagnosis was at the nominal cutoff of $\alpha = 0.05$. Suboptimal placement was more likely for those with a trauma diagnosis or a left-sided EVD placement. Larger degrees of midline shift were also directly related to the probability of a suboptimal placement. Larger bicaudate indices were associated with a lower odds of suboptimal placement; an increase in the bicaudate index of one standard deviation (0.07 units) was associated with a 44% reduction in the odds of suboptimal placement.

An ROC analysis was additionally performed for midline shift and bicaudate index to assess the utility of different cut points. A cut point of 0.13 for the bicaudate index resulted in a sensitivity of 0.64 and a specificity of 0.63 (Area Under the Curve = 0.66, $p = 0.015$). No cut points on midline shift achieved a sensitivity greater than 0.33, but using a cut point of 1 cm was associated with a sensitivity of 0.33 and specificity of 0.80 (Area Under the Curve = 0.58, $p = 0.185$).

A stepwise selection for the multivariable logistic with regression resulted in two variables being selected in the final model: bicaudate index and EVD side. Individuals who had an EVD on the left side were more likely to have suboptimal placement (Kakarla grade 3) than those on the right (OR = 3.22; 95% CI: 1.13 – 9.22; $p = 0.029$). Higher levels of the bicaudate index were associated with lower rates of suboptimal placement. For an increase of one standard deviation in the bicaudate index (SD = 0.07), the rates of suboptimal placement were nearly halved (OR = 0.53; 95% CI: 0.31 – 0.90; $p = 0.019$). In the multivariable model, trauma diagnosis was found to be highly correlated with the lower bicaudate index and consequently was dropped out of the model. When both were included, the regression estimates became unstable due to multicollinearity, therefore only bicaudate index was selected.

### 3.1.2. Kakarla grade 2 and 3

Similar results are obtained when suboptimal placement is defined as Kakarla grade 2 and 3, presented in the latter half of Table 2. However, midline shift was no longer significantly related to suboptimal placement. Suboptimal placement was between two to three times more likely for those with a trauma diagnosis or a left sided EVD placement. Larger bicaudate indexes were associated with lower odds of suboptimal placement – a standard deviation increase was associated with a 35% reduction in the odds of suboptimal placement.

An ROC analysis for the bicaudate index found that a cut point of 0.20 was associated with high sensitivity, 0.85, but low specificity at 0.33 (Area Under the Curve = 0.61, p = 0.037).

## 3.2. Hemorrhage

Of the 131 EVD placements, 16 (12.2%) developed small tract hemorrhage, 8 (6.1%) developed large intraparenchymal hemorrhage; thus, 24 (18.3%) developed any hemorrhage. No EVD placement resulted in isolated new intraventricular hemorrhage. Any hemorrhage that is more than a small amount of blood identified by radiology along the tract of the EVD catheter was categorized under large/intraparenchymal hemorrhage. None of the patients with intraparenchymal hemorrhage required surgical intervention. Trauma diagnosis, Kakarla score, EVD placement side, MLS bicaudate index, and preoperative medicines including antiplatelets and anticoagulant medicines were all investigated for any association with hemorrhage. However, none of these variables were significantly related to the presence of any type of hemorrhage (Table 3).

