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Original Article

Ventriculostomy supply cart decreases time-to-external ventricular drain placement in the emergency department

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ABSTRACT

Background: Minimizing time-to-external ventricular drain (EVD) placement in the emergency department (ED) is critical. We sought to understand factors affecting time-to-EVD placement through a quality improvement initiative.

Methods: The use of process mapping, root cause analyses, and interviews with staff revealed decentralized supply storage as a major contributor to delays in EVD placement. We developed an EVD "crash cart" as a potential solution to this problem. Time-to-EVD placement was tracked prospectively using time stamps in the electronic medical record (EMR); precart control patients were reviewed retrospectively.

Results: The final cohorts consisted of 33 precart and 18 postcart cases. The mean time-to-EVD in the precart group was 99.09 min compared to 71.88 min in the postcart group (two-tailed *t*-test, *P* = 0.023). Median time-to-EVD was 92 min in the precart group compared to 64 min in the postcart group (rank sum test, *P* = 0.0165). Postcart patients trended toward improved outcomes with lower modified Rankin score scores at 1 year, but this did not reach statistical significance (two-tailed *t*-test, *P* = 0.177).

Conclusion: An EVD "crash cart" is a simple intervention that can significantly reduce time-to-EVD placement and may improve outcomes in patients requiring an EVD.

Keywords: Emergency department, Hydrocephalus, Quality improvement, Ventriculostomy

INTRODUCTION

Ventriculostomy placement is one of the most common neurosurgical bedside procedures. More than 20,000 external ventricular drains (EVDs) are placed annually in the United States.[21] Indications for EVD placement have expanded since the introduction of the EVD in the 18th century.[23] For example, patients presenting to the emergency department (ED) with acute

hydrocephalus from an obstructing tumor, subarachnoid hemorrhage from a ruptured aneurysm, traumatic brain injury, or intraventricular hemorrhage may require urgent placement of an EVD.[5,6,8,10,11,16] EVD placement requires seamless coordination among emergency room physicians, neurosurgery physicians, nursing staff, pharmacy, core laboratory, and others. Prompt EVD placement has been shown to improve long-term patient outcome and decrease length of ICU and hospital stays.[6,11]

The majority of EVDs at our institution are placed in the ED, especially for patients with more urgent needs for EVD placement who require EVD placement before an ICU bed becomes available. Indications for emergent EVD placement in the ED are case specific, but typically include cases of aneurysmal subarachnoid hemorrhage with a Hunt and Hess grade of 3 or higher, acute hydrocephalus with a Glasgow Coma Scale (GCS) score of <15, intraventricular hemorrhage with hydrocephalus, and traumatic brain injuries that meet the Brain Trauma Foundation criteria for intracranial pressure (ICP) monitoring.[3] Our neurosurgery team had observed frequent delays in the process of placing an EVD in the ED. We sought to identify and address factors that delay EVD placement at our ED through a quality improvement framework. Surveying all the departments involved in the decision-making and placement of EVDs enabled us to identify potential time delays.[24] Process mapping and root cause analysis revealed decentralized supply storage as a significant contributor to delayed EVD placement[4,17,24] [Figures 1 and 2]. We developed and implemented an EVD supply cart for the ED and prospectively assessed the impact on time-to-EVD placement.

MATERIALS AND METHODS

Study characteristics, inclusion/exclusion criteria

Data were collected both prospectively and retrospectively. The study was approved by our institution's IRB (Protocol #20190342). All patient data were anonymized and unidentifiable throughout the data analysis process. We prospectively collected data on patients who underwent EVD placement in the ED after initiation of the EVD supply cart in the ED in January 2018. For our control group, we retrospectively reviewed patients who underwent EVD placement in the ED before implementation of the EVD supply cart. Patients were excluded from our analysis if there was a delay to EVD placement unrelated to the standard protocol (administration of blood products before EVD placement, reversal of decision to not place EVD based on delayed neurologic decline) or if accurate time stamps were not recorded in the electronic medical record (EMR) and complete EMRs were unable to be obtained. All patients that did not meet the exclusion criteria were included in

the study. Cohort demographics (age, arrival, GCS, sex, and etiology) were collected and analyzed [Table 1]. Preliminary data from a pilot study estimated an average time-to-EVD placement of 82.14 min (standard deviation of 37.53 min), with a mean reduction of 29.44 min (standard deviation of 23.87 min) on the initial implementation of the EVD cart. Therefore, a clinically significant effect size (Cohen's *d*) of 0.94 was determined to be of interest. Assuming an alpha of 0.05, a power of 0.8, and equal allocation of cases to both the pre-EVD group and the post-EVD group, a total of 38 cases were determined to be needed.

