

Reducing the Time to Blood Administration after Pediatric Injury: A Quality Improvement Initiative

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Abstract

Introduction: Hemorrhage is the leading cause of preventable death in pediatric trauma patients. Timely blood administration is associated with improved outcomes in children and adults. This study aimed to identify delays to transfusion and improve the time to blood administration among injured children. **Methods:** A multidisciplinary team identified three activities associated with blood transfusion delays during the acute resuscitation of injured children. To address delays related to these activities, we relocated the storage of un-crossmatched blood to the emergency department (ED), created and disseminated an intravenous access algorithm, and established a nursing educator role for resuscitations. We performed comparative and regression analyses to identify the impact of these factors on the timeliness and likelihood of blood administration. **Results:** From January 2017 to June 2021, we treated 2159 injured children and adolescents in the resuscitation area, 54 (2.5%) of whom received blood products in the ED. After placing a blood storage refrigerator in the ED, we observed a centerline change that lowered the adjusted time-to-blood administration to 17 minutes (SD 11), reducing the time-to-blood administration by 11 minutes ($\beta = -11.0$, 95% CI = -22.0 to -0.9). The likelihood of blood administration was not changed after placement of the blood refrigerator. We observed no reduction in time following the implementation of the intravenous access algorithm or a nursing educator. **Conclusions:** Relocation of un-crossmatched blood storage to the ED decreased the time to blood transfusion. This system-based intervention should be considered a strategy for reducing delays in transfusion in time-critical settings. (*Pediatr Qual Saf* 2022;7:e563; doi: 10.1097/pq9.0000000000000563; Published online June 14, 2022.)

INTRODUCTION

Hemorrhage is the leading cause of preventable death among injured patients. About 50% of deaths from exsanguination occur

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within the 6 hours following injury, with most deaths occurring during the first hour.¹⁻⁴ Early recognition and intervention of hemorrhagic shock is associated with decreased 24-hour and 30-day mortality in adults.^{5,6} Every minute delay in the time to blood cooler arrival, among adult trauma patients requiring massive blood transfusion, increases the odds of mortality by 5%.⁵

In both children and adults, timely blood administration is associated with decreased in-hospital morbidities, including reduced hospital and intensive care unit stay and fewer hospital-acquired infections.⁵⁻¹⁰ In adult trauma centers, several methods have successfully reduced the time to blood transfusion by increasing the accessibility of blood products, including relocation of blood storage to the emergency department (ED).¹¹ Although these approaches decrease the time to administration of blood products in adults, the impact of these approaches has not been evaluated in pediatric trauma centers. Ensuring rapid blood administration after pediatric injury may be more challenging during the initial resuscitation period because transfusion is less often needed, and hemodynamic changes associated with hemorrhagic shock are delayed in children.

We formed a multidisciplinary team to identify potential barriers to timely transfusion after injury at our institution. This study aimed to reduce the time to blood

transfusion in pediatric trauma victims by implementing and evaluating the impact of structural and process changes addressing identified transfusion related barriers.

METHODS

Selection of Subjects

Children's National Hospital is a level-one pediatric trauma center serving the Washington D.C. metropolitan area. Based on regional triage criteria, about 500 injured children are initially managed each year in the ED by a multidisciplinary team. This project was undertaken as a Quality Improvement Initiative at Children's National Hospital. Because it does not constitute human subjects research, it was not under the oversight of the Institutional Review Board. We included all patients initially managed as trauma activations between January 2017 and June 2021. We identified a subset of these patients who received a transfusion of packed red blood cells in the ED.

Performance Improvement Initiative

Trauma activations are video recorded and reviewed for quality improvement and research at our institution. The number of videos available for analysis changed during the study period. Before the first intervention in this study, videos without consent were deleted when consent was not obtained for their use. Institutional policies were modified in October 2018 to allow the use of all videos for quality improvement.

