Risk factors for hemorrhage associated with external ventricular drain placement and removal

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OBJECTIVE External ventricular drains (EVDs) have an important role in the management of neurological disease, and their placement is a frequently performed neurosurgical procedure. Hemorrhage is a common complication of EVD placement and occurs more frequently than originally believed. There is also risk of hemorrhage with removal of an EVD, which has not been well described. The authors investigated the risk factors associated with placement and removal of EVDs at their institution.

METHODS A database was created including patients who required EVD placement from March 2008 to June 2014 at the University of Minnesota. A retrospective chart review was completed, and data were collected for each patient. All cranial imaging studies during the index hospitalization were reviewed to identify hemorrhages associated with either EVD placement or removal. The study was performed using a research protocol approved by the University of Minnesota's institutional review board.

RESULTS Four hundred eighty-two EVDs were placed during the designated time period. Among the cases in which patients underwent imaging after the placement procedure, hemorrhage was found in 94 (21.6%). The hemorrhage volume ranged from 0.003 cm³ to 45.9 cm³ (mean [± SD] 1.96 ± 6.48 cm³). Two of these hemorrhages resulted in additional interventions: 1 surgical evacuation and 1 contralateral EVD. In 55 (22.5%) of the 244 cases in which imaging was performed after EVD removal, hemorrhage associated with removal was identified. The mean volume of these hemorrhages was 8.25 ± 20.34 cm³ (range 0.012–82.08 cm³). Two EVDs were replaced, and 1 patient died as a result of a large hemorrhage. Large hemorrhages (> 30 cm³) occurred in 2 patients on placement (0.46%) and in 5 patients on removal (2.0%). In this series, decreased platelet levels on admission and an increasing number of EVD placement attempts correlated with an increased risk of hemorrhage on placement. Only those with an EVD placed at bedside were more likely to have hemorrhage on EVD removal.

CONCLUSIONS Multiple studies have reported varying EVD hemorrhage rates while very few studies have described hemorrhage secondary to EVD removal. This is the first reported analysis of risk factors associated with hemorrhage on EVD removal. Hemorrhages occur relatively frequently following EVD placement and removal, though clinical significance of these events seems to be low.

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KEY WORDS complication; external ventricular drain; hemorrhage; removal; hydrocephalus

EXTERNAL ventricular drain (EVD) placement has an important role in the management of neurological disease and is one of the most common neurosurgical procedures. An estimated 42,000 EVD placements were performed in 2006 in the United States, and this volume has increased over the past decade.^{27,32} EVDs are primarily used for CSF diversion and monitoring of intracranial pressure. Conditions for which they are placed include severe closed head injury, hydrocephalus, intraventricular hemorrhage, CSF fistulas, infections, and intracranial hypertension.

As with any invasive procedure, EVD placement carries risk; however, the reported complication rates are low enough to justify the routine use of ventriculostomies. The 2 most common complications associated with EVDs are infection and hemorrhage, with numerous published reports focusing on each complication. The widespread use of CT has resulted in increased postprocedural or surveillance imaging. Consequently, the incidence of hemorrhage following EVD placement has been shown to be much higher compared with historical reports. The contemporary literature describes the incidence of EVD-associated

ABBREVIATIONS EVD = external ventricular drain; INR = international normalized ratio; OR = odds ratio.

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hemorrhage ranging broadly from 0% to 42%.^{1,6–11,13–15,17–26,28–31,33,34} The majority of these hemorrhages appear to be small and not clinically significant.

While the risks associated with EVD placement have been studied extensively, there is little information regarding risks with EVD removal (Table 1). The incidence of hemorrhage associated with removal of an EVD has been documented in a few articles but has not been studied rigorously.^{8,18,28} The risk factors for EVD removal seem similar intuitively to those for EVD placement, but removal of an EVD is typically viewed as a trivial procedure. Given the relative scarcity of data on the subject, we investigated the incidence of hemorrhage and associated risk factors with both EVD placement and removal.

