VARIABLES ASSOCIATED WITH THE RECEIPT OF BLOOD TRANSFUSIONS AMONG CRITICAL PEDIATRIC TRAUMA PATIENTS AT A SINGLE LEVEL 1 TRAUMA CENTER, HOUSTON, TEXAS - 2011 TO 2016

A Dissertation

by

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ABSTRACT

Massive blood loss due to trauma requires faster recognition and treatment using established protocols to prevent death. Currently, adult guidelines are used for pediatric patients. This is not an optimal approach due to differences in blood volume, physiology, and body weight between adults and children. The lack of consistency in the indicators used in hospital massive transfusion protocols must be addressed in order to improve treatment for critically injured pediatric trauma patients.

Cases of critical pediatric trauma patients (17 years and younger) from 2011 to 2016 were retrospectively analyzed from Memorial Hermann Texas Medical Center. Patients given blood products within 24 hours of injury were evaluated. Descriptive profiles were constructed through bivariate and means analysis that generated descriptive statistics for patient population explanation. Spearman correlations, Mann-Whitney tests, and Kruskal-Wallis tests were conducted to determine associations between demographic and clinical indicators and patient mean arterial pressures.

Of the 397 cases, critical pediatric trauma patients who received blood products in the prehospital or in-hospital environment were more likely to have been intubated (odds ratio = 1.61; 95% confidence interval: 1.04, 2.51); more likely to have lower mean arterial pressures (mean arterial pressure ≤ 59: odds ratio = 4.04; 95% confidence interval: 1.95, 8.37); more likely to have lower systolic blood pressures (systolic blood pressure ≤ 89: odds ratio = 3.69; 95% confidence interval: 2.02, 6.76); and more likely to have lower heart rates (heart rate ≤ 59: odds ratio = 5.12; 95% confidence interval: 1.67, 15.70) compared to patients not given blood products. Critical pediatric trauma patients who received prehospital blood products came directly from emergency scenes, were preteenagers, were more frequently intubated, and had lower heights, weights, mean arterial pressures, systolic blood pressures, and heart rates than critical pediatric trauma patients who received blood products in-hospital. Critical pediatric trauma patient mean arterial pressures showed a moderate overall correlation with age, weight, and height.

Profiled critical pediatric trauma patients show that mean arterial pressure, intubation, heart rate, height, weight, systolic blood pressure, and lack of severe head injury are associated with blood transfusion and prehospital blood transfusion. More research is needed to determine more appropriate factors associated with critical pediatric trauma patient massive transfusion protocol and prehospital treatment.

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NOMENCLATURE

ABC	Assessment of Blood Consumption
AIS	Abbreviated Injury Scale
ALB	Albumin
BD	Base Deficit
BP	Blood Pressure
bpm	Beats Per Minute
CI	Confidence Interval
CR	Crystalloid
CRYO	Cryoprecipitate
dL	Deciliter
ED	Emergency Department
EMS	Emergency Medical Services
FAST	Focused Assessment with Sonography in Trauma
FDP	Freeze-Dried Plasma
FFP	Fresh Frozen Plasma
g	Gram
GCS	Glasgow Coma Scale
HB	Hemoglobin
HCT	Hematocrit
HR	Heart Rate
ICC	Intraclass Correlation Coefficient

INR	International Normalized Ratio
IQR	Interquartile Range
IRB	Institutional Review Board
ISS	Injury Severity Score
kg	Kilogram
LL	Lactic Acid Level
LOS	Length of Stay
MAP	Mean Arterial Pressure
MHLF	Memorial Hermann Life Flight
MHTMC	Memorial Hermann Texas Medical Center
mL	Milliliter
mmHg	Millimeters of Mercury
MOI	Mechanism of Injury
MT	Massive Transfusion
MTP	Massive Transfusion Protocol
OR	Odds Ratio
PBGA	Point-of-Care Blood Gas Analysis
PLM	Plasma
PLT	Platelet
PRBC	Packed Red Blood Cell
PT	Prothrombin Time
PTT	Partial Thromboplastin Time
RISC	Revised Injury Severity Classification

RR	Respiratory Rate
SBGS	Serial Blood Gas Samples
SBP	Systolic Blood Pressure
SD	Standard Deviation
SHI	Severe Head Injury
TASH	Trauma-Associated Severe Hemorrhage
TBV	Total Blood Volume
TEG	Thromboelastography
THR	Thrombin
TRISS	Trauma and Injury Severity Score
TXA	Tranexamic Acid