Using their domain expertise, a multidisciplinary team consisting of a surgeon, emergency medicine physician, resident surgeon, clinical nurse specialist, ED nurse, and nurse practitioner identified areas of improvement for reducing the time from patient arrival to packed red blood cell transfusion ("time-to-blood") using video review of transfused patients from January 2017 to August 2019. Two individuals independently reviewed videos of trauma resuscitations where blood was transfused in the emergency department. All witnessed and potential barriers were documented and brought to a multidisciplinary discussion. Analysis of the video review and domain expertise identified three activities associated with delays in the time-to-blood: the location of blood products, establishing intravenous (IV) access, and using the rapid fluid infuser. Our team developed a key aim driver diagram to formulate interventions associated with the three identified delays (Fig. 1). In response to this quality initiative, we placed a blood storage refrigerator in the ED in August 2019. The refrigerator is stocked with three units of O negative, un-crossmatched blood and maintained by the blood bank. Before the blood refrigerator was placed in the ED, there were significant delays because providers had to identify a need for blood transfusion, contact and request blood products from the institutional blood bank, and send a runner to retrieve and deliver the products. Second, an algorithm focusing on IV placement, emphasizing

the impact of timely IV access among patients in shock, was created by this multidisciplinary team and disseminated to the ED staff by a didactic lecture. This lecture was recorded for online review in June 2020 through an institutional portal. This algorithm aimed to reduce the time to IV placement by increasing awareness of the barriers to rapid access. The algorithm defined when to establish access by IV and intraosseous routes, the number of recommended access attempts, and recommended time limits for each route. This project's final quality improvement initiative was creating a nursing educator position in September 2020. Responsibilities of this new role were preparing and debriefing nurses regarding emergency department resuscitations, including mentoring new staff members and coaching nurses in using the rapid fluid infuser. Following the implementation of the blood refrigerator, two individuals within the multidisciplinary team continue to review every trauma resuscitation video to evaluate the impact and barriers with each intervention.

Data Collection

Using the hospital trauma registry and the electronic health record, we obtained data for children and adolescents treated from January 1, 2017, to June 30, 2021. We evaluated patient, resuscitation, and outcome characteristics, including age, initial systolic blood pressure and heart rate, the need for cardiopulmonary resuscitation, the initial Glasgow Coma Scale (GCS), Abbreviated Injury Scale (AIS) severity score values by body region, injury type, level of triage, the time of day and day of the week of the event, transfer status, pre-arrival notification time and 6-hour mortality. We used age-based mean and SD to define hypotension (<2 SD below mean) and abnormal heart rate (<2 SD below or >2 SD above mean).¹⁻⁴ We used the motor component of GCS (GCSm) to identify moderate or severe injury (<6).⁵ We used AIS severity scale values to determine the presence of severe (≥ 3) injury to four major body regions: head, chest, abdomen, and extremities. We classified the injury type as either penetrating or nonpenetrating (blunt, burn, and other types).

At our hospital, the triage level is defined based on regional criteria as "stat" (standard level acuity), "transfer" (standard level acuity arriving after initial evaluation at another hospital), and "attending" (highest level acuity). Because of the larger required team size for "attending" activations, we classified activations either as "attending" level or not "attending." Patients are triaged as "attending" regardless of transfer status from another institution if still meeting "attending" level criteria. We classified the time of patient arrival as either day (7 AM to 7 PM) or night (7 PM to 7 AM) and days as either weekday or weekend (including federal holidays). We classified transfer status as "transferred" if arriving after initial treatment at another hospital rather than from the injury scene.

