Effects of an external ventricular drain alert protocol on ventriculostomy placement time in the emergency department

Henry Chang, BS,¹ Michael A. Silva, MD,^{1,2} Alexander Giner, RN,⁴ Selina Ancheta, RN,⁵ José G. Romano, MD,³ Ricardo Komotar, MD,^{1,2} and Iahn Cajigas, MD, PhD^{1,2}

¹University of Miami Miller School of Medicine, Miami; and Departments of ²Neurosurgery, ³Neurology, ⁴Emergency, and ⁵Quality and Patient Safety, Jackson Memorial Hospital, Miami, Florida

OBJECTIVE Timely ventriculostomy placement is critical in the management of neurosurgical emergencies. Prompt external ventricular drain (EVD) placement has been shown to improve long-term patient outcomes and decrease the length of ICU and hospital stays. Successful and efficient EVD placement requires seamless coordination among multiple healthcare teams. In this study, the authors sought to identify factors favoring delayed ventriculostomy via a quality improvement initiative and to implement changes to expedite EVD placement.

METHODS Through process mapping, root cause analysis, and interviews with staff, the authors identified the lack of a standardized mechanism for alerting necessary healthcare teams as a major contributor to delays in EVD placement. In December 2019, an EVD alert system was developed to automatically initiate an EVD placement protocol and to alert the neurosurgery department, pharmacy, core laboratory, and nursing staff to prepare for EVD placement. The time to EVD placement was tracked prospectively using time stamps in the electronic medical record.

RESULTS A total of 20 patients who underwent EVD placement between December 2019 and April 2021, during the EVD alert protocol initiation, and 18 preprotocol control patients (January 2018 to December 2019) met study inclusion criteria and were included in the analysis. The mean time to EVD placement in the control group was 71.88 minutes compared with 50.3 minutes in the EVD alert group (two-tailed t-test, $p = 0.025$). The median time to EVD placement was 64 minutes in the control group compared with 52 minutes in the EVD alert group (rank-sum test, $p = 0.0184$). All patients from each cohort exhibited behavior typical of stable processes, with no violation of Shewhart rules and no special cause variations on statistical process control charts.

CONCLUSIONS A quality improvement framework helped identify sources of delays to EVD placement in the emergency department. An automated EVD alert system was a simple intervention that significantly reduced the time to EVD placement in the emergency department and can be easily implemented at other institutions to improve patient care.

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KEYWORDS emergency department; hydrocephalus; quality improvement; ventriculostomy

VENTRICULOSTOMY is a common procedure in neurosurgery, with more than 20,000 external ventricular drains (EVDs) placed annually in the United States alone.¹ Common indications for placement of an EVD include obstructive hydrocephalus, aneurysmal subarachnoid hemorrhage, traumatic brain injury, and intracranial hypertension, among others.^{2–6} Ventriculostomy placement is a mainstay in the management of critically ill neurosurgery patients.^{4,7} When done promptly, EVD placement has been shown to improve patient outcomes and length of stay.^{1–4,7} Our institution principally places EVDs in the emergency department (ED), which presents

several logistical challenges. For patients requiring EVD placement in the ED, efficiently carrying out the ventriculostomy procedure at bedside is dependent on the coordination of multiple healthcare teams, including ED physicians, neurosurgeons, nursing staff, and the pharmacy.

We sought to understand factors affecting the amount of time required to commence the EVD placement procedure via a quality improvement initiative, and to implement changes to address placement delays. Surveying the healthcare teams involved in EVD placement, process mapping, and root cause analysis allowed us to identify contributors to delayed EVD placement, which revealed

ABBREVIATIONS ED = emergency department; EVD = external ventricular drain; GCS = Glasgow Coma Scale; SPC = statistical process control.

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FIG. 1. Root cause analysis to delayed ventriculostomy. A cause-and-effect chart (fishbone diagram) identifying sources of delays to ventriculostomy.

the lack of a standardized mechanism for alerting necessary healthcare teams as a major factor.^{8–10} In December 2019, we developed an EVD alert system to automatically alert the neurosurgery department, pharmacy, core laboratory, and nursing staff to initiate necessary procedures to expeditiously prepare for EVD placement.

Methods

EVD Alert Protocol

Using a process map and root cause analysis fishbone chart, we identified the lack of a standardized mechanism for alerting necessary healthcare teams as a major contributor to delays in EVD placement (Fig. 1). A paging system, similar to that of a stroke alert or code blue, was designed to initiate a standardized protocol to prepare for EVD placement and to alert all teams necessary for the procedure (Fig. 2). In the protocol, patients with aneurysmal subarachnoid hemorrhage, obstructive hydrocephalus with neurological compromise, or intracerebral hemorrhage with intraventricular hemorrhage and hydrocephalus met criteria for the ED physician to initiate an EVD alert. Equivocal cases were discussed with the neurosurgery on-call physician, who could then trigger the EVD alert.