Root cause analysis and process mapping

The conception of the EVD cart began with the collection of baseline data through surveys conducted at our institution between June 2017 and December 2017. Residents were asked to complete an anonymous survey regarding their comments on the EVD placement process and to record their individual time-to-EVD placement. The baseline self-estimated time-to-EVD data collected from residents were then corroborated with EMR time stamps. Additional surveys were conducted among ED nurses, ED attending physicians, CT staff, and trauma nurses on potential delays on time-to-EVD. A root cause analysis framework was used to identify possible sources of delayed EVD placement. A process map as shown in [Figure 1] was generated by identifying all steps

Table 1: Demographics.

Characteristics	Precart (*n*=33)	Postcart (*n*=18)	*P*
Age (years), mean (SD)	48.79 (19.17)	54.44 (12.58)	0.27[†]
Arrival GCS*, mean (SD)	7.27 (4.15)	10.11 (4.70)	0.03[†]
Sex			
Male (%)	22 (67%)	5 (28%)	0.01[‡]
Female (%)	11 (33%)	13 (72%)	
Etiology			
Subdural hematoma	11	0	0.02[§]
Subarachnoid hemorrhage (nontraumatic)	10	9	
Subarachnoid hemorrhage (traumatic)	6	1	
Intracerebral hemorrhage	6	6	
Interventricular hemorrhage	0	1	
Obstructive mass	0	1	

*Glasgow Coma Scale, [†]two-sample *t*-test, [‡]Fisher's exact test, [§]Chi-squared test
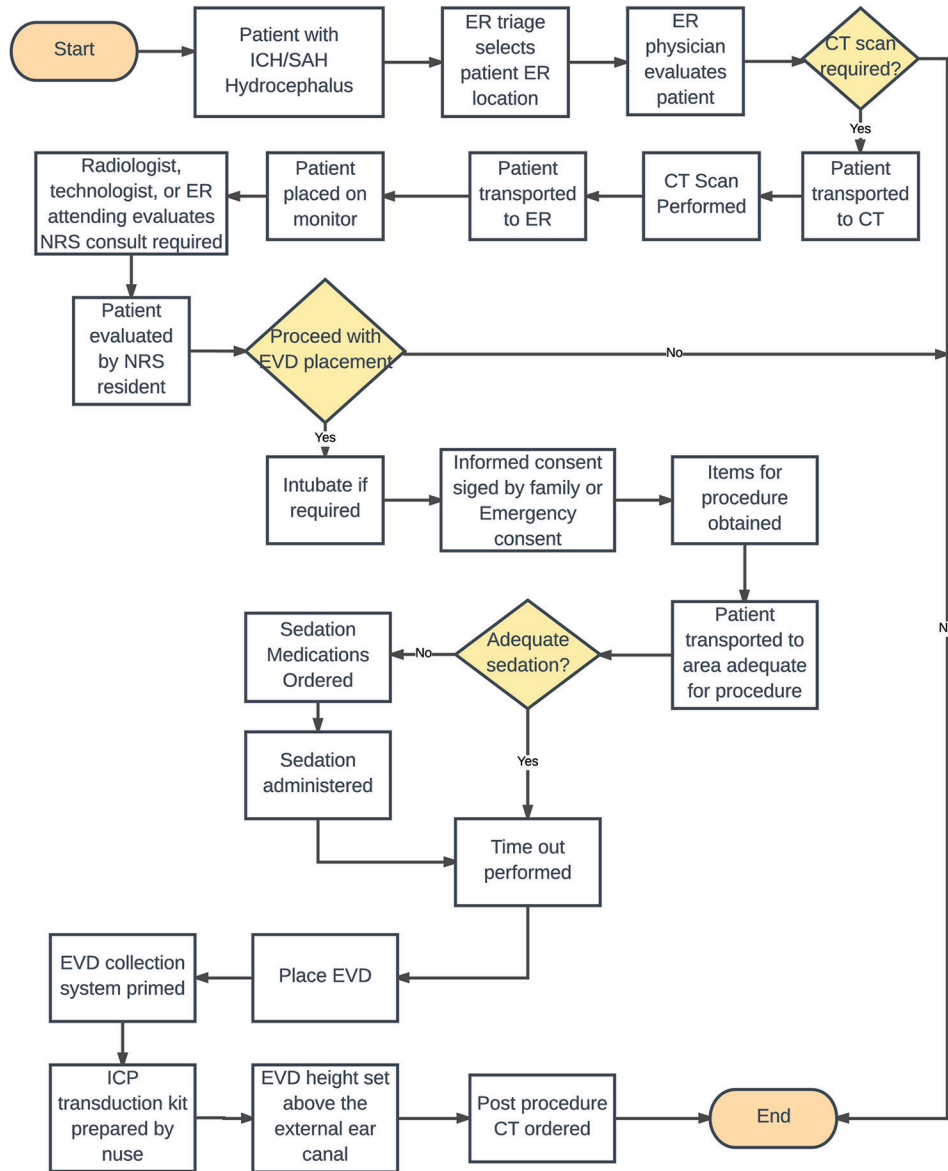
Figure 1: Process map for external ventricular drain (EVD) placement in the emergency department. Algorithm for decision on EVD placement and steps involved leading to the procedure. The EVD cart seeks to reduce the time necessary for obtaining supplies for the procedure.

involved in the process of EVD placement, starting from the arrival of the patient to the ED to successful placement of the EVD. Decentralized supply storage was identified as a source of delays, as depicted in the root cause analysis fishbone chart in [Figure 2]. Centralizing supply availability with an EVD "crash cart" was identified as a possible solution.