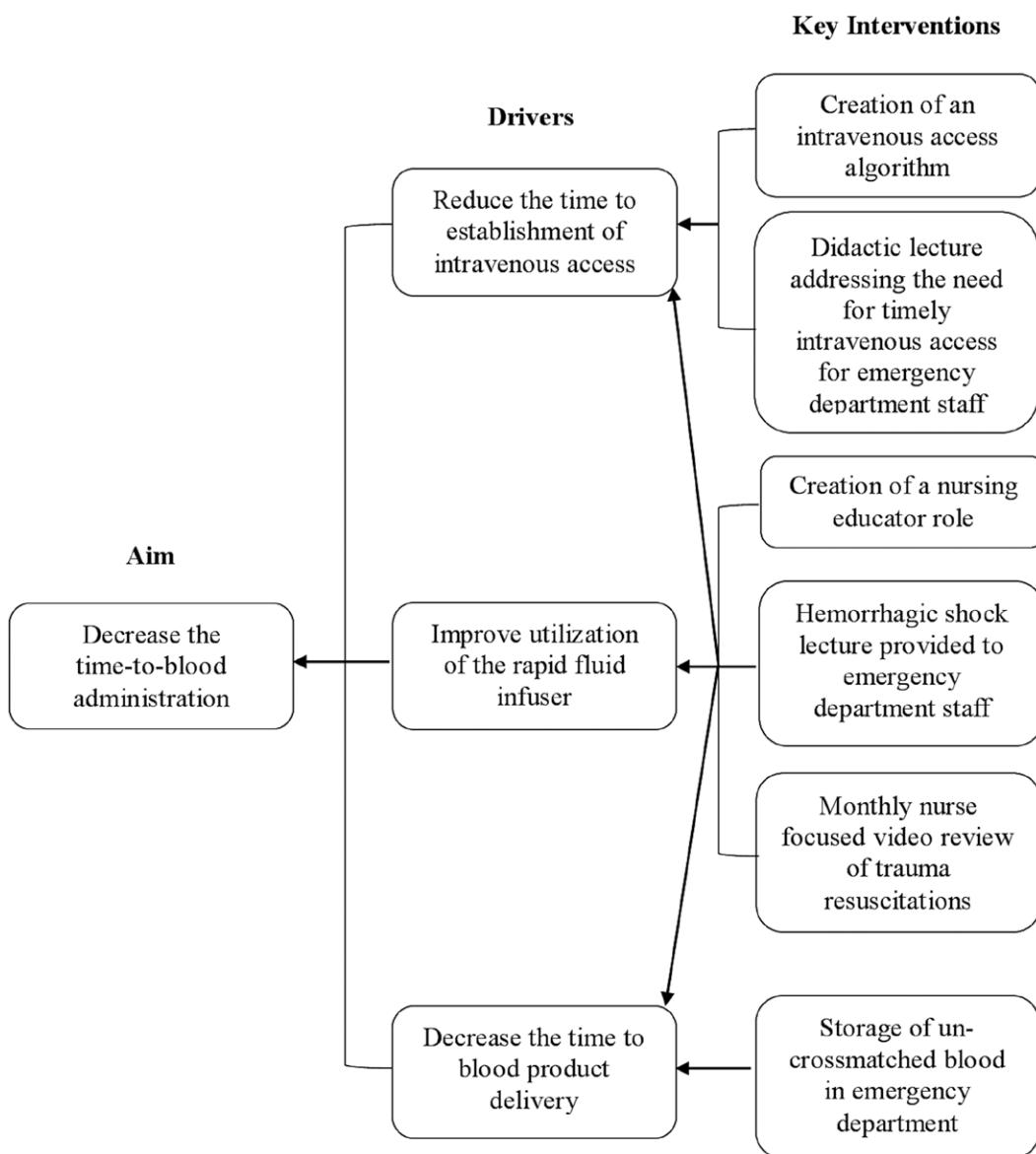


Fig. 1. Key Aim Driver diagram to decrease the time until blood transfusion.

Statistical Analysis

The primary outcome assessed was the time from patient arrival until blood was transfused in the ED. We selected factors to adjust for this time using the least absolute shrinkage and selection operator, choosing the most parsimonious model based on the Schwarz Bayesian information criterion.⁶⁻¹¹ Factors evaluated for inclusion included age, systolic blood pressure, need for pre-hospital cardiopulmonary resuscitation, injury type, severe injury to body regions, activation level, time of day and week, transfer status, and pre-arrival notification time. We constructed a statistical process control chart to analyze adjusted times for patients receiving blood using the selected variables. We identified a centerline shift using the American Society of Quality suggested rule of 10 of 11 points below the initial established centerline. As a secondary outcome,

we evaluated the association of the study duration time with the odds of receiving blood among all patients, adjusting for patient and resuscitation features. We also selected variables for this model using least absolute shrinkage and selection operator and Schwarz Bayesian information criterion.⁷