Methods

Patient Selection

This study was completed in accordance with a research protocol approved by the institutional review board at the University of Minnesota Medical Center. It followed the Health Insurance Portability and Accountability Act standards for privacy of personal health information. A de-

partmental database was searched for any patient in whom an EVD was placed from March 2008 to June 2014. All medical records and brain images (MRI and helical CT) were reviewed for parameters including admission date and time; admission diagnosis; medical comorbidities; indication for ventriculostomy; coagulation parameters and platelet counts at admission, prior to EVD placement and prior to EVD removal; blood product transfusions administered prior to the procedure; location of EVD; number of passes needed for successful placement; time of post-procedural imaging; new hemorrhage on postprocedural imaging; duration of EVD; time of imaging following removal; hemorrhage on imaging following removal; and any other related complications during hospitalization.

Technique of EVD Placement

The majority of ventriculostomies were performed in the frontal region, using a standard technique. The patient is placed supine, and the entry point is identified just anterior to the coronal suture in the midpupillary plane. The area is shaved, prepared, and draped in a sterile fashion, and the planned incision is infiltrated with local anesthetic. A small opening is made in the skull with a twist

TABLE 1. Example articles on EVD-related hemorrhage

Authors & Year	No. of EVDs	Placement Hemorrhage		Routine Post-EVD CT	Removal Hemorrhage	
		No. of Cases	%		No. of Cases	%
Friedman & Vries, 1980	100	1	1.0	N	—	—
Narayan et al., 1982	207	4	1.9	Y	—	—
North & Reilly, 1986	199	2	1.0	N	—	—
Paramore & Turner, 1994	253	4	1.6	Y	—	—
Khanna et al., 1995	106	0	0	N	—	—
Guyot et al., 1998	274	9	3.3	N	—	—
O'Leary et al., 2000	49	0	0	Y	—	—
Roitberg et al., 2001	103	1	1.0	N	—	—
Wiesmann & Mayer, 2001	92	6	6.5	Y	—	—
Ross & Dhillon, 2003	51	2	3.9	—	2	3.9
Krötz et al., 2004	52	1	1.9	Y	—	—
Anderson et al., 2004	68	12	17.7	Y	—	—
Hoh et al., 2005	119*	12	10.1	Y	—	—
	251	25	10.0			
Maniker et al., 2006	160	52	32.5	Y	—	—
Leung et al., 2006	133	1	0.8	N	—	—
Huyette et al., 2008	98	18	18.4	Y	—	—
Kakarla et al., 2008	346	17	4.9	Y	—	—
Saladino et al., 2009†	212	15	7.1	Y	—	—
Gardner et al., 2009	188	64	34.0	Y	13	6.9
Kung et al., 2011†	91	16	14.7	Y	1	1.1
	50*	16	32.0		3	2
Phillips et al., 2013	47	5	10.6	Y	—	—
Scholz et al., 2013	27	4	14.8	Y	—	—
Ko et al., 2014†	370	76	20.5	Y	—	—
Sussman et al., 2014	69	22	31.9	Y	—	—

N = no; Y = yes; — = not reported in article.

* Indicates those patients receiving anticoagulant agent.

† Both EVD and ventriculoperitoneal shunt were included in the analysis.

drill, and the dura is punctured with a spinal needle. An antibiotic-impregnated ventricular catheter (Bactiseal, DePuy Synthes) is advanced over a stylet perpendicular to the brain, and the frontal horn of the lateral ventricle is cannulated. The catheter is then tunneled subcutaneously out a separate stab incision approximately 5 cm away from the insertion site, secured to the scalp, and connected to a closed drainage system.

An occipital approach was used for some patients. The insertion technique is similar, except that the patients are placed prone, with the entry point made 6 cm above the external occipital protuberance and 3 cm lateral to midline. The trajectory for the catheter is toward the ipsilateral medial canthus, and the catheter is inserted to a length up to 12 cm.

