Relationship between external ventricular drain clamp trials and ventriculoperitoneal shunt insertion following nontraumatic subarachnoid hemorrhage: a single-center study

*Luis C. Ascanio, MD,¹ Raghav Gupta, BS,¹ Nimer Adeeb, MD,² Justin M. Moore, MD, PhD,^{1,3} Christoph J. Griessenauer, MD,⁴ Julie Mayeku, MD,¹ Yaw Tachie-Baffour, BS,¹ Ranjit Thomas,¹ Abdulrahman Y. Alturki, MBBS, MSc, FRCSC,^{1,5} Philip G. R. Schmalz, MD,⁶ Christopher S. Ogilvy, MD,¹ and Ajith J. Thomas, MD¹

¹Neurosurgical Service, Beth Israel Deaconess Medical Center, Harvard Medical School; ²Department of Neurosurgery, Louisiana State University, Shreveport, Louisiana; ³Department of Neurosurgery, Boston Medical Center, Boston University, Boston, Massachusetts; ⁴Department of Neurosurgery, Geisinger Medical Center, Danville, Pennsylvania; ⁵Department of Neurosurgery, National Neuroscience Institute, King Fahad Medical City, Riyadh, Saudi Arabia; and ⁶Department of Neurosurgery, University of Alabama at Birmingham Medical Center, Birmingham, Alabama

OBJECTIVE Currently, there is no established standard regarding the ideal number of external ventricular drain (EVD) clamp trials performed before ventriculoperitoneal (VP) shunt insertion following nontraumatic subarachnoid hemorrhage (SAH). In this study, the authors aimed to evaluate this relationship.

METHODS A retrospective review of all patients presenting with SAH between July 2007 and December 2016 was performed. Patients with SAH who had received an EVD within the first 24 hours of hospital admission and had undergone at least 1 clamp trial prior to EVD removal were eligible for inclusion in the study. Patient demographics, clinical presentations, SAH etiologies and grades, clamp trial data, hospital lengths of stay, and functional outcomes were recorded.

RESULTS One hundred fourteen patients with nontraumatic SAH complicated by posthemorrhagic hydrocephalus were included in the study. The median patient age was 57 years (range 28–90 years), with a male/female ratio of 1:1.7. A ruptured aneurysm was the underlying etiology of SAH in 79.8% of patients. A majority of patients (69.4%) had a Hunt and Hess grade III–V on admission. The median number of clamp trials performed was 2 (range 1–6). A VP shunt was required in 40.4% of patients. In those who underwent 2 and 3 clamp trials, 60% and 38.9%, respectively, did not require subsequent VP shunt placement.

CONCLUSIONS Surgical placement of a VP shunt is associated with complications. Clamp trials are routinely performed before making the decision to insert a shunt. In the present study, the authors found that a significant percentage of patients passed their second and third clamp trials without requiring subsequent shunt insertion. These data support performing multiple clamp trials prior to shunt placement.

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KEY WORDS external ventricular drain; ventriculoperitoneal shunt; subarachnoid hemorrhage; hydrocephalus; clamp trials; vascular disorders

ABBREVIATIONS CSF = cerebrospinal fluid; EVD = external ventricular drain; GCS = Glasgow Coma Scale; HH = Hunt and Hess; ICP = intracranial pressure; SAH = subarachnoid hemorrhage; VP = ventriculoperitoneal; WFNS = World Federation of Neurosurgical Societies.

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* L.C.A. and R.G. contributed equally to this study and share first authorship.

HYDROCEPHALUS is a frequent complication of subarachnoid hemorrhage (SAH).^{12,15,17,19} The pathophysiological basis for hydrocephalus in these patients includes obstructive mechanisms such as cerebrospinal fluid (CSF) circulation obstruction caused by blood and blood breakdown products, alterations in CSF flow dynamics, and impairment in the absorption of CSF at the arachnoid granulations.⁶ An estimated 6.5%–67% of patients with SAH present with acute hydrocephalus.^{10,16,21,24,26} External ventricular drains (EVDs) are widely used in the management of acute hydrocephalus following SAH to divert CSF and reduce intracranial pressure (ICP). O’Kelly et al. and Connolly et al. have found that between 6.0% and 48.0% of these patients develop chronic hydrocephalus requiring ventriculoperitoneal (VP) shunt placement.^{4,20} However, VP shunt placement is associated with complications such as mechanical dysfunction and infection requiring revision surgery, prolonged hospital stays, and substantial costs.^{14,15}

Placement of an EVD in the context of SAH has been reported to be a strong predictor of the need for future VP shunt insertion.^{6,12,19} Approximately 15%–52% of patients with EVDs for SAH require VP shunt placement.^{6,17,26} Prior studies have looked at patient sex, EVD output volume, CSF content, Hunt and Hess (HH) grade, modified Fisher CT grade, continuous versus intermittent CSF drainage, and rapid versus gradual EVD weaning as factors predictive for VP shunt placement.^{1,6,8,12,15,17,19,27} Even though a clamp trial is part of the process by which patients are weaned from EVDs, there is currently no established standard regarding the number of clamp trials performed before insertion of a VP shunt. This study aims to delineate the relationship between patients who required a VP shunt and the number of clamp trials performed.