As appropriate, we performed univariate comparisons using the Kruskal Wallis, Mann-Whitney, or Fisher exact test. Logistic regression model performance was analyzed using discrimination (c-statistic) and calibration (Hosmer-Lemeshow goodness-of-fit test). We assessed linear regression model performance using R^2 value. Significance was defined at $P < 0.05$ using 2-sided tests. We performed statistical process control analysis using the Q.I. Macros add-in for Microsoft Excel 2018 (KnowWare International Inc, Denver, Colo.) and all other analyses using SAS 9.4 (Cary, N.C.).

RESULTS

Characteristics of Study Patients

During the study period, 2159 patients were treated as trauma activations in the ED, with 54 receiving a blood transfusion (Table 1). The median age of all trauma patients was 7.5 years (interquartile range 2.9–12.4). Most patients ($n = 1645$, 76.2%) presented with normal initial vital signs. Among those with abnormal vital signs, 42 were hypotensive (1.9%), and 472 were either tachycardic or bradycardic (21.9%). Pre-hospital cardiopulmonary resuscitation was performed in 56 patients (2.6%). GCSm values were normal in most patients ($n = 1881$, 87.1%). Serious injuries (AIS ≥ 3) to the head and neck ($n = 392$, 18.2%) were most common, followed by the abdomen ($n = 103$, 4.8%), thorax ($n = 102$, 4.7%), and extremities ($n = 101$, 4.7%). Patients arrived most often at night ($n = 1206$, 55.9%) and on weekdays ($n = 1343$, 62.2%). Most patients were transported directly from injury scene ($n = 1520$, 70.4%). Prearrival notification was provided for most patients ($n = 1729$, 80.1%).

Delays to Blood Transfusion

Before any interventions, twelve patients had an available video to analyze for potential causes of blood transfusion delays. Using this review, we identified several factors associated with delays, including the need to bring blood to the emergency department, inexperience using the rapid fluid infuser, difficult IV access, the need to perform additional procedures (intubation and chest tube placement), and provider indecisiveness (Fig. 2A). Four patients had blood ordered in the emergency department before arrival. Two patients had delayed blood transfusion because of provider indecisiveness. Once the decision was made to transfuse, delays due to waiting for the blood cooler arrival occurred most often ($n = 8$) followed by delays related to the use of the rapid infuser ($n = 6$), IV access ($n = 5$), and invasive procedures ($n = 3$). The longest duration of delay was related to transport of the blood cooler to the emergency department [9.5 min (SD

10.9) and the second-longest related to the use of the rapid fluid infuser (7.1 min (SD 9.5)) (Fig. 2B).

Likelihood of Transfusion

We performed a multivariable logistic regression to evaluate the location of blood product storage effect on the number of transfusions. Based on variable selection criteria, we adjusted for hypotension, GCSm < 6 , AIS thorax ≥ 3 , and injury type in a model evaluating the likelihood of transfusion. In this model, the odds of receiving a blood transfusion were not increased after the introduction of the blood refrigerator (OR = 0.2, 95% CI = 0.01–4.7), suggesting no difference in the misuse or waste of blood products from pre-to-post intervention (Table 2).

Time-to-Blood Administration

Based on variable selection criteria, we adjusted the time-to-blood with 3 factors: hypotension, penetrating injury, and severe injury to the head. Hypotensive patients received blood 13 minutes faster ($P = 0.01$), patients with penetrating injuries received blood 12 minutes faster ($P = 0.005$), and those with severe injury to head received blood 8 minutes slower ($P = 0.08$) (Table 3). Adjusting for these variables, the average baseline time-to-blood administration was 28 minutes (SD 20). Following introduction of the blood refrigerator, we observed a centerline change that lowered the average adjusted time-to-blood administration to 17 minutes (SD 11), reducing the time-to-blood administration by 11 minutes ($\beta = -11.0$, 95% CI = -22.0 to -0.9) (Fig. 3). We did not observe any additional process changes following the IV algorithm and nursing educator interventions.