Determination of EVD-Related Hemorrhage

One author reviewed all imaging studies obtained during the index hospitalization for hemorrhage and compared findings to official radiology reports. Any imaging from the time of placement or removal to 3 days after was examined for hemorrhage to ensure that slowly forming hemorrhages were not missed. A hemorrhage related to EVD placement was defined as any new hemorrhage along the ventricular catheter tract noted on postprocedural imaging that was not present on preprocedural imaging. Hemorrhage related to EVD removal was described as any new hemorrhage noted along the prior catheter tract or within the ventricles after removal. This definition required that the post-EVD removal imaging was compared with an imaging study obtained following EVD insertion. The size and volume of each hemorrhage was calculated by measuring the maximal dimensions in the X (A), Y (B), and Z (C) axes and using the formula $A \times B \times C / 2$.¹⁶ Medical records were reviewed to determine the clinical significance of the hemorrhage. We defined a hemorrhage to be clinically significant if the patient exhibited a temporally related deterioration in neurological examination. There was some difficulty in determining clinical significance of the hemorrhage if other processes confounded the patient's neurological condition.

Statistical Analysis

To compare groups, a 2-sample t-test was used for continuous variables (age, duration of EVD), and a chi-square test or Fisher's exact test was used for categorical variables (comorbidities, location). Logistic regression analysis was performed to examine potential risk factors for hemorrhage on EVD placement and EVD removal. The method of generalized estimating equations was used to account for within-patient correlations since some patients had multiple EVDs. Backward selection was conducted to select the strongest set of risk factors using statistical analysis software (version 9.3, SAS Institute Inc.). A 2-sided p value < 0.05 was considered statistically significant.

Results

From March 2008 to June 2014, 482 EVDs were placed in 380 patients (Table 2). Four hundred nine EVDs were placed in adult patients (age 18–81 years), and 73 were placed in pediatric patients (age 2 weeks–17 years). The

TABLE 2. Demographics and clinical characteristics of patients requiring EVD placement*

Characteristic	No. of Pts (n = 380)
Pediatric	73
Adult	409
Location of EVD	
Frontal	457
Occipital	14
Temporal	3
Parietal	8
Placement site	
Bedside	267
Operating room	215
Navigation	
Frameless stereotaxy	53 (1 bedside)
Ultrasound	25
Endoscopic	13
None	390

Pts = patients.

* A total of 482 EVDs were placed.

majority of the EVDs were placed in the frontal region (457), followed by the occipital (14), parietal (8), and temporal regions (3). Fifty-five percent of the procedures (267) were performed at bedside, with the remainder (215) placed in the operating room. Frameless stereotactic image guidance was used in 54 ventriculostomies, ultrasound guidance for 25, and endoscopy for 13. Table 3 displays the indications for EVDs, the most frequent of which was hemorrhage (213).

The length of time for which an EVD was necessary varied from 1 to 38 days (mean [± SD] 8.56 ± 6.17 days). Seventy-six EVDs (15.8%) were eventually converted to permanent CSF shunts. The mean length of time during which the EVD was in place in this group was 12.0 ± 7.52 days. Care was withdrawn in 87 patients (22.9%) while the EVD was in place.

One hundred sixteen EVDs were placed in patients who had been on anticoagulants or antiplatelet agents upon presentation to the hospital. Forty-six EVDs were placed in patients with underlying systemic coagulopathies due to liver disease, end stage renal disease, lymphoproliferative disorders, and chemotherapy, while 25 were placed in patients with both prior anticoagulant/antiplatelet and a systemic coagulopathy. Anticoagulation or antiplatelet therapy was initiated prior to EVD removal in 148 cases.

Hemorrhage Associated With Placement

Imaging was obtained after 435 EVD placements, and 94 hemorrhages (21.6%) were identified (Fig. 1). Three hundred forty-one EVDs were not associated with a hemorrhage, while no imaging was obtained after 47 EVD placements. The hemorrhage volume ranged from 0.003 cm³ to 45.9 cm³ (mean 1.96 ± 6.48 cm³). The vast majority of these hemorrhages (83) were intracerebral, in addition to 1 intraventricular hemorrhage, 3 epidural hematomas, 2 subdural hematomas, and 5 events that were a combi-

TABLE 3. Reasons for EVD placement

Reason	No. of EVDs
Hemorrhage	
SAH	119
IPH/IVH/SDH	85
Cerebellum	9
Tumor	86
Shunt infection/malfunction	57
Hydrocephalus	48
Stroke/edema	17
Trauma	8
Other	53

IPH = intraparenchymal hemorrhage; IVH = intraventricular hemorrhage; SAH = subarachnoid hemorrhage; SDH = subdural hematoma.

nation of hemorrhages. One patient had a large intraparenchymal hemorrhage that required surgical evacuation (hemorrhage volume 36.8 cm³), and 1 patient required the placement of a contralateral EVD. Two patients with hemorrhage had withdrawal of care shortly after EVD placement given their poor prognosis from their underlying disease.