EVD supply cart

A supply cart similar to a code cart was obtained and stocked with all necessary EVD supplies, including cranial access kit, burette collection system, ICP transduction kit, stapler,

dressing kit, syringes, needles, and gauze [Supplementary Figure 1]. Drawers were labeled accordingly and organized in logical fashion to facilitate obtaining materials before the procedure. The cart was placed in the center of the ED and locked for use only when an EVD needed to be placed. ED nursing staff was tasked with restocking the cart after EVD placement in a manner identical to code cart restocking. In-service teaching was offered for emergency room physician and nursing staff to increase understanding of the EVD placement indications and procedure and to increase awareness of EVD cart availability. The in-service sessions were led by neurosurgery physicians and ICU nurses and
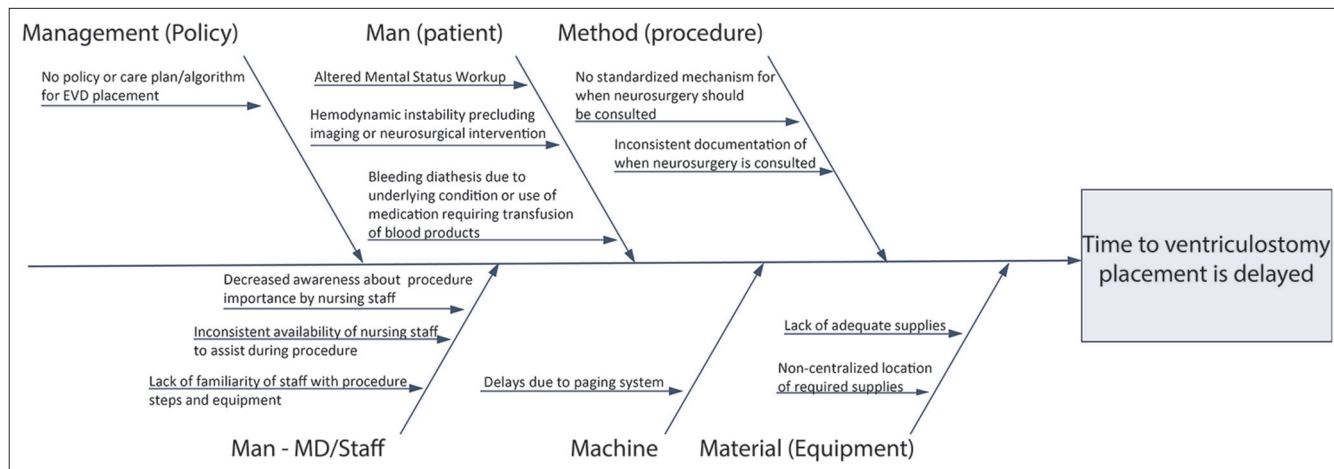
Figure 2: Root cause analysis for delays to ventriculostomy placement. A fishbone diagram outlining sources of delays to external ventricular drain (EVD) placement. The EVD cart seeks to address potential delays originating at the material (Equipment) level.

sessions included hands-on interaction with EVD equipment and discussion on appropriate calibration and monitoring.

Data collection and statistical analysis

Prospective data collection for patients undergoing EVD placement in the ED began in January 2018 after the development of the EVD cart. Retrospective review of patients who underwent EVD placement in the ED generated our control group. These patients were identified by reviewing resident case logs and neurological intensive care unit patient logs for patients who had an EVD placed in the ED; patients were excluded if the EVD was placed after arrival to the ICU or if the EVD was placed in another part of the hospital (e.g. in the trauma bay since ventriculostomy equipment is readily available there).

Time stamps as recorded in the EMR for the following events were collected: time of arrival and registration in the ED, time of initial head CT, time of neurosurgery consult (when recorded), and time of nursing procedure time out for EVD placement. Time-to-EVD was defined as the time from neurosurgical consultation to the time of the procedural time-out. In the case that time of neurosurgical consultation was not recorded, the time of initial head CT was used since neurosurgery is consulted immediately after head CT is performed in these patients. Procedure time-out was used as the endpoint to isolate the impact of the cart of preparation for EVD placement, irrespective of the time taken to place the EVD (which depends on the individual case and the practitioner placing the EVD). All EVDs were placed by neurosurgical resident physicians. To assess the impact of the intervention on clinical outcome, we also reviewed patient records to determine modified Rankin score (mRS) for each patient 1 year after EVD placement.