Mortality

During the study period, 11 transfused patients died within 6 hours of arrival (20.3%). Compared with the baseline period, the unadjusted 6-hour mortality rate was lower following the introduction of the blood refrigerator (6/22, 27.3% versus 5/32, 15.6%) ($P = 0.32$).

Table 1. Summary Statistics

Characteristics	Pre-intervention (n = 1174)	Interventions (n = 985)
Age (y, median [interquartile range])	7.5 (2.8–12.4)	7.3 (3.0–12.4)
Hypotension (age-adjusted), n (%) ^a	19 (1.6)	18 (1.8)
Tachycardia/bradycardia (age-adjusted), n (%) ^a	266 (22.7)	206 (20.9)
Pre-hospital cardiopulmonary resuscitation, n (%)	34 (2.9)	22 (2.2)
Glasgow coma scale – motor < 6, n (%)	167 (14.2)	111 (11.3)
Abbreviated Injury Scale severity ≥ 3 , n (%)		
Head	225 (19.2)	167 (17.0)
Thorax	62 (5.3)	40 (4.1)
Abdomen	59 (5.0)	44 (4.5)
Extremities	51 (4.3)	50 (5.1)
Penetrating injury type, n (%)	75 (6.4)	82 (8.3)
Attending level activation, n (%)	153 (13.0)	95 (9.7)
Nighttime arrival, n (%)	650 (55.4)	556 (56.5)
Weekend/federal holiday, n (%)	465 (39.6)	351 (35.7)
Transfer, n (%)	363 (30.9)	276 (28.0)
No prearrival notification, n (%)	217 (18.5)	213 (21.6)

^aOne patient had missing data.