Univariate analysis was performed on all recorded parameters in patients with hemorrhage following EVD placement, and several parameters were found to be statistically significant: international normalized ratio (INR) at admission, admission platelet count, pre-EVD platelet count, number of placement attempts, presence of liver or renal disease, transfusion prior to placement, and setting for placement (Table 4). After backward model selection, we found that only admission platelet count and the number of attempts at placement were associated with hemorrhage on EVD placement (odds ratio [OR], 95% CI 0.99–0.99, $p = 0.01$; OR 3.06, 95% CI 1.81–5.18, $p < 0.01$, respectively). For an admission platelet count increase of 1000, we expect to see a 0.3% decrease in the odds of hemorrhage on EVD placement. For each additional attempt, we expect to see a 306% increase in the odds of hemorrhage on EVD placement.

Hemorrhage Associated With EVD Removal

Fifty-five new hemorrhages (22.5%) were noted after 244 EVD removals in patients in whom imaging was obtained after the EVD was removed (Fig. 2). Imaging was not obtained after 238 EVD removals, with approximately one-third (87) of these patients progressing to death. The mean hemorrhage volume was 8.25 ± 20.34 cm³ (range 0.012–82.08 cm³). Intracerebral hemorrhages, again, accounted for the majority of the hemorrhages (46), as well as intraventricular hemorrhage in 6 patients and a combination of hemorrhages in 3 patients. No patients required surgical evacuation; however, 2 patients needed EVD replacement. One patient died due to a large intracerebral hemorrhage after EVD removal (hemorrhage volume 82.08 cm³). Eighteen patients had hemorrhage on both EVD placement and removal.

The only parameter found to be statistically significant on univariate analysis for hemorrhage following EVD re-

FIG. 1. CT scans of examples of hemorrhages occurring on EVD placement showing the variation in hemorrhage size from moderate (left, arrow) to small (right, arrow). Figure is available in color online only.

moval was the use of image guidance (Table 5). Multivariate analysis was completed with only the physical location for EVD placement (bedside vs operating room) being associated with hemorrhage (OR 1.00, 95% CI 1.00–1.00, reference p value; OR 0.47, 95% CI 0.26–0.85, $p = 0.01$, respectively). We found that the odds of a hemorrhage occurring on EVD removal were 53% lower for placement procedures carried out in the operating room than for those performed at the bedside.

Discussion

Ventriculostomy is one of the most common neurosurgical procedures and is the mainstay of management for many neurosurgical conditions. The most common complications of ventriculostomy are infection and hemorrhage. A review of 13 studies from 1970 to 2008, comprising 1790 EVDs, found the incidence of hemorrhage associated with placement to be 5.7%.⁴ A meta-analysis of 16 studies over the same period involving 2428 EVDs reported an incidence of 7.0%.³ The recent literature on hemorrhage related to EVD placement has shown that it is more prevalent than previously reported.^{8,11,15,20,33} This may be due to standard imaging protocols, which have become more routine in contemporary practice, and advancements in imaging, allowing the detection of very small hemorrhages.

Numerous articles have reported hemorrhage associated with EVD placement, and several have identified related risk factors. In a study investigating the use of tissue plasminogen activator in patients with intraventricular hemorrhage, there was an increased risk of hemorrhage if the EVD had been incorrectly placed.¹² A separate study showed patients over the age of 75 years who presented with intracerebral hemorrhage had an increased incidence of hemorrhage related to EVD placement.³³ Another report claimed that admission diagnosis of cerebrovascular disease increased the incidence of EVD placement hemorrhage.²⁰ The presence of antiplatelet exposure prior to EVD placement in studies has also been associated with increased hemorrhage rates.^{15,18} Two studies have also reported a trend toward increased rates of hemorrhage with