Once an EVD alert is called, the following protocol is initiated. 1) An automated page stating that an EVD alert has been called is sent to the neurosurgery department, pharmacy, and nursing staff; the patient's location is also included in the page. 2) The patient is moved to one of several areas of the ED designated as ideal for EVD placement. 3) Necessary preprocedural laboratory

samples are drawn by nursing staff (coagulation studies, type and cross, and platelet function assay, when indicated). The laboratory is made aware that these are for an EVD alert and processes these samples in an expedited fashion. 4) The arterial line is placed, and antihypertensive agents are initiated for a goal systolic blood pressure < 160 mm Hg (or as instructed by the neurosurgeon). 5) Blood products are ordered and administered, if indicated based on laboratory results. 6) The nursing staff assists the neurosurgeon in preparing supplies for the procedures and confirming that all supplies are bedside. A procedural time-out is performed prior to beginning the procedure.

Nursing staff in the ED underwent onboarding education on the EVD alert protocol. Regular staff reeducation sessions were held by the ED nursing administration in conjunction with neurosurgery residents.

Study Design

This study was approved by our institution's IRB. Data were collected prospectively, and all patient information was anonymized throughout data analysis. For the control cohort (pre-EVD alert protocol), data on time to EVD placement were collected prospectively for all patients who underwent EVD placement from January 2018 until the inception of the EVD alert system in December 2019. Patients prior to January 2018 were excluded because we launched a centralized EVD supply cart in January 2018 and, therefore, sought to eliminate this as a confounder in our analysis.¹¹ For the intervention group, for which an EVD alert protocol was initiated, data were collected for

FIG. 2. EVD alert system protocol. Flowchart detailing steps from the initiation of an EVD alert to the placement of an EVD.

patients who underwent EVD placement from December 2019 to April 2021. Patients were excluded if EVD placement was delayed due to causes unrelated to the standard EVD placement protocol, including delays due to the administration of blood products or a delay in the decision to place the EVD. Although the EVD alert protocol initiates expedited patient laboratory processing and early workup for patients requiring blood products, the alert system itself is not a standardized protocol for completing the administration of blood products. Therefore, patients receiving blood products were excluded in both the control cohort and the intervention cohort to avoid potential confounders due to unforeseen delays and variability in the administra-

tion of blood products. Patients were also excluded if the EVD was placed in another area of the hospital (e.g., the operating room or trauma bay). All patients who did not meet the exclusion criteria were included in the analysis. The control cohort and EVD alert intervention cohort were both subjected to the same inclusion and exclusion criteria.

The time to EVD placement was defined as the time from the initial neurosurgery consultation to the point of the surgical team time-out. Use of the procedure time-out as the endpoint enabled us to avoid any confounding factors associated with variation in the time of the actual procedures due to patient-specific factors and practitioner experience level. For cases without a documented neuro-

TABLE 1. Demographics of patients in the pre- and post-EVD alert protocol cohorts

Characteristic	Pre-EVD Alert (n = 18)	Post-EVD Alert (n = 20)	p Value
Mean age, yrs (SD)	54.44 (12.58)	58.95 (13.12)	0.29*
Mean arrival GCS score (SD)	10.11 (4.70)	8.35 (3.56)	0.20*
Sex, n (%)			0.20†
M	5 (28)	10 (50)	
F	13 (72)	10 (50)	
Etiology, n			0.10‡
Subdural hematoma	0	0	
Subarachnoid hemorrhage (nontraumatic)	9	4	
Subarachnoid hemorrhage (traumatic)	1	0	
Intracerebral hemorrhage	6	15	
Interventricular hemorrhage	1	0	
Mass	1	1	

* Two-sample t-test.

† Fisher's exact test.

‡ Chi-square test.

surgery consultation, the time of the initial head CT was used to calculate the time to EVD placement since the neurosurgery consultation occurred immediately following head CT.

Time to EVD placement in the preintervention period (mean 71.88 minutes, SD 39.076) was compared with initial preliminary data on time to EVD placement following the implementation of the EVD alert system (mean 43.67 minutes, SD 11.547) to determine the sample size needed to conduct this study. A mean reduction of 28.21 minutes and clinically significant effect size (Cohen's *d*) of 0.98 were determined to be of interest. Therefore, assuming a two-tailed alpha of 0.05, a power of 0.8, and equal case allocation to both the control and intervention arms, a total of 36 cases was determined to be needed.