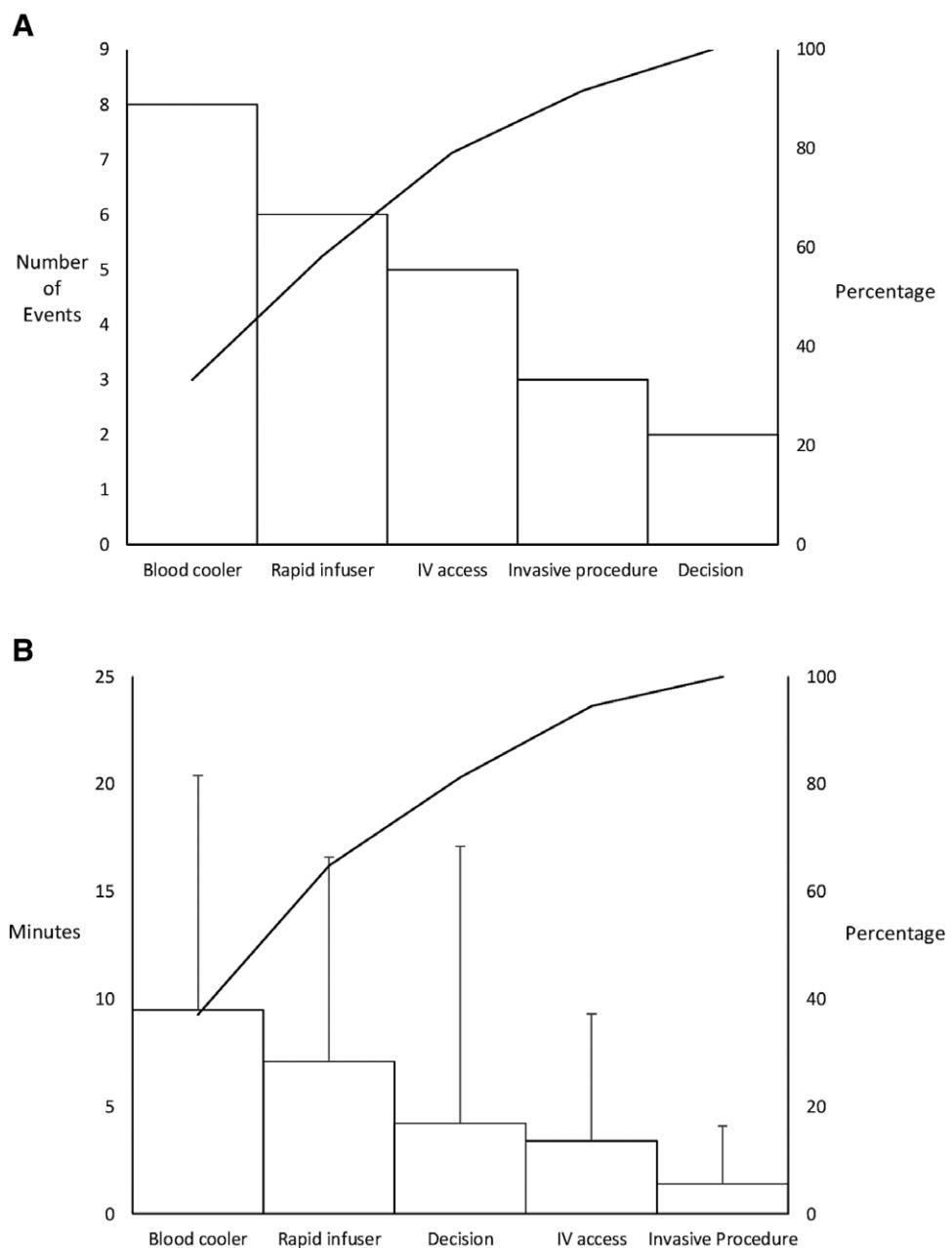


Fig. 2. Pareto chart representing delays in blood transfusion after injury: (A) number of delay occurrences and (B) average time of delay (minutes) with SD.

DISCUSSION

In this single-institution study, we identified and intervened in 3 activities associated with delays in the time-to-blood during the resuscitation of injured children. We observed that blood was given faster after patient arrival when un-crossmatched blood products were available in the resuscitation area of the ED. We did not observe an impact with a didactic intervention focused on reducing delays in establishing IV access or introducing a nursing educator focused on system issues associated with blood administration. Unadjusted mortality comparisons showed a decrease in 6-hour mortality following our interventions, suggesting a potential association of these

interventions on outcome. The immediate availability of blood was not associated with more frequent blood administration, implying that patient and injury characteristics most influenced the transfusing decision.

Hemorrhagic shock is difficult to recognize in its early stages. In children, recognizing hemorrhagic shock is even more challenging. About 40% blood loss can occur before significant vital sign derangements occur in children, such as hypotension and tachycardia.² Early recognition of hemorrhagic shock after an injury is needed as timely blood administration has been associated with improved outcomes in children and adults. In adults, earlier activation of the massive blood transfusion protocol

Table 2. Odds of Receiving a Blood Transfusion Determined by Multivariable Logistic Regression

Parameter	Odds Ratio (95% Confidence Interval)	P
Hypotensive (age-adjusted)	3.7 (1.3–10.0)	0.01
Glasgow coma score – motor < 6	11.0 (5.2–22.0)	<0.001
Abbreviated Injury Scale severity ≥ 3 – thorax	4.3 (2.0–9.0)	<0.001
Penetrating injury	17.0 (8.4–34.0)	<0.001
Intervention group: blood refrigerator	0.2 (0.01–4.7)	0.32

[†]Area under the ROC curve = 0.89, Hosmer-Lemeshow $P = 0.63$.

Table 3. Minutes from Patient Arrival until Blood Transfusion

Variable	Present		Absent		P
	Time	n	Time	n	
Hypotension (age-adjusted)	12 (5.8–20)	16	25 (10–37)	38	0.01
Tachycardia/bradycardia (age-adjusted)	19 (8.8–32)	26	20 (8.3–30)	28	0.82
Pre-hospital cardiopulmonary resuscitation	15 (6.5–22)	13	21 (9.5–36)	41	0.07
Glasgow coma scale – motor < 6	19 (8.0–26)	31	20 (9–37)	23	0.37
Abbreviated Injury Scale severity ≥ 3					
Head	22 (12–40)	25	14 (8–28)	29	0.08
Thorax	19 (7.3–31)	18	20 (9–32)	36	0.90
Abdomen	12 (9–27)	9	20 (8.5–33)	45	0.57
Extremities	25 (15–28)	8	18 (8–33)	46	0.43
Penetrating injury type	14 (6–22)	27	26 (12–39)	27	0.005
Attending level activation	16 (8.8–26)	38	29 (8.3–37)	16	0.25
Nighttime arrival	18 (8.8–28)	34	21 (8.3–40)	20	0.52
Weekend/federal holiday	21 (9–30)	19	19 (7–32)	35	0.62
Transfer	24 (10–39)	16	16 (8–29)	38	0.33
No prearrival notification	8.5 (5.8–29)	10	21 (11–33)	44	0.09