TABLE 4. Statistical analysis of the relationship between variables and hemorrhage on EVD placement

Parameter	All Pts	Univariate Analysis		p Value	Multivariate Analysis	
		Hemorrhage	No Hemorrhage		Adjusted OR (95% CI)	p Value
No. of Pts	482	94	388			
Age in years				0.06	1.00 (0.99–1.02)	0.58
Mean		48.1	43.8			
SD		18.5	23.2			
Admit INR				0.03	1.87 (0.84–4.167)	0.12
Mean		1.31	1.11			
SD		0.90	0.26			
Admit PC				0.02	0.99 (0.99–1.00)	0.30
Mean		228	253			
SD		91	118			
Pre-EVD INR				0.31	0.53 (0.08–3.33)	0.50
Mean		1.11	1.09			
SD		0.19	0.15			
Pre-EVD PC				0.03	1.00 (0.99–1.00)	0.90
Mean		221	246			
SD		97	±116			
No. of attempts				<0.01	3.09 (1.76–5.43)	<0.01
Mean		1.3	1.05			
SD		0.72	0.31			
Resident year				0.14	0.96 (0.83–1.12)	0.62
Mean		3.13	3.42			
SD		1.72	1.76			
Comorbidities, n (%)				0.01		
No LD or RD	426	75 (17.6)	351 (82.4)		Ref	
LD	23	8 (34.8)	15 (65.2)		1.33 (0.51–3.43)	0.56
RD	33	11 (33.3)	22 (66.7)		2.46 (0.94–6.46)	0.07
Smoker, n (%)				0.45		
N	297	56 (18.9)	241 (81.1)		Ref	
Y	103	18 (17.5)	85 (82.5)		0.73 (0.37–1.43)	0.36
Past	82	20 (24.4)	62 (75.6)		1.39 (0.72–2.70)	0.33
Coagulopathy, n (%)				0.11		
N	436	81 (18.6)	355 (81.4)		Ref	
Y	46	13 (28.3)	33 (71.7)		0.87 (0.40–1.88)	0.72
Prior anticoag/antiplate, n (%)				0.71		
N	366	70 (19.1)	296 (80.9)		Ref	
Y	116	24 (20.7)	92 (79.3)		0.52 (0.26–1.02)	0.06
Prior transfusion, n (%)				<0.01		
N	410	71 (17.3)	339 (82.7)		Ref	
Y	72	23 (31.9)	49 (68.1)		1.68 (0.79–3.56)	0.17
Placement site, n (%)				0.02		
Bedside	267	62 (23.2)	205 (76.8)		Ref	
Operating room	215	32 (14.9)	183 (85.1)		0.76 (0.42–1.39)	0.38
Image guidance, n (%)				0.39		
N	390	79 (20.3)	311 (79.7)		Ref	
Y	92	16 (16.3)	77 (83.7)		0.97 (0.47–2.00)	0.93

Anticoag = anticoagulation; antiplate = antiplatelet; LD = liver disease; PC = platelet count; RD = renal disease; Ref = reference.

EVDs placed while patients were in the intensive care unit compared with those placed while patients were in an operating room.^{6,8}

In our study population, the incidence of hemorrhage on EVD placement was 21.6% in all patients who under-

went postventriculostomy imaging. The vast majority of these hemorrhages were small (87 of 94 were less than 5 cm³), and only 1 patient required surgical intervention. To our surprise, we did not find an association between the use of antiplatelet agents and increased risk of hemorrhage

FIG. 2. CT scans showing intracerebral hemorrhages on EVD removal that vary in size and clinical significance. The large hemorrhage (left, arrow) resulted in withdrawal of care and the small hemorrhage (right, arrow) was asymptomatic. Figure is available in color online only.

following EVD placement, as has been reported in previous studies. However, we did find that a decreased platelet count on admission was associated with hemorrhage following placement. We found only 1 other study that included admission platelets in its analysis, but no correlation was found between this variable and hemorrhage.³³ In our population, an increasing number of attempts for EVD placement was also found to have an increased risk of hemorrhage. This differs from a study reviewing multiple passes during EVD placement, in which no connection was identified between the number of passes and incidence of hemorrhage.²⁵