Median time to EVD was compared between the pre- and post-cart cohorts using one-way ANOVA and Kaplan–Meier analysis through the rank-sum test. Mean time to EVD was compared between groups using a two-tailed t-test. Difference in mean mRS score between the two groups was compared using a two-tailed t-test. Pre- and post-cart cohort patient demographics were compared using a two-sample t-test (age and arrival GCS), Fisher's exact test (sex), and Chi-squared test (etiology). All statistical analyses comparing both cohorts were completed in MATLAB® (MathWorks®; Natick, MA, USA). Univariate linear regression and multiple linear regression were used to assess potential cohort demographic confounders on the time to EVD. Similarly, univariate logistic regression and multiple logistic regression were used to assess potential confounders on dichotomized mRS outcomes of each cohort. The patient ability to care for self was analyzed with the dichotomization of mRS with scores of 0–2 (able to care for self) versus scores of 3–6 (unable to care for self). The patient disability was assessed through dichotomization of mRS with scores of 0–1 (no significant disability) versus scores of 2–6 (any disability). Analysis for trends and special cause variations on case times to EVD were assessed through Statistical Process Control (SPC) charts. Regression and SPC chart analysis were completed in R (R Core Team, 2020). Power analysis was completed in G*Power (Faul, Erdfelder, Lang, and Buchner, 2007). $P < 0.05$ was set as a threshold for statistical significance.

RESULTS

The EVD supply cart was placed in the ED in January 2018. A total of 18 postcart patients who underwent EVD placement in the ED between January 2018 and October 2019 met our inclusion criteria and were included in our analysis. A total of 33 precart cases between April 2012 and

January 2018 made up our control cohort. Thirteen patients were excluded from our postcart cohort and 71 patients were excluded from the control cohort based on our exclusion criteria. Time-to-EVD placement was compared between the control and the intervention groups. There was no significant difference between the two cohorts in age, there were significant differences in arrival GCS, sex, and etiology [Table 1].

Patients underwent EVD placement for nontraumatic subarachnoid hemorrhage (aneurysmal in most cases) in 20 cases (10 in the precart and 10 in the postcart cohorts), nontraumatic intracerebral hemorrhage in 12 cases (6 in the precart and 6 in the postcart cohorts), and traumatic intracranial hemorrhage in 17 precart patients, isolated intraventricular hemorrhage in 1 postcart patient, and obstructive pineal mass in 1 postcart patient.

Time-to-EVD placement was decreased in our postcart cohort [Figure 3]. Median time-to-EVD placement in the precart cohort was 92 min compared to 66.5 min in the postcart cohort (F statistic 5.5175, $P = 0.0229$). Mean time to EVD was 99.1 min in the precart cohort compared to 71.9 min in the postcart cohort (t statistic 2.3489, $P = 0.0229$). As shown in [Figure 4], KM analysis confirmed a significant reduction on median time-to-EVD placement from 92 min in the precart group compared to 64 min in the postcart group (rank sum test, $P = 0.0165$). There was no statistically significant association between time–to-EVD placement and variations in arrival GCS, sex, and etiology through univariate linear regression ($P = 0.3694$, $P = 0.7952$, and $P = 0.3474$, respectively) or in multiple linear regression ($P = 0.2833$). On the basis of the final effect size observed ($d = 0.7$), *post hoc* power analysis revealed that this study achieved a power of 0.65.
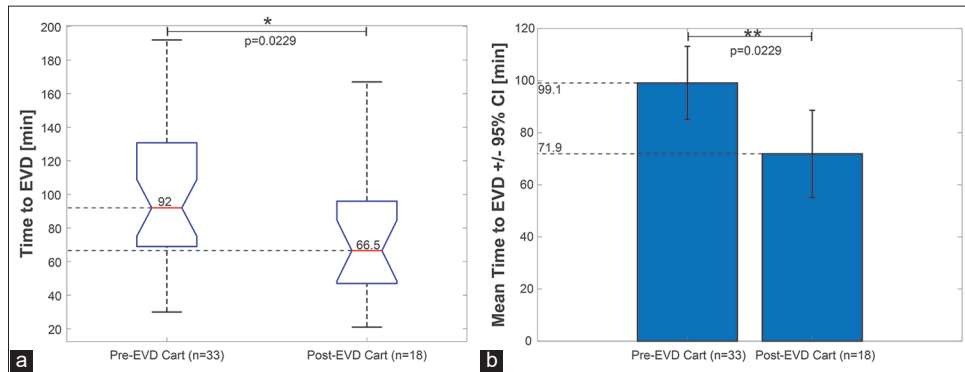