[†]Data presented as median with interquartile range.

is associated with shorter hospital and intensive care unit stay, fewer hospital acquired infections, and reduction in 24-hour and 30-day mortality.^{5,6} When blood arrival is delayed during massive transfusion protocol activation in adults, the odds of mortality is increased by 5%.⁵ This type of analysis has not been performed for injured children. In children, delaying blood transfusion by the initial administration of crystalloid did not decrease the need for blood transfusion but was associated with longer hospital and intensive care unit duration and increased mechanical ventilation days.^{8–10} In our study, we observed an 11-minute reduction in the time-to-blood administration. A trend toward lower mortality was observed, but no statistical significance can be attributed to the differences in mortality rates.

The location of blood product storage can influence the timeliness of blood administration in the ED and other settings.^{11–14} Several approaches have been used to increase the accessibility of blood products at the bedside, including the use of portable refrigerators containing blood products,¹³ storage of blood products at the site,^{11,12,14} tubing systems that transport blood products,¹¹ and “runners” to transport blood products.¹¹ At adult trauma centers, these methods decrease the time to blood administration to less than 10 minutes. Similar to these findings, relocating un-crossmatched blood storage to the ED reduced the time required for blood administration. The storage of blood at the delivery site may not be feasible in all settings because of infrequent blood use and the cost associated with the equipment and training required

to store blood products at remote sites.^{12,15} Because blood transfusion is less common after injury in children than adults, other blood product delivery methods have been used to avoid the costs associated with remote blood storage. The selection of the optimal strategy for making blood available should balance the beneficial impact of timely blood transfusion and the financial costs when transfusion need is less frequent.

The IV access didactic lecture and nursing education leader had no change in the time-to-blood administration. Although frequently used, passive educational strategies, such as didactic lectures or video modules, have variable success for quality improvement.¹⁶ Educational initiatives are optimal when a knowledge gap exists and requires frequent repetition for success. The Institute of Healthcare Improvement acknowledges education as common practice for healthcare improvement but that these initiatives have a high failure rate or low reliability.¹⁶ In our study, the educational initiative may not have an impact for several reasons, including the design, mode of delivery, and additional workload proposed by the educational lecture. Project designs that increase the bedside provider’s complexity of work or add additional workload onto an already busy environment are unsustainable.^{17–20} Improving the available assets and resources to design a “work-smarter, not harder” intervention may increase the initial and sustained success of the intervention.

Our study has several limitations. First, this study was performed at a single pediatric trauma center. Validation