To our knowledge, hemorrhage following removal of EVD has only been cited in 3 articles. These studies reported the incidence, which ranged from 1.1% to 6.9%, but did not explore the possible causative factors. In the present study, we found an incidence of 22.5%, although it is important to note that only half of our patients underwent imaging after EVD removal. It is possible that the incidence may be higher with additional small asymptomatic hemorrhages not being identified. Several parameters were evaluated in this study to determine their relationship to hemorrhage on EVD removal. We found that only the bedside placement was associated with an increase in EVD removal hemorrhage. This correlation may be incidental as we did not study the relationship between location of the procedure and the number of attempts. Unexpectedly, the INR value prior to placement and removal was not related to hemorrhage risk. This finding has also been found in trauma patients, where supratherapeutic INRs (> 1.2) were not associated with an increased risk of EVD hemorrhage.^{2,5}

While the mechanism of hemorrhage on EVD placement is understood, the exact etiology for hemorrhage on EVD removal is unclear. There are several potential causes for these hemorrhages. In patients with intraventricular hemorrhage, pulling of the EVD may draw some of this blood along the catheter tract. In a similar manner, it is possible that scalp bleeding may track along the course of the catheter. The catheter itself may injure and tamponade a small vessel during insertion, or its radio-opacity may obscure a small hemorrhage until it is removed. The catheter can become adherent to the choroid plexus or sur-

rounding parenchyma that may hemorrhage on removal. Direct trauma to the parenchyma from EVD withdrawal is possible, although removals are performed without a rigid inner stylet. The removal of EVDs is often viewed as a benign procedure, and many clinicians may have less stringent requirements for coagulation parameters and the use of anticoagulants or antiplatelet agents, which could lead to these hemorrhages.

The majority of the hemorrhages found in this study were small and asymptomatic (Fig. 3). Small hemorrhages of less than 10 cm³ usually do not cause mass effect, as we found with 89 of 94 placement hemorrhages and 47 of 54 removal hemorrhages. Large hemorrhages (> 30 cm³) only occurred in 2 of 94 placement hemorrhages and 5 of 54 removal hemorrhages, with 1 hemorrhage necessitating an EVD, 1 requiring surgical evacuation, and 1 leading to withdrawal of care. Interestingly, 3 of the large hemorrhages noted with EVD removal were entirely intraventricular. Regardless of the size of the hemorrhage, there can be associated clinical consequences, such as potential seizure focus, parenchymal damage, and neurocognitive changes. EVD-related hemorrhages can also affect a patient's recovery, length of hospitalization stay, and may require additional procedures. A large hemorrhage after EVD removal resulted in the death of 1 of our patients. Despite the small size of many of these hemorrhages, it is important to recognize the potential serious complications associated with this procedure.

This analysis is a retrospective, single institution study with several limitations. We maintain a database specifically for EVD placement, and the data are entered by the operators following each procedure. A procedure note is also written in the electronic medical record after every procedure, which includes the number of attempts. Consequently, there may be underreporting of the number of attempts needed for each EVD placement. There is no uniform protocol for obtaining routine imaging after EVD placement or removal, and the decision to do so is often left to the neurosurgeon's discretion. It is possible that some hemorrhages were missed in patients who did not undergo imaging. If so, these hemorrhages were of small volume, as clinically significant hemorrhages often lead to neurological changes prompting further imaging. The underlying neurological disease that necessitates an EVD often obscures the examination, making it difficult to determine whether a hemorrhage is asymptomatic or clinically significant. Given that many of our patients had a substantial degree of neurological dysfunction, it is possible that any new deficits related to the EVD placement or removal were not detected.