**Table 3**
Analysis of post-procedural hemorrhage in patients with EVD placement. Small/tract Hemorrhage

| Predictor | Odds Ratio | *p*-value |
|---|---|---|
| Side of EVD (ref = R) | 0.47 (0.10–2.20) | 0.336 |
| Midline Shift | 0.97 (0.85–1.11) | 0.662 |
| Bicaudate index | 0.94 (0.56–1.56) | 0.799 |
| *Diagnosis* | | |
| SAH vs Trauma | 1.13 (0.28–4.63) | 0.643 |
| Hemorrhagic Stroke vs Trauma | 1.13 (0.28–4.63) | 0.643 |
| Trauma vs Other | 0.56 (0.09–3.32) | 0.403 |
| *Kakarla grade* | | |
| 1 vs 3 | 3.63 (0.45–29.19) | 0.181 |
| 2 vs 3 | 1.62 (0.09–28.12) | 0.888 |
| *Preop Medicine* | | |
| Anticoagulation vs None | 0.87 (0.10–7.54) | 0.948 |
| Antiplatelets vs None | 0.87 (0.23–3.12) | 0.93 |
| Large/intraparenchymal Hemorrhage | | |
| Predictor | Odds Ratio | *p*-value |
| Side of EVD (ref = R) | 1.10 (0.21–5.76) | 0.911 |
| Midline Shift | 1.05 (0.93–1.19) | 0.446 |
| Bicaudate index | 1.44 (0.74–2.82) | 0.2857 |
| *Diagnosis* | | |
| SAH vs Trauma | 1.82 (0.15–21.11) | 0.953 |
| Hemorrhagic Stroke vs Trauma | 1.82 (0.15–21.11) | 0.953 |
| Trauma vs Other | 3.88 (0.38–39.63) | 0.221 |
| *Kakarla Score* | | |
| 1 vs 3 | 1.42 (0.16–12.40) | 0.898 |
| 2 vs 3 | 1.62 (0.09–28.12) | 0.795 |
| *Preop Medicine* | | |
| Anticoagulation vs None | 8.76 (1.25–61.42) | 0.099 |
| Antiplatelets vs None | 3.83 (0.73–20.20) | 0.743 |
| Any type of hemorrhage | | |
| Predictor | Odds Ratio | *p*-value |
| Side of EVD (ref = R) | 0.64 (0.20–2.06) | 0.454 |
| Midline Shift | 1.01 (0.91–1.11) | 0.903 |
| Bicaudate index | 1.10 (0.72–1.68) | 0.651 |
| *Diagnosis* | | |
| SAH vs Trauma | 1.30 (0.37–4.60) | 0.829 |
| Hemorrhagic Stroke vs Trauma | 1.30 (0.37–4.60) | 0.829 |
| Trauma vs Other | 1.23 (0.32–4.89) | 0.96 |
| *Kakarla Score* | | |
| 1 vs 3 | 2.67 (0.58–12.38) | 0.218 |
| 2 vs 3 | 1.67 (0.21–13.43) | 0.981 |
| *Preop Medicine* | | |
| Anticoagulation vs None | 2.67 (0.60–11.85) | 0.309 |
| Antiplatelets vs None | 1.52 (0.53–4.41) | 0.908 |

### 3.3. Infection

Sixty-eight patients (51.9%) had at least one CSF sample collected as part of fever or infection work-up. Nine patients (6.8% of patients) had a culture-proven CSF bacterial infection. Species included Staphylococcus epidermidis (N = 4), Staphylococcus aureus (N = 3), Weissella confusa (N = 1), and Cupriavidus pauculus (N = 1). Among the patients with bacterial meningitis, all CSF nucleated cells were elevated (median: 430/μL, range: 12–3505/μL), and CSF glucose levels were low (median: 40 mg/dL, range: 3–73 mg/dL) except for 2 patients – one infected with Weissella confusa and one infected with Staphylococcus epidermidis. None of the patients with bacterial meningitis presented to the hospital with positive methamphetamine on their urine drug screen; 3 patients (33.3%) had associated positive blood cultures, and 2 patients (22.2%) had associated positive urine cultures.

## 4. Discussion

The optimal location of the ventriculostomy catheter tip is in the ipsilateral frontal horn of the lateral ventricle close to the foramen of Monroe (Kakarla grade 1). This was achieved in 72.5% of EVD placements whereas 16.8% of placements were deemed inaccurate (Kakarla 3). Several variables were found to be statistically related to inaccurate EVD placement (Kakarla grade 3) including: trauma diagnosis, low bicaudate index, high midline shift and left-sided placement. When all are included in a multivariable model with regression, trauma diagnosis drops out due to multicollinearity with bicaudate index and only left-sided placement and bicaudate index remain statistically significant.