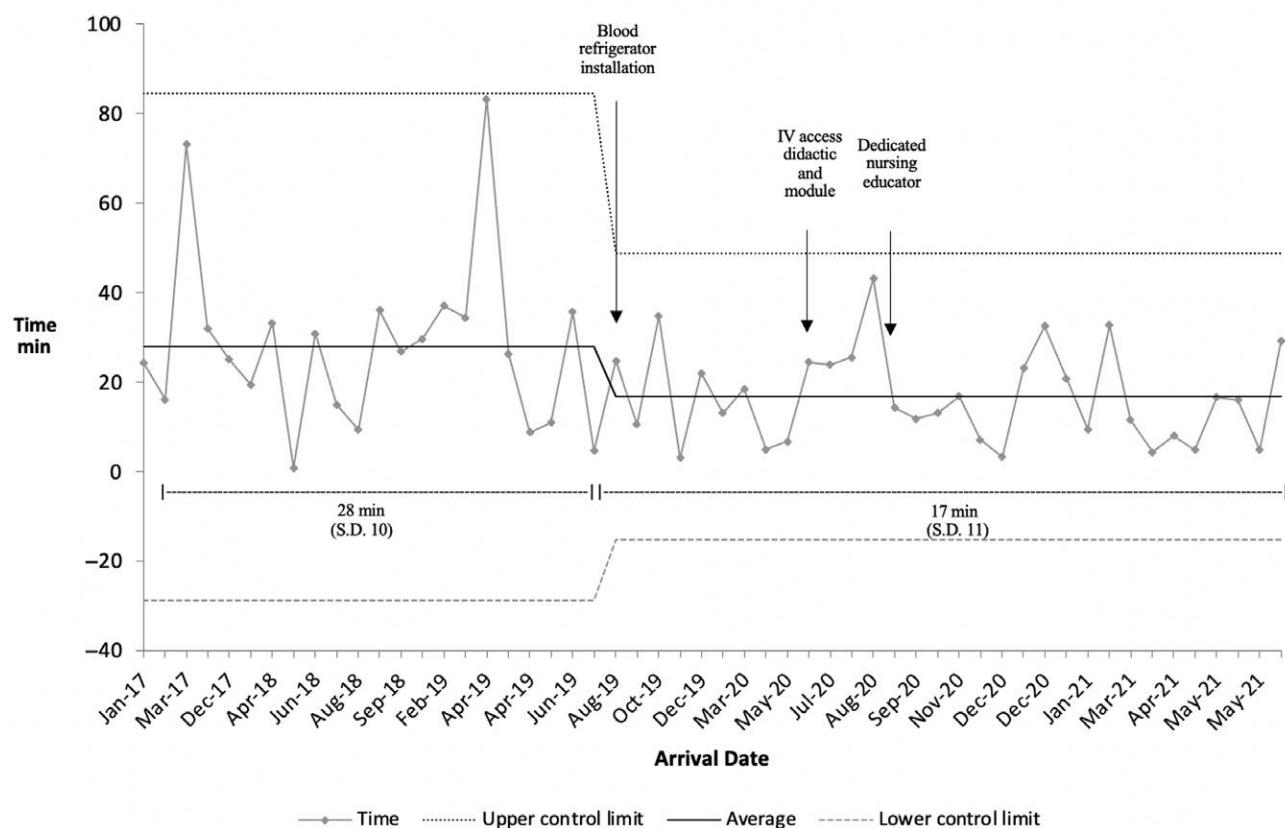


Fig. 3. X-bar chart: adjusted time from patient arrival until blood transfusion statistical process control chart. *Adjusted for hypotension, penetrating injuries, and severe injury to head.

of the impact of the interventions will require evaluation in other settings. Second, all patients activated as a trauma team response receiving blood in the ED were included. The decision to transfuse may have been related to needs other than injury-related hemorrhage, including hemorrhage secondary to bleeding disorders or medical disease. Third, the reasons for delays were identified in 2 independent video reviews and shown using a Pareto chart and key-aim-driver diagram. Other tools may identify additional delays and areas of improvement, including a Failure Modes and Effects Analysis. Fourth, this study had a small sample size of transfused patients. A larger population of transfused patients will be necessary to validate our results. Fifth, continuing video review shows that provider indecisiveness continues to contribute to delays in blood transfusion. Although we did not address this issue in the current study, our next interventions will include strategies aiding clinicians in assessing the hemorrhage risk of individual patients. Finally, our outcome data were limited to 6-hour mortality and did not account for other demographic, physiological, injury, and resuscitative factors. A much larger population of transfused patients would be needed to establish a statistically significant difference in mortality.

Hemorrhagic shock is challenging to identify in injured children. Prompt recognition and interventions

are needed to treat hemorrhagic shock and ultimately to improve mortality, decrease hospital length of stay, ventilator days, ventilator associated pneumonia, severe sepsis, multi-organ system failure, and abdominal compartment syndrome. This study shows that relocating the storage of blood products to the ED decreases the time-to-blood from patient arrival to transfusion.

DISCLOSURE

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