Statistical Analysis

The median time to EVD placement was compared between the control cohort and the EVD alert cohort through one-way ANOVA and Kaplan-Meier analysis via the rank-sum test. The mean time to EVD placement was compared between the two cohorts using Welch's two-sample t-test. Demographic characteristics between both cohorts were compared using a two-sample t-test (age and arrival Glasgow Coma Scale [GCS] score), Fisher's exact test (sex), and the chi-square test (underlying etiology). Statistical analysis comparing both groups was performed in MATLAB (MathWorks) and subsequently corroborated in R version 1.3.1093 (The R Project). Case times to EVD placement were assessed for any special cause variations or trends via statistical process control (SPC) charts. SPC analysis was completed in R. Power analysis and sample size calculation were completed in G*Power.¹² A *p* value < 0.05 was set as the threshold for statistical significance.

Results

A total of 20 patients who underwent EVD placement from December 2019 to April 2021 met our inclusion

criteria and constituted our EVD alert cohort. Our pre-intervention control group consisted of 18 patients who underwent EVD placement from January 2018 to December 2019. All EVDs were placed by neurosurgical resident physicians. Demographic characteristics (age, sex, GCS score, and underlying etiology) did not differ significantly between the two cohorts (Table 1).

The time to EVD placement decreased after implementation of the EVD alert system. The median time to EVD placement in the postintervention cohort was 53.5 minutes compared with 66.56 minutes in the control group (F statistic 5.47, *p* = 0.025) (Fig. 3A). The mean time to EVD placement among patients included in the EVD alert protocol was 50.3 minutes compared with 71.88 minutes among control patients (T statistic 2.2627, *p* = 0.033) (Fig. 3B). Kaplan-Meier analysis confirmed a reduction in the median time to EVD placement (median 52 minutes in the EVD alert group vs 64 minutes in the control group; rank-sum test, *p* = 0.0184) (Fig. 4). Based on the final effect size observed (Cohen's *d*) of 0.75, this study achieved a final power of 0.61. There were no unintended consequences as a direct result of the EVD alert system.

SPC chart analysis of both cohorts revealed no trends or patterns in time to EVD placement. The EVD alert cohort had 17 patients within 1 standard deviation and 3 patients within 2 standard deviations of the mean time to EVD placement (Supplementary Fig. 1). Times among the control cohort included 13 patients within 1 standard deviation, 4 patients within 2 standard deviations, and 1 patient within 3 standard deviations of the mean time to EVD placement (Supplementary Fig. 2). Standard deviations for case times among the EVD alert cohort and control cohort were 18.95 minutes and 36.19 minutes, respectively. No case times exceeded control limits, and no Shewhart rules were violated (Supplementary Figs. 3 and 4).

Discussion

Avoidable adverse events in healthcare often have

FIG. 3. Median and mean times to EVD placement. **A:** Boxplot showing the distribution of time to EVD placement for both cohorts. The median and inner IQRs are shown within the outlined region. The median times to EVD placement in the EVD alert and control cohorts were 53.5 minutes and 66.56 minutes, respectively. The p value corresponds to one-way ANOVA. **B:** The mean and 95% CI on the time to EVD placement for both cohorts. The mean times to EVD placement for the EVD alert and control cohorts were 50.3 minutes and 71.88 minutes, respectively. The p value corresponds to Welch's two-sample t-test.

many contributing causes.¹³ Therefore, root cause analysis has become a key tool in healthcare to analyze the sources contributing to adverse events.¹⁴ Root cause analysis seeks to identify sources of latent and direct factors favoring the occurrence of avoidable adverse events.¹⁵ Additionally,

process mapping may be employed to visualize complex healthcare processes and to isolate the individual components contributing to an event.¹⁰ Our group has previously published our efforts of applying this framework to centralizing EVD supplies to expedite EVD placement.¹¹ Af-

FIG. 4. Kaplan-Meier curve comparing the time to EVD placement before and after initiation of the EVD alert system. The curve illustrates the probability of no EVD placement from the time of neurosurgery consultation. The median times to EVD placement were 64 minutes for the control cohort (n = 18) and 52 minutes for the EVD alert cohort (n = 20). The median time was determined from the 0.5 probability of no EVD placement for both cohorts. The p value corresponds to the rank-sum test.

ter implementing an EVD crash cart containing supplies that needed to be expeditiously prepared for EVD placement, we observed a statistically significant decrease of 27.46% in the mean time to EVD placement and 30.4% in the median time to EVD placement.¹¹ Utilizing the same quality improvement framework, we identified the lack of a standardized protocol and alert system to be another major cause of delays to EVD placement.