Figure 3: Comparison of median and mean time-to-external ventricular drain (EVD) placement between the precart and postcart cohorts. (a) Boxplot showing the distribution of times to EVD placement with median and inner interquartile range (25–75% of the times) within the box outlined region. *P*-value corresponds to F-test. (b) Mean and 95% confidence interval on the mean for pre- and post-EVD cart groups. *P*-value corresponds to two-tailed *t*-test.
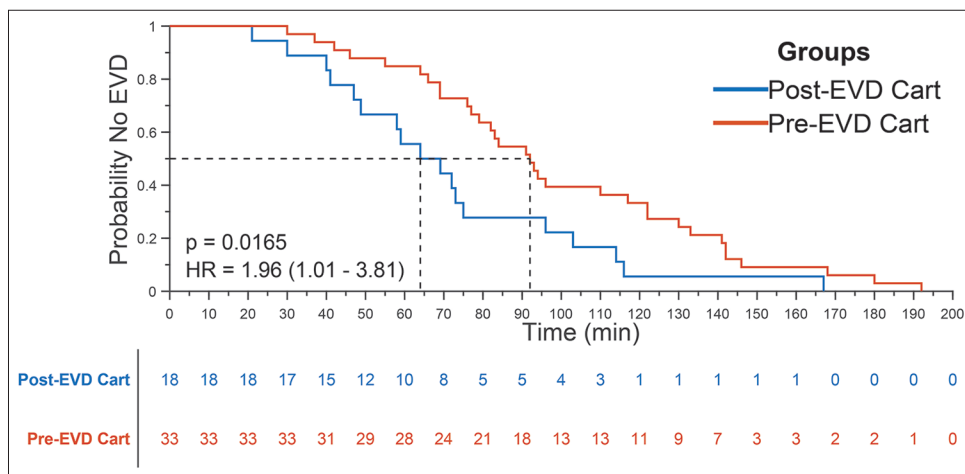

Figure 4: Kaplan–Meier curve comparing time-to-external ventricular drain (EVD) placement before and after initiation of EVD supply cart. A Kaplan–Meier curve illustrating the probability of no EVD placement from time of patient presentation. The median time-to-EVD placement among the postcart cohort (*n*=18) was 64 min, representing a statistically significant (rank-sum test, *P*=0.0165) reduction in time from the median time of 92 min among the precart cohort (*n*=33). The median time was determined from the 0.5 probability of no EVD placement for both cohorts.

Individual case times to EVD were assessed with SPC charts. Twenty-five cases among the precart cohort had time-to-EVD placement within one standard deviation of the mean, seven cases were within two standard deviations, and one case within three standard deviations [Supplementary Figure 2]. Case times to EVD among the postcart cohort included 13 cases within one standard deviation, four within two standard deviations, and one within three standard deviations of the mean [Supplementary Figure 3]. No case times exceeded control limits or violated Shewhart rules [Supplementary Figures 4 and 5]. No trends or patterns were observed within either cohort.

We also sought to assess clinical impact of the intervention by comparing mRS score at 1 year after EVD placement between the pre- and post-cart groups. Postcart patients trended toward improved outcomes with lower mRS score at 1 year, but this did not reach statistical significance (two-tailed *t*-test, *P* = 0.177). Cohort demographic variations among arrival GCS and etiology did not have a statistically significant association with mRS scores (mRS 0–2 vs. mRS 3–6; patient able to care for self vs. not able to care for self) when analyzed through univariate logistic regression (*P* = 0.866 and *P* = 0.995–0.112, respectively). Cohort variations in sex did have a statistically significant relationship with mRS on univariate logistic regression (*P* = 0.042). When analyzing mRS regarding patient disability (mRS 0–1 vs. mRS 2–6; no significant disability vs. any disability), sex did not have a statistically significant association but did have a trend toward sex significance on univariate logistic regression (*P* = 0.0791). The multiple logistic regression on mRS outcomes at 1 year for cohort sex and the use of the EVD cart revealed no statistically significant results when analyzing for patient ability to care for self (*P* = 0.0895 and *P* = 0.5382, respectively; mRS 0–2 vs. mRS 3–6) or presence of disabilities (*P* = 0.126 and *P* = 0.755, respectively; mRS 0–1 vs. mRS 2–6). There were no unintended consequences as a result of the EVD cart. In addition, no patients or intervention data were lost to follow-up among the pre- and post-cart groups.

DISCUSSION

Root cause analysis for health-care quality improvement seeks to identify latent causes of avoidable adverse events or inefficiency.[18] When combined with process mapping, individual steps in complex health-care processes can be measured, analyzed, and studied to improve quality of care.[12,17] Both of these methods were employed in this study to identify the remote and immediate factors associated with delayed EVD placement, highlighting decentralized EVD supply storage as a key contributor to delays in EVD placement.

To the best of the authors' knowledge, this is the first study of a dedicated EVD supply cart in the literature. Similar interventions have proven effective for other applications.

Anesthesia medication carts have been shown to reduce the likelihood of medication-related adverse events, medication selection errors, and overall time spent searching for medication.[22] Code carts are well established in hospitals throughout the country; several studies have demonstrated that an organized and central supply of resuscitation medication and equipment reduces time of resuscitative efforts and improves the likelihood of good outcomes.[7,13,14,20] While there are limited studies directly quantifying the reduction in time to procedure for different procedure carts, improvements in time of up to 46–60% have been observed in the literature regarding a pediatric resuscitation cart and a neurological emergency medication cart, respectively.[1,19] Based on these studies, an EVD "crash cart" with centralized supply of equipment for EVD placement was identified as a possible solution to reduce time-to-EVD placement.