Among other studies, the desired target of EVD was achieved in 40% [5], 73% [8], 77% [6] of placements. Inaccurate placement leads to significantly higher revision rate [5] and insertional injury to eloquent brain structures similar to what is observed in Deep Brain Stimulator (DBS) microlesioning effect [9]. However, the clinical sequelae of suboptimal EVD placement is difficult to isolate from the main pathology and some studies report no clinical morbidity associated with misplaced catheter [6].

The bicaudate index, ratio of width of two lateral ventricles at the level of the head of the caudate nucleus to the distance between outer tables of skull at the same level, is a novel radiographic predictor of EVD misplacement. It was selected over Evans ratio to reflect the volume of the desired target (frontal horn) especially in patients with cerebral edema or compressed frontal horns. To our knowledge, low bicaudate index was never reported as a predictor of EVD misplacement before.

Guidance devices:

Freehand EVD placement is a blind procedure that relies on the operator's ability to visualize the anatomy of the ventricles especially when they are displaced. One way to improve the accuracy of EVD placement is to use navigation system. Shtaya *et al.* demonstrated lower complication rates and higher optimal EVD location with image guidance when compared to freehand technique. Their results were especially significant when the ventricles were small [10]. Other examples of navigation systems that showed superior results to freehand technique are: CT scan guidance [11], bedside electromagnetic neuro-navigation guidance [12], bedside wearable mixed-reality technology [13], integrated flat detector CT with fluoroscopic guidance (iGuide) [14], and Smart Stylet guidance [15].

Patients with traumatic brain injury are often young with baseline small ventricles and fully developed brains occupying the entire cranial vault. As we age, our brain parenchyma atrophies allowing the ventricles to enlarge. Our study found a significant correlation between high bi-caudate index and older patients ($r = 0.448$, $p < 0.001$). Trauma patients require an EVD for ICP monitoring in the setting of cerebral edema, or hydrocephalus. TBI-related acute coagulopathy is also a problem that is extensively documented to associate with delayed brain injury and poor outcomes [16,17]. It is primarily due to hemodilution and fluid resuscitation followed by a course of disseminated intravascular coagulation [18]. In this study, our trauma subgroup had a significantly higher misplaced catheters (Kakarla grade 3) calculated to be 28.1% of TBI patients with EVD which is close what Kakarla *et al.* and other researchers reported [6]. Post-EVD hemorrhage; however, was not significantly higher in the trauma population.

There was no correlation between post-procedural hemorrhage and the use of antiplatelet or anticoagulation medicines on presentation, Kakarla grade or diagnosis (Table 3). Several articles have investigated the same questions but the conclusion is still unclear. Leschke *et al.* 2017 reported that there was not a significant difference in hemorrhage rates between patients taking anti-platelet medication at presentation and those who were not on anti-platelet medication. They reported that 25% of patients on anti-platelet medication experienced post-EVD hemorrhage compared to 14.3% that were not on the anti-platelet medication ($p = 0.29$) [19]. Similarly, Yuen *et al.* 2018 conducted a retrospective study and reported that anticoagulation/antiplatelet use did not increase the rate of hemorrhage at their center [20].

Catheter-related CSF infection is difficult to define especially in the presence of intracranial hemorrhage [21]. Our study demonstrated that 6.8% of patients were infected based on gram stain and culture. To reduce infection rate, several institutions implemented a protocol for EVD placement to standardize the steps of placement and to prospectively detect potential causes of infection [1,22]. In 2010, Harrop *et al.* published their findings on the impact of a standardized protocol and antibiotic-impregnated catheters on EVD-related infections in cerebrovascular patients. They found that patients who had EVD placement with a standardized protocol and antibiotics-impregnated catheters had the lowest infection rate (0.9%; $p = 0.0001$) [23].

## 5. Study limitation

There are several limitations to our retrospective study including the lack of documentation of the number of EVD passes, the year of training of the operator, environment of the procedure, the type of ventriculostomy catheters other than being unimpregnated with antibiotics, and a focused neurological exam tailored to the possible injury caused by a misplaced catheter.

## 6. Conclusion

Risk factors for inaccurate EVD placement are left sided EVD placement, trauma diagnosis, midline shift and low bicaudate index. When they are recognized, the use of a navigation system may be helpful.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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