Emergency alert systems have been shown to be efficacious in improving communication and reducing the overall time to commencement of procedures in a variety of settings. For example, stroke alert protocols have been effective in reducing the time to thrombolysis in patients with ischemic stroke and an automated pager system resulted in a trend toward reduced turnaround time for critical laboratory values.^{16,17} Despite the variety of applications for which this framework has been applied, standardized alert systems and procedural protocols have consistently demonstrated noteworthy clinical improvements.¹⁸ We modeled the EVD alert after these systems, devising a protocol to page all teams that are necessary for EVD placement and to initiate time-sensitive processes automatically.

With the inception of the EVD alert system, a statistically significant reduction in time to EVD placement in the ED was observed. The median time to EVD placement for the EVD alert cohort was reduced by 13.06 minutes, representing a 19.6% reduction in time when compared with the control cohort ($p = 0.025$). This marked an overall reduction in time to EVD placement by 41.8% when compared with the preintervention time (without either the EVD crash cart or EVD alert system).¹¹ With respect to the mean time to EVD placement, the EVD alert cohort demonstrated a 21.58-minute reduction, representing a 30.0% reduction in time when compared with the control cohort ($p = 0.033$). Overall, this constituted a 49.2% reduction in time when compared with preintervention cases.¹¹ Analysis of times from both cohorts via SPC charts revealed no special cause variations and no violations of Shewhart rules, consistent with the behaviors of stable processes under statistical control. Furthermore, the EVD alert cohort case times exhibited less variations in time to EVD placement compared with the control cohort. These results suggest that the EVD alert system was a direct factor in the reduction of time to EVD placement. Additionally, our analysis likely did not capture the full effect of the intervention because we excluded patients who required the administration of blood products. Part of the EVD alert protocol is designed to expedite this process, yet we excluded those patients for the purposes of consistent analysis. Thus, our results likely underestimate the full impact of the EVD alert intervention.

The limitations of this study include the potential of additional factors outside of the EVD alert system that might have impacted the time to EVD placement. The time required before EVD placement is affected by many factors (e.g., healthcare decisions, necessity for additional emergency procedures, and turnaround time of laboratory and pharmacy services), some of which might have caused variations in the collected data. Furthermore, changes in clinical practice patterns and neurosurgery resident familiarity of the EVD alert protocol might have impacted

the time to EVD placement. The nature of the study was such that we compared preintervention with postintervention cohorts; thus, temporal changes in practice patterns and other factors may have influenced our findings. Additionally, while healthcare teams and surgeons were not explicitly told of the study objective, there also remains a possibility that a Hawthorn effect impacted the study results due to improved awareness among staff following the implementation of the EVD cart. Finally, the final sample size ($n = 38$) and achieved power of this study may impact the significance of the statistical analysis performed. On the basis of this study's final observed effect size (Cohen's d) of 0.75, a total of 60 cases would have been required to reach a statistical power of 0.8, assuming a two-tailed significance of 0.05. Rigorous statistical analysis, thorough chart review, and strict inclusion and exclusion criteria help in limiting the impact of these potential confounders.

The EVD alert system represents a robust and consistent method that significantly reduces time to EVD placement in the ED and may be used to augment other interventions (e.g., EVD crash cart) aimed at reducing the time required to begin procedures. While the generalizability of the current study results remains to be proven, a procedure alert system is a versatile tool that may be expanded into other departments outside of neurosurgery to improve patient care. Development of the EVD alert system was straightforward and is easily applicable at other institutions. Education and frequent reeducation of ED staff are vital for the success of such an intervention. Implementation of the EVD alert system at other institutions will enable further investigation of the clinical impact and generalizability of this intervention.

Conclusions

A quality improvement framework helped to identify the lack of a standardized protocol and communication system as a major source of delay to EVD placement in our ED. The study data suggest that an automated EVD alert system significantly reduces the time to EVD placement and can be easily integrated into most healthcare systems to expedite the care of critically ill neurosurgery patients. Expansion of this intervention at other institutions will improve the external validity of this study.

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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: Komotar, Silva, Cajigas. Acquisition of data: Chang, Silva, Giner, Ancheta, Cajigas. Analysis and interpretation of data: Chang, Silva, Cajigas. Drafting the article: Chang, Silva, Cajigas. Critically revising the article: Komotar, Chang, Silva, Giner, Cajigas. Reviewed submitted version of manuscript: Chang, Silva, Cajigas. Statistical analysis: Chang, Silva, Cajigas. Administrative/technical/material support: all authors. Study supervision: Komotar, Chang, Silva, Cajigas.

Supplemental Information

Online-Only Content

Supplemental material is available online.

Supplementary Figures 1–4. <https://thejns.org/doi/suppl/10.3171/2021.8.FOCUS21378>.

Correspondence

Ricardo Komotar: University of Miami Miller School of Medicine, Miami, FL. rkomotar@med.miami.edu.