Methods

Patient Selection Criteria and Treatment Protocols

Institutional review board approval was obtained prior to beginning this study. We conducted a retrospective review of all consecutive patients with SAH who, between July 2007 and December 2016, had presented to the neurosurgical department at a single major academic institution in the United States. Inclusion criteria for this study were patients with nontraumatic SAH who had undergone EVD placement within the first 24 hours of their hospital admission and had undergone at least 1 clamp trial prior to EVD removal. Patients were excluded if they died prior to hospital discharge, if they had no available data regarding EVD clamp trial conduction, and/or if they underwent VP shunt placement in a separate admission period.

The following protocol was used by the two cerebrovascular neurosurgeons (C.S.O. and A.J.T.) involved in the management of SAH patients presenting to our institution: An EVD was placed in all cases of acute hydrocephalus (confirmed via radiographic and/or clinical findings) or suspected increased ICP. Drains in all patients were set at an initial opening pressure of 15 cm H₂O. If possible, after securing the source of the hemorrhage, the pressure was

lowered to 5 cm H₂O. Weaning typically began 1 week after the drain was initially placed in the patients without radiographic vasospasm, as determined by an angiogram obtained on day 7 post-SAH. In patients with angiographic vasospasm (with or without concomitant clinical vasospasm), weaning was started after the vasospasm had resolved. The pressure was raised in 5-cm H₂O increments up to 20 cm H₂O over a span of 24–48 hours. A clamp trial was then performed if radiographic and/or clinical resolution of the patient’s acute hydrocephalus or stable ICP was observed.

Clamp Trial Protocol

Clamp trials were defined as EVD clamping lasting longer than 24 hours and not performed to transport patients, to obtain imaging, or to administer intraventricular medications. A clamp trial was considered a success if the patient remained asymptomatic and there was no worsening of hydrocephalus on imaging 24 hours after clamping the EVD. A clamp trial was considered a failure if ICP rose above 25 cm H₂O for 5 minutes or longer after clamping, if the patient’s condition deteriorated clinically within 24 hours of clamping, or if there was progression of ventricle size on CT scanning.

The decision to insert a VP shunt rather than to perform additional clamp trials was based on several criteria, including the number of clamp trials that had been already performed, the severity of the hydrocephalus as determined via CT scanning, and the rise in ICP once the EVD was clamped. If ICP was found to consistently rise above 25 cm H₂O each time the EVD was clamped, the decision to insert a shunt was typically made. Other factors, such as a high HH grade and a high Fisher CT grade on admission, each of which has been found to independently predict shunt-dependent hydrocephalus, were used to guide decision making. Ultimately, however, the clinical gestalt of the two cerebrovascular neurosurgeons involved in the management of these patients often heavily influenced the decision to insert a shunt or to perform additional clamp trials. A clamp trial was not performed in patients who could not tolerate the EVD weaning process or, conversely, in patients who did not undergo EVD weaning given marked improvement in clinical and/or radiographic presentation.

Data Collection

The variables collected for each patient included demographics (age, sex, smoking status, history of hypertension, history of antiplatelet/anticoagulant use), initial clinical presentation (HH grade,¹¹ Glasgow Coma Scale [GCS] score,²³ World Federation of Neurosurgical Societies [WFNS] grade,⁷ focal neurological deficits on admission), SAH etiology, Fisher CT grade,⁹ duration of EVD, ICU length of stay, and hospital length of stay.

Statistical Analyses

The chi-square test was used for the analysis of categorical variables. The Mann-Whitney U-test and Kruskal-Wallis test were used for analyzing continuous variables.

FIG. 1. Flowchart of patients included in the study.

Significance was defined with a p value < 0.05 . Statistics were performed using IBM SPSS Statistics version 20 (IBM Corp.).