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

Page

CHAPTER I

PREHOSPITAL BLOOD TRANSFUSION IN CRITICAL PEDIATRIC TRAUMA PATIENTS: INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Pediatric Trauma Background

Emergency medical services (EMS) and hospital systems respond to trauma and provide medical services to trauma patients outside and inside the hospital in both rural and urban environments. The internal and external signs of massive blood loss due to trauma require fast recognition and treatment using established protocols to prevent death.[1, 2] For severely injured pediatric trauma patients, providing blood transfusion and massive transfusion (MT) may improve outcomes.[3, 4] There is increasing interest in identifying pediatric-specific protocols and guidelines to treat critically injured pediatric patients requiring blood transfusion, but there is a discrepancy among protocols and appropriate timing for a blood transfusion or MT in these patients.[5–9]

Research on both military and civilian populations has led to the development of several blood transfusion standards for adult patients. [9–11] Adult MT standards include replacing more than 50% of total blood volume (TBV) in a 3-hour period or an entire blood volume in 24 hours.[4, 12, 13] Blood transfusions have been designated as MTs when 10+ units of packed red blood cells (PRBCs) are given to a patient in a 24-hour period.[4, 12, 13] In pediatric patients, standards include replacing more than 50% TBV within 3 hours.[4, 12, 13] MT for pediatric patients is considered receiving more than 100% TBV within 24 hours or ongoing blood replacement at 10% TBV/min for active bleeding.[4, 12, 13] Because of different physiologies between adult and pediatric patients, though, blood transfusions should be completed based on weight and type of blood product used.[14–17]

The United States military has developed new standards for pediatric MT.[10, 14, 17] These include replacement of 1 TBV, or 10 mL/kg intervals of blood products, in a pediatric patient under 40 kg, as well as closer to a unit of blood for pediatric patients weighing 40+ kg.[3, 7, 10, 14,18, 19]Additionally, protocol suggests replacing PRBCs in 4-mL/kg increments to increase pediatric hemoglobin (HB) by 1 g/dL with transfusion as needed (or a total of 40 mL/kg within 24 hours).[7, 10] Research has focused on the efficacy, safety, and timing of MT in adult populations, leading to advances in protocols.[4, 8, 20–24] However, studies in pediatric patients are limited primarily to those conducted by the United States military.[10, 17, 20, 21]

Currently, MTs are recommended for severe hemorrhage cases, and studies show that earlier administration of MT may lead to better prognosis.[3, 5, 11, 23, 25] MTs are given in a variety of environments, such as the hospital emergency department (ED), intensive care unit, operating room, and before or after surgery. [13, 18, 26, 27] MTs can be provided immediately upon arrival at a hospital or in the surgical environment.[4, 23, 28] Blood transfusions vary in quantity, amount, and product type (PRBCs, fresh frozen plasma [FFP], and platelets [PLTs]) in both the prehospital and hospital settings.[5, 11, 13, 18, 26–28] The prehospital environment includes emergency scenes, ambulances, helicopters, initial entry to the ED, and the time when initial vitals are taken in the ED. Gaps in the current literature surround the appropriate indicators of MTs in pediatric patients, as well as the appropriate timing to administer blood products to pediatric patients (prehospital versus hospital).[2, 3, 5, 11, 22]

Many hospitals have adopted modified versions of adult MT protocols to improve pediatric outcomes and reduce the number of missed cases.[1, 2, 22] The desire to improve MT protocols in the hospital environment has led to adult studies in the prehospital environment, though. Unfortunately, blood product quantities, timing, and ratios used for adult procedures and protocols may not translate to pediatric trauma patients.[9, 11, 16, 20, 23, 25, 29–31] According to a pediatric blood transfusion study, adult-based MT protocol activation criteria do not work in children and place them at further risk for unfavorable outcomes.[29] Children have smaller veins, lower TBVs, lower body weights, shorter heights, and different vital sign ranges.[3, 12, 13, 16, 29] Furthermore, pediatric trauma patients have inadequate HB and hematocrit (HCT) level measurements.[8, 29] Clinical parameters like blood pressure (BP) and heart rate (HR), along with laboratory results and demographics, may more accurately assist in developing transfusion protocols for pediatric patients.[8, 29] A lack of pediatric-specific protocols leaves ambiguity regarding the factors associated with blood product reception for pediatric trauma patients—additional research is needed in this area.[5, 9, 32, 33]