Implementation of our EVD cart led to a statistically significant decrease in EVD placement time in the ED. The mean time-to-EVD placement in the postcart group was reduced by 27.21 min, representing a 27.46% reduction in overall time (*P* = 0.023), compared to the precart cohort. Median time-to-EVD placement was reduced by 28 min, 30.4% reduction (*P* = 0.017). The reduction in time-to-EVD placement was not found to be related with variations in arrival GCS, sex, or etiology, but did have a statistically significant association with the use of the EVD cart. When analyzed through SPC charts, both cohorts exhibited behavior typical of stable processes, with no violation of Shewhart rules and no special cause variations. These results suggest that centralized supply plays a key role in directly reducing overall time to ventriculostomy.

We also observed a trend toward improved clinical outcomes in the postcart cohort based on mRS score at 1 year after EVD placement. However, these results did not reach statistical significance (*P* = 0.177). Differences in cohort sex did have a statistically significant association on the outcome of a patient's ability to care for themselves (*P* = 0.042) and a trend toward significance on patient disability (*P* = 0.0791). In both cases, the use of the EVD cart, when accounting for the sex variable, did not have statistically significant associations with patient outcomes (*P* = 0.5382 and *P* = 0.755, respectively). This is potentially due to the wide range of pathologies in this study. A larger clinical cohort will be needed to ascertain the clinical impact of EVD placement times on complication rates and clinical outcome. Nonetheless, an EVD "crash cart" represents a simple and easy to implement intervention with the ability to significantly reduce time to ventriculostomy. There exists the potential that this intervention also improves overall clinical outcome, but more data will be needed to thoroughly assess this.

There are several limitations of this study, including the inherent limitation of a partially retrospective study and

audit nature of the study design: our intervention group (postcart cohort) was compared to a control cohort that was drawn from several years of precart patients. All cases from both cohorts were subject to the same inclusion and exclusion criteria. In addition, the final sample size (n = 51) and achieved power of this study may impact the significance of the statistical comparisons conducted; based on the final observed effect size d of 0.7, a total of 66 cases (assuming equal allocation) would have been needed to obtain a statistical power of 0.8. Furthermore, many factors impact time-to-EVD placement (clinical decision-making, administration of blood products, speed of laboratory and pharmacy services, etc.), which can lead to substantial variability in time to ventriculostomy. Surgeons and ED staff were minimally aware that they were being timed and were not explicitly informed that time-to-EVD placement was being measured. That said, implementation of the EVD cart was a quality improvement initiative with the goal of improving time-to-EVD placement, thus it is possible that a Hawthorne effect impacted our findings. There exists the possibility that external factors contributed to improved times to EVD placement that is not directly related to the EVD cart (improved nursing or surgeon awareness, evolving practice patterns, and changes in resident comfort) and may confound our findings about impact of the EVD cart. Strict inclusion and exclusion criteria and large sample size help mitigate this concern.

As the EVD cart was designed for use in the ED, this study is limited by the fact that the influence of location of EVD placement on outcomes could not be assessed in this study. Increased risk of EVD-related infections has been proposed to be associated with EVD placement in the ED when compared to EVD placement in the operating room, however, there is no consensus in the literature.[2,9,15] Kohli *et al.*[15] reviewed 190 EVD placements and noted no significantly greater risk of infections or complications in EVDs placed at the bedside compared to those placed in the operating room. Meanwhile, Altschul *et al.*,[2] in a study of 710 EVD placements, found that EVDs placed in the ED had a significantly higher rate of infection when compared to EVDs placed in the operating room. At our institution, EVDs are universally placed at the bedside unless the patient is taken to the operating room for a separate indication, and all of the EVDs in our study were placed in the ED. Our study sought to identify ways to optimize EVD placement in the ED setting, therefore, the study population was restricted to only patients who underwent EVD placement in the ED. The study does not assess the impact of location on EVD placement as the intervention was specifically designed for the ED setting; further studies are needed to investigate the relationship between location and outcomes after EVD placement.

The generalizability of our results remains to be proven but represents an exciting opportunity for neurosurgeons to improve the care of some of their most acutely ill patients. Further, investigation and validation on data from other institutions are needed to thoroughly evaluate the generalizability of our intervention and better assess the effect on patient outcomes. Investigation of the clinical impact of the EVD cart would require a larger, more homogenous cohort. Expansion of this intervention to other institutions will allow us to test the generalizability of our results and better assess the effect on patient outcomes. This type of intervention may also be useful outside of neurosurgery, inspiring the creation of similar procedure supply carts for other applications throughout medicine.