Results

Patients Characteristics

One hundred fourteen patients with nontraumatic SAH and posthemorrhagic hydrocephalus were included in the study (Fig. 1). The median patient age was 57 years (range 28–90 years), with a male/female ratio of 1:1.7. Smoking and hypertension were comorbidities in 36.3% and 48.1% of patients, respectively. Most patients presented to the emergency department with a GCS score of less than 8 (48.0%; Table 1).

Characteristics of SAH

A ruptured aneurysm was the cause of SAH in 79.8% of the patients and an arteriovenous malformation/fistula in 8.8%. The cause could not be identified in 11.4% of cases. More than two-thirds of the patients (69.4%) had an HH grade of III–V on presentation, whereas the Fisher grade was 3–4 in 93.0%. The median length of stay in the ICU and the hospital was 16 and 23 days, respectively (Table 1).

Number of Clamp Trials and VP Shunt Placement

An EVD was in place for a median of 13 days. Among patients who had 1–3 clamp trials, the EVD remained in place a median of 12 days; the median duration increased to 22 days among those who underwent 4 clamp trials (Table 2). These differences were not statistically significant, however ($p = 0.17$). Ninety-six percent of our patient

cohort underwent 1–3 clamp trials (median 2, range 1–6). A VP shunt was required in 40.4% of all patients. Most of the patients who underwent either 1 or 2 clamp trials did not require a VP shunt (Table 3). Among those who underwent 2 or 3 clamp trials, 60.0% and 38.9%, respectively, did not require a VP shunt. Among the patients who did not receive a VP shunt, the EVD remained in place for a median of 12 days (range 3–22 days), compared with 14 days (3–33 days) among those who did receive a shunt ($p = 0.008$). A trend toward increased VP shunt placement following multiple clamp trials (1 vs 3) was observed, but this was not statistically significant (OR 3.1, $p = 0.09$). Of note, 7 patients (excluded from the present study; Fig. 1)—though they had passed their initial clamp trials—subsequently underwent shunt placement in a later hospital admission given the development of delayed-onset hydrocephalus. They had undergone 1 (3 patients), 2 (2 patients), or 3 (2 patients) clamp trials during their initial admissions.

EVD Infections and ICU Length of Stay Versus Number of Clamp Trials

Thirteen patients (11.4%) had EVD infections (Table 4). The median number of clamp trials performed in patients with and without EVD infections was the same (median 2 trials, $p = 0.52$). Similarly, the ICU length of stay did not vary significantly as the number of clamp trials increased ($p = 0.54$; Table 5). Of note, 53 patients were diagnosed with infections unrelated to their EVD during their hospital admissions. Twenty-four of these patients (45.3%) required a VP shunt, as compared with 18 (29.5%) of the 61 patients who did not have an infection. This difference was not significant ($p = 0.43$).

TABLE 1. Characteristics of patients with nontraumatic SAH who underwent EVD placement

Parameter	Value
No. of patients	114
Median age in yrs (range)	57 (28–90)
Sex	
Male	43 (37.7)
Female	71 (62.3)
Smoking*	
Yes	33 (36.3)
No	58 (63.7)
Hypertension†	
Yes	51 (48.1)
No	55 (51.9)
Antiplatelet/anticoagulant use‡	
Yes	24 (23.5)
No	78 (76.5)
Focal neurological deficits on admission§	
Yes	15 (13.6)
No	95 (86.4)
Admission HH grade**	
I–II	34 (30.6)
III–V	77 (69.4)
GCS score on admission‡	
≤8	49 (48.0)
9–13	38 (37.3)
14–15	15 (14.7)
Fisher CT grade on admission	
1–2	8 (7.0)
3–4	106 (93.0)
WFNS on admission††	
1–2	43 (43)
3–5	57 (57)
Type of vascular lesion	
Aneurysm	91 (79.8)
AVF, AVM	10 (8.8)
None identified	13 (11.4)
Median duration of EVD use in days (range)	13 (3–33)
No. of clamp trials performed on each patient	
Median (range)	2 (1–6)
1	51 (44.7)
2	40 (35.1)
3	18 (15.8)
4	3 (2.6)
5	1 (0.9)
6	1 (0.9)
VP shunt	
Yes	46 (40.4)
No	68 (59.6)
Median ICU LOS in days (range)	16 (4–43)
Median hospital LOS in days (range)	23 (7–73)

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TABLE 1. Characteristics of patients with nontraumatic SAH who underwent EVD placement

Parameter	Value
mRS score at discharge‡‡	
0–2	73 (68.2)
3–5	34 (31.8)
mRS score at last FU§§	
0–2	77 (87.5)
3–5	10 (11.4)
6	1 (1.1)

AVF = arteriovenous fistula; AVM = arteriovenous malformation; FU = follow-up; LOS = length of stay; mRS = modified Rankin Scale.