Pediatric trauma blood transfusion literature contains only a few published studies. Most available research focuses on a specific trauma or injury type.[9, 12] Another significant focus area is timing, complications, efficacy, efficiency, and subsequent outcomes of in-hospital blood transfusions.[9, 12] Studies do exist on using adult blood transfusion protocols in pediatrics for nontrauma patients such as surgery.[3, 5, 9, 12] The purpose of this literature review is to determine if prehospital blood transfusion influences pediatric trauma patient outcomes.

METHODS

A title search was performed in the Academic Search Complete databases, which include JovE Medicine, Access Emergency Medicine, Access Pediatrics, Access Medicine, McGraw-Hill Medical, ProQuest Central, Springer Link, Springer Protocol, ERIC EBSCO, EBSCOhost, National Library of Medicine Catalog, PubMed, Medline Ovid, Medline ProQuest, PubMed

Central, PubMed Health, and Medline Complete. Key terms were entered separately and jointly and included “prehospital,” “pediatric,” “trauma,” “blood,” and “transfusion.” This search recovered 4,846 publications within the past 30 years (1987 to 2017). The words “pediatric,” “trauma,” and “transfusion” were required to be in the title of the manuscripts assessed for relevance, leading to the exclusion of 2,106 articles.

The limits of “articles” and “pediatrics” were placed in the Springer Link database to ensure peer-reviewed and full-text articles found were within the pediatric scope. Other limits imposed for other databases included a 30-year interval, “full-text articles,” and “prehospital,” available in some databases such as Medline Complete. When these limits were introduced, results were reduced to 638. The medical subject headings “blood,” “massive,” and “prehospital” were also searched and subsequently combined with “transfusion,” while the medical subject heading field was also searched and eventually combined with “pediatric trauma” or the entire phrase to find other potentially relevant manuscripts. After the initial limits were imposed, bibliographies were considered, consolidation of articles was completed, and duplicates were removed.

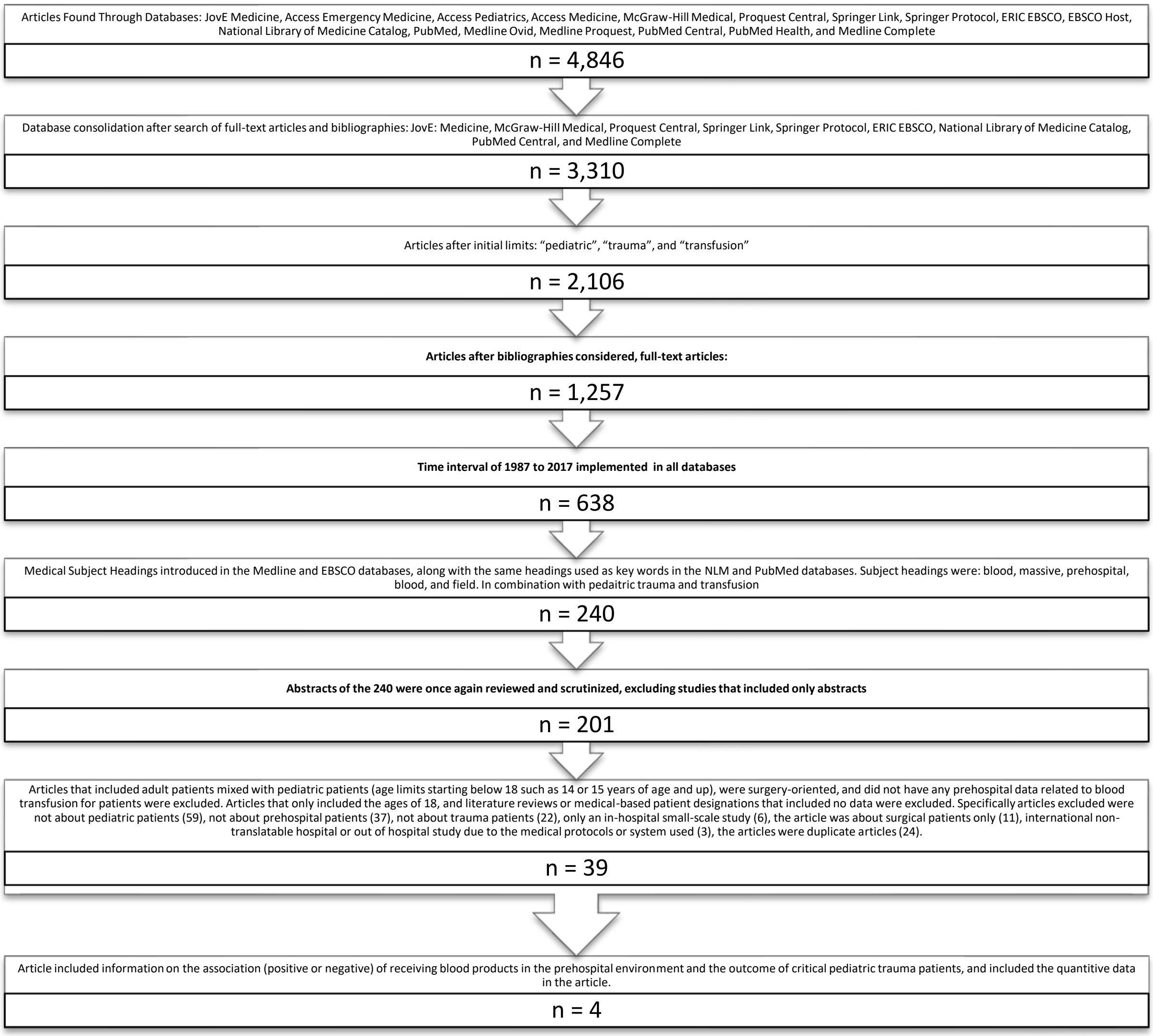
The titles and abstracts of 240 articles relevant to pediatric blood transfusion were reviewed. Articles were excluded that included adult patients mixed with pediatric patients, that were surgery-oriented, and that did not have any prehospital data related to blood transfusion. Also excluded were abstracts only, those including only patients aged 18+, and literature reviews or medical-based patient designations without data (n = 162). The full-text articles were reviewed and scrutinized for the location of blood product receipt. They were also searched for outcomes reporting the effect of blood product receipt.