CONCLUSION

Timely placement of an EVD is critical for the care of acute hydrocephalus.[6,11] Through a root cause analysis, we identified decentralized supply storage as a source of delays to EVD placement. Our study demonstrates that an EVD "crash cart" is an effective and easily implemented intervention that significantly reduces time–to-EVD placement and showed a trend toward improved patient outcomes. This intervention can be easily implemented at other institutions which will help improve the external validity of the study.

Declaration of patient consent

Institutional Review Board (IRB) permission obtained for the study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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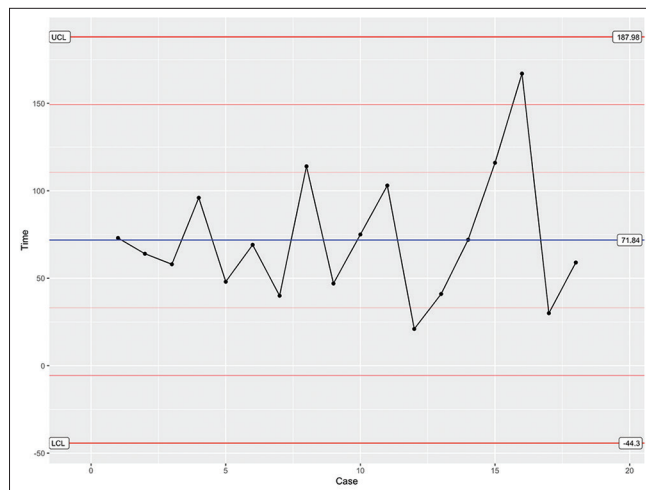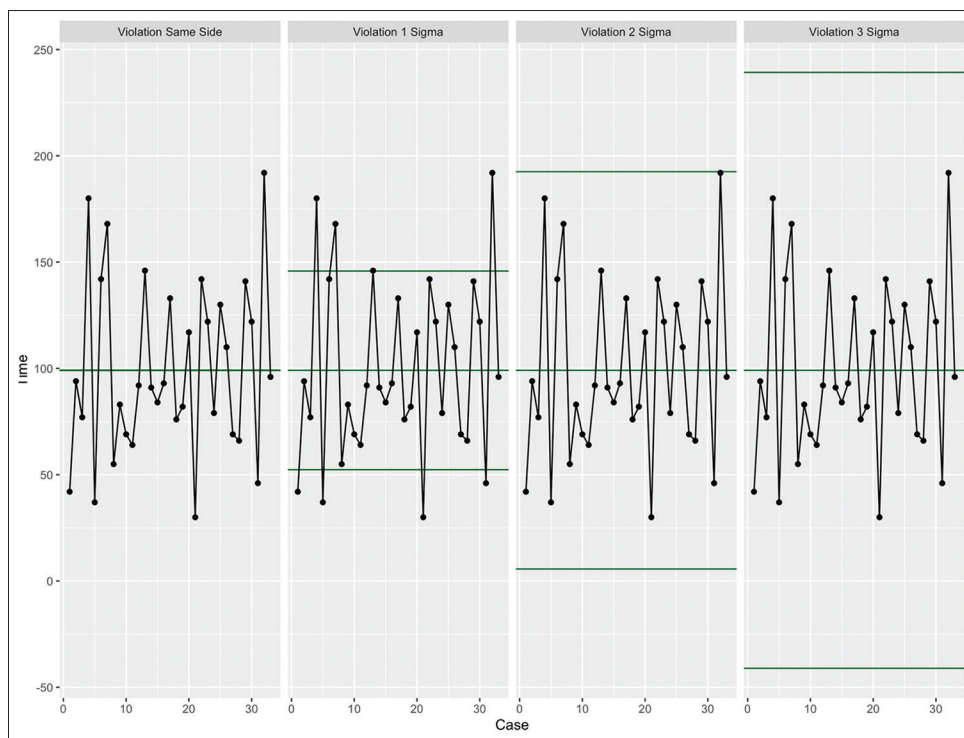
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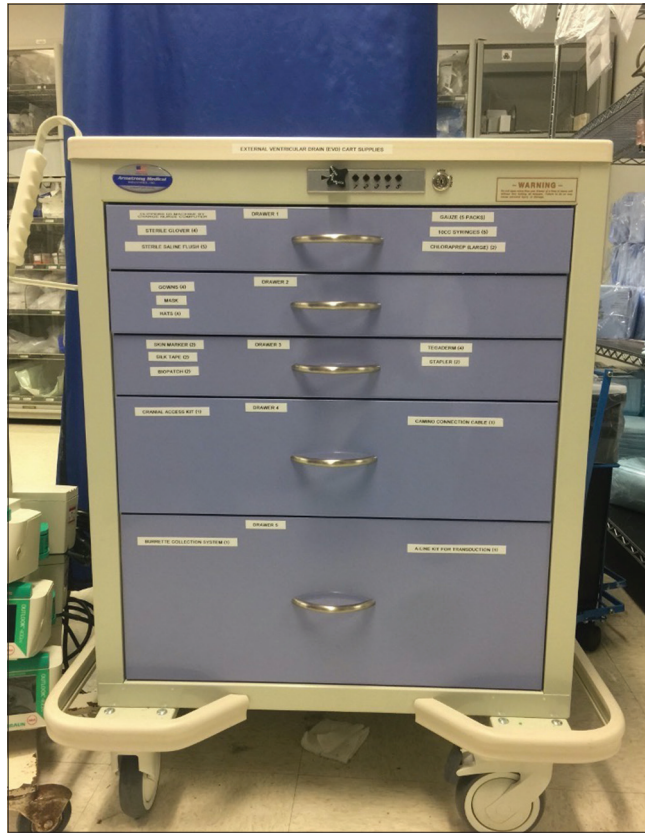