Values expressed as number (%), unless otherwise indicated.

* Data on 23 patients were missing.

† Data on 8 patients were missing.

‡ Data on 12 patients were missing.

§ Data on 4 patients were missing.

** Data on 3 patients were missing.

†† Data on 14 patients were missing.

‡‡ Data on 7 patients were missing.

§§ Data on 26 patients were missing.

Discussion

Subarachnoid hemorrhage is a devastating condition often complicated by acute hydrocephalus. A significant fraction of these patients develop chronic hydrocephalus, which is typically managed by a CSF diversion procedure, such as shunt insertion.^{4,20} In the United States, 30,000 CSF shunting procedures are performed annually for the management of chronic hydrocephalus.^{2,25} However, complications associated with shunt insertion are well established and include mechanical dysfunction and/or obstruction of the shunt, infection, and overdrainage.²⁵ In a survey study of 773 cases of nontumoral hydrocephalus, Di Rocco et al. reported shunt failure in 29% of cases within the first year of implantation.⁵ In a retrospective cohort study, Wu et al. similarly analyzed all nonfederal hospital admissions in California between 1990 and 2000 and documented a 27% complication rate following shunt placement.²⁵ Because of these complications, shunt revisions are common and can be required in up to 50% of cases.³ Bacterial shunt infections are equally important

TABLE 2. Clamp trials and EVD duration*

No. of Clamp Trials	Median Days w/ EVD (range)	Total No. of Patients
1	12 (3–29)	51
2	13 (5–33)	40
3	12 (8–17)	18
4	22 (10–24)	3
5		1
6		1

* Median days an EVD remained in place versus number of clamp trials, $p = 0.17$.

TABLE 3. Number of clamp trials versus rate of VP shunt placement*

Parameter	VP Shunt Placement (no. [%])		Total No. of Patients	OR (95% CI)
	Yes	No		
No. of clamp trials				
1	17 (33.3)	34 (66.7)	51	
2	16 (40)	24 (60)	40	1.33 (0.57–3.15)
3	11 (61.1)	7 (38.9)	18	3.14 (1.03–9.56)
4	1 (33.3)	2 (66.7)	3	1.00 (0.08–11.82)
5	0 (0)	1 (100)	1	5.91 (0.23–152.83)
6	1 (100)	0 (0)	1	0.657 (0.03–16.98)
Total no. of patients	46 (40.4)	68 (59.6)	114	

* Number of clamp trials versus VP shunt placement, $p = 0.09$.

to consider, and previous studies have found that nearly a third of shunts are infected in the perioperative or postoperative setting.²²

Motiei-Langroudi and colleagues have developed a scoring system that identified a high HH grade and high modified Fisher CT grade, as well as EVD insertion within the first 24 hours, as the most important predictors of VP shunt insertion following aneurysmal SAH.¹⁹ The association between the number of clamp trials performed before EVD removal and the need for VP shunt insertion, however, has not been well elucidated. Moreover, the number of clamp trials that should be performed before inserting a shunt has not been examined in the neurosurgical literature.¹ One study assessed the factors predicting the need for shunt insertion based on ICP waveforms; however, the authors considered only a single clamp trial failure to be sufficient to take the patient for VP shunt placement.¹

In the present study, 38.9% of patients did not require VP shunt insertion even after the third clamp trial, and 60% of patients did not require VP shunt insertion after 4, 5, or 6 clamp trials. This suggests that the failure of initial clamp trials does not necessarily indicate that a patient

TABLE 4. EVD infection status versus the number of clamp trials*

Parameter	Positive CSF Culture w/ EVD in Place	
	Yes	No
No. of patients	13	101
No. of clamp trials		
Median (range)	2 (1–4)	2 (1–6)
1	5 (9.8%)	46 (90.2%)
2	5 (12.5%)	35 (87.5%)
3	1 (5.6%)	17 (94.4%)
4	0 (0%)	3 (100%)
5	1 (100%)	0 (0%)
6	1 (100%)	0 (0%)
Total no. of patients	13 (11.4%)	101 (88.6%)

* EVD infection versus number of clamp trials, $p = 0.52$.