A significant potential confounder for this study is the possibility that radio-opaque catheters may obscure small hemorrhages associated with placement, and that these hemorrhages may not be identified until the catheter is removed. Without performing the study with radiolucent catheters, which are not available at our institution, it is impossible to identify these hemorrhages. Of the 55 hemorrhages recorded after EVD removal, 34 of these hemorrhages had volumes less than 1.0 cm³, a volume that has the possibility of being obscured by a catheter. The imaging for this subset of patients was reviewed a second time. Based on the volume and location, 24 of these hemorrhages could

TABLE 5. Statistical analysis of the relationship between variables and hemorrhage on EVD removal

Parameter	All Pts	Hemorrhage	No Hemorrhage	p Value	Adjusted OR (95% CI)	p Value
No. of Pts	482	55	427			
Age in years				0.38	0.98 (0.96–1.00)	0.07
Mean		42.3	44.9			
SD		21.0	22.6			
No. of attempts				0.73	0.99 (0.53–1.86)	0.99
Mean		1.13	1.10			
SD		0.55	0.42			
Resident year				0.09	0.91 (0.74–1.12)	0.37
Mean		3.00	3.41			
SD		1.64	1.77			
Pre-removal INR				0.99	0.65 (0.11–3.88)	0.64
Mean		1.11	1.11			
SD		0.15	0.16			
Pre-removal PC				0.51	0.99 (.099–1.00)	0.55
Mean		250	262			
SD		132	129			
Days with EVD				0.33	0.95 (0.90–1.01)	0.12
Mean		7.78	8.58			
SD		5.59	6.26			
Comorbidities, n (%)						
No LD or RD	426	47 (11.0%)	379 (89.0%)	0.26	Ref	
LD	23	5 (21.7%)	18 (78.3%)		1.63 (0.51–5.23)	0.41
RD	33	3 (9.1%)	30 (90.9%)		0.81 (0.20–3.20)	0.76
Smoker, n (%)						
N	297	32 (10.8%)	265 (89.2%)	0.28	Ref	
Y	103	16 (15.5%)	87 (84.5%)		1.50 (0.72–3.12)	0.28
Past	82	7 (8.5%)	75 (94.5%)		0.84 (0.32–2.22)	0.72
Coagulopathy, n (%)						
N	436	46 (10.6%)	390 (89.4%)	0.07	Ref	
Y	46	9 (19.6%)	37 (80.4%)		1.70 (0.60–4.86)	0.32
Prior anticoag/antiplate, n (%)						
N	366	41 (11.2%)	325 (88.8%)	0.80	Ref	
Y	116	14 (12.01%)	102 (87.9%)		1.37 (0.60–3.09)	0.45
Placement site, n (%)						
Bedside	267	39 (14.6%)	228 (85.4%)	0.13	Ref	
Operating room	215	16 (7.4%)	199 (92.6%)		0.48 (0.18–1.25)	0.13
Image guidance, n (%)						
N	390	49 (12.6%)	341 (87.4%)	0.01	Ref	
Y	92	6 (6.5%)	86 (93.5%)		0.65 (0.22–1.95)	0.44
DVT prophylaxis/anticoag, n (%)						
N	334	37 (11.1%)	297 (88.9%)	0.73	Ref	
Y	148	18 (12.2%)	130 (87.8%)		1.36 (0.68–2.74)	0.39
Removal site						
Bedside	396	43 (10.9%)	353 (89.1%)	0.41	Ref	
Operating room	86	12 (13.9%)	74 (86.1%)		2.00 (0.95–4.22)	0.07

DVT = deep vein thrombosis.

have been obscured by the catheter while 10 of the hemorrhages would have been evident with the catheter in place.

Conclusions

Multiple studies have investigated hemorrhage related

to EVD placement, with rates varying from 0% to 42%, while very few studies have described hemorrhage secondary to EVD removal. This is the first reported analysis of risk factors associated with hemorrhage on EVD removal. In this series of patients, decreased platelet count on admission and an increasing number of attempts for

FIG. 3. Bar graph showing the breakdown of hemorrhage volumes for EVD placement and EVD removal. The majority of hemorrhages had volumes less than 5 cm³, and only a small percentage had moderate or large volumes. Figure is available in color online only.

placement correlated with an increased risk of hemorrhage on EVD placement. Bedside placement was more likely to be associated with hemorrhage on EVD removal.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: both authors. Acquisition of data: Miller. Analysis and interpretation of data: Miller. Drafting the article: Miller. Critically revising the article: Miller. Reviewed submitted version of manuscript: Miller. Approved the final version of the manuscript on behalf of both authors: Miller. Statistical analysis: Miller. Study supervision: Tummala.

Supplemental Information

Previous Presentations

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