Supplementary Figure 1: Labeled external ventricular drain supply cart as developed for our emergency department.
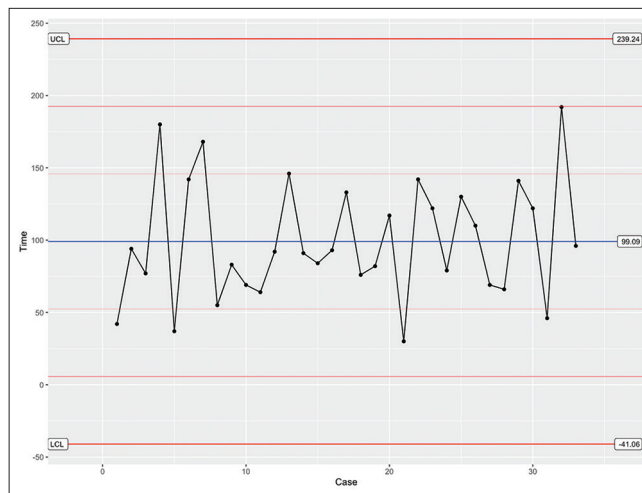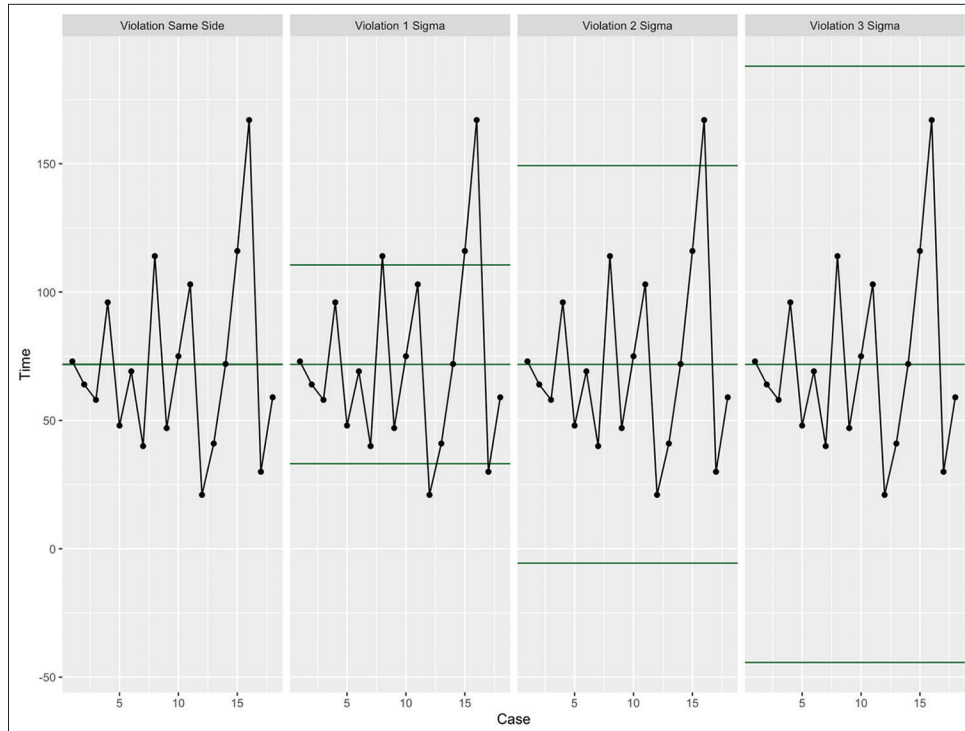

Supplementary Figure 2: Precart cohort statistical process control chart. Precart case times to external ventricular drain (EVD) placement (*n*=33) with mean time (99.09), upper control limit (UCL, 239.24), and lower control limit (LCL, −41.06) labeled. Cases are arranged by date of EVD placement.

Supplementary Figure 3: Postcart cohort statistical process control chart. Postcart case times to external ventricular drain (EVD) placement (*n*=18) with mean time (71.9), upper control limit (UCL, 187.98), and lower control limit (LCL, −44.3) labeled. Cases are arranged by date of EVD placement.

Supplementary Figure 4: Precart cohort statistical process control checked against Shewhart rules.

Supplementary Figure 5: Postcart cohort statistical process control checked against Shewhart rules.