TABLE 5. Number of clamp trials versus ICU length of stay*

No. of Clamp Trials	Median Days in ICU (range)	Total No. of Patients
1	15 (4–30)	51
2	17 (8–43)	40
3	15 (9–29)	18
4	24 (10–30)	3
5		1
6		1

* Number of clamp trials versus ICU length of stay, $p = 0.54$.

should receive a shunt. Esposito et al. indirectly reached this conclusion when they reported on a cohort of 32 patients who failed their initial clamp trials; of these patients, only 19 (59.4%) underwent CSF shunting.⁸

While EVD infections could influence the number of clamp trials performed by preempting a less aggressive weaning process, we did not find a difference in the rate of infection among the patients who underwent multiple clamp trials. Similarly, one could contend that the decision to place a shunt or proceed with clamp trials may be influenced by the desire to reduce the ICU length of stay.¹ However, in the present study, no differences in the ICU length of stay were observed when patients were stratified based on the number of clamp trials performed.

Seven patients who were excluded from our analysis developed delayed-onset hydrocephalus, which required VP shunt placement in a separate hospital admission. These patients represented 5.8% of the total cohort of the 121 patients who underwent EVD placement within the first 24 hours after nontraumatic SAH, who did not die before hospital discharge, and who had clamp trial data available (Fig. 1). Given the small number of patients in this subgroup, the relationship between the number of clamp trials performed and the incidence of delayed-onset hydrocephalus could not be thoroughly examined in the present study and should be considered in future analyses.

Because of the numerous complications associated with shunting, the decision to insert a shunt should not be taken lightly. In the current study, we found that a marked percentage of patients who had multiple clamp trials did not require a VP shunt. This would support a shift in the clinical management of patients presenting with acute hydrocephalus in the context of nontraumatic SAH toward conducting multiple clamp trials before inserting a shunt. This finding should be confirmed in a prospective fashion in subsequent studies.

As the presence of intraventricular hemorrhage is an important predictor of acute hydrocephalus, pathological obstruction of the ventricular foramina and increased resistance to CSF flow are implicated in the development of hydrocephalus. However, impaired CSF absorption due to blockage of arachnoid villi by red blood cells post-SAH has also been postulated.¹⁸ Thus, acute hydrocephalus may be the result of both a decreased absorptive capacity for CSF and a physiological obstruction to CSF flow. Alternatively, recent data have indicated that CSF hypersecretion by the choroid plexus epithelium may also contribute to the pathogenesis of posthemorrhagic hydrocephalus.¹³

Whether a clamp trial is evidence that a patient's hydrocephalus condition has improved or whether the trial itself invokes a return to normal CSF flow dynamics is unclear and needs further investigation.

Study Limitations

This study is limited by its retrospective design. A larger study cohort may be useful for further delineation of trends related to the management of patients with chronic hydrocephalus in the context of nontraumatic SAH. Additionally, a very limited number of patients underwent 4, 5, or 6 clamp trials; therefore, one should be cautious in extrapolating data from this subgroup of patients. The decision to place a shunt or to perform an additional clamp trial was made by the attending neurosurgeon on a per-patient basis. Different neurosurgeons may have different thresholds for shunt insertion, which can be difficult to control for. However, only two cerebrovascular neurosurgeons were involved in the management of all SAH patients presenting to our institution. Given that weekly neurovascular conferences were held to enable tabled discussion regarding the optimal treatment regimen for each patient, we believe the provider variance was negligible and that neither end (several vs few clamp trials) of the spectrum was disproportionately represented.

Conclusions

Ventriculoperitoneal shunt placement is associated with complications such as mechanical dysfunction of the device and surgical site infections. Clamp trials are routinely performed by neurosurgeons in patients with EVDs before deciding to proceed with shunt insertion or concluding that the hydrocephalus has resolved. In the present study, a significant proportion of patients passed their second or third clamp trial attempt. This supports a shift in the initial management of patients presenting with acute hydrocephalus following nontraumatic SAH.

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Author Contributions

Conception and design: Ascanio, Gupta. Acquisition of data: Ascanio, Gupta, Adeeb, Mayeku, Tachie-Baffou, R Thomas. Analysis and interpretation of data: Ascanio, Gupta, Adeeb, Alturki, Schmalz. Drafting the article: Ascanio, Gupta. Critically revising the article: AJ Thomas, Moore, Griessenauer, Alturki, Schmalz, Ogilvy. Reviewed submitted version of manuscript: AJ Thomas, Moore, Griessenauer, Ogilvy. Statistical analysis: Adeeb. Administrative/technical/material support: AJ Thomas, Moore, Griessenauer, Ogilvy. Study supervision: AJ Thomas, Ogilvy.

Correspondence

Ajith J. Thomas: Harvard Medical School, Beth Israel Deaconess Medical Center, Boston, MA. athomas6@bidmc.harvard.edu.