Thirty-nine full-text articles met the aforementioned criteria and were then assessed and reviewed for eligibility based on the study aim surrounding prehospital blood products being given to critical pediatric trauma patients. A manuscript was found to be relevant and of possible value if it included information on the association (positive or negative) of receiving blood products in the prehospital environment and the outcome of critical pediatric trauma patients. Articles were organized into subheadings related to the different aspects of patient outcomes, including term of impact (long-term, short-term, acute, chronic), type of blood product used (PRBCs, FFP, PLTs, whole blood, albumin [ALB] concentrates, cryoprecipitate concentrates, thrombin [THR] concentrates, freeze-dried plasma [FDP], n = 31), influence of blood products on patient vital signs (positive or negative, n = 19), and other events potentially influencing transfusion decisions and other items evaluated separately by each study (e.g., laboratory results for low HCT and HB, internal gastrointestinal bleeds, sickle cell disease, chronic hypovolemia, kidney failure, liver failure, aneurysms, n = 27).

Four articles were found to meet all search criteria. These four studies were the only articles addressing the treatment of critical pediatric trauma patients given blood transfusions in emergent prehospital environments. The other 35 articles were excluded for several reasons. Even though they did involve blood transfusion in pediatrics, some articles had other medical diagnoses, urgencies, and environments for transfusion. Some were simply literature reviews without data or results to report, and others contained information about patients with only burns. Neonatal patient studies were excluded at this step, as well as those on patients given blood transfusions after ED evaluation and clinical impression during hospital care.

Likewise, articles were removed that didn’t have a pediatric basis or in which the transfusions were administered in non-ED departments. There were articles about medically diagnosed patients, surgical patients, pre-operation patients, post-operation patients, and adult trauma patients. International patients treated with medical system parameters not similar to what is currently used in the United States were excluded as well. This effort led to the review being narrowed to the four selected articles. Of the four studies, one was a military operation case study, and the remaining three were civilian in the prehospital/hospital setting, including a study from another country with similar parameters to the United States. The search process and study selection are summarized in Figure 1.

Figure 1. PRISMA 2009 flow table



RESULTS

The studies analyzed were comparative studies (one prospective case study, three retrospective cohort studies) looking at patients who received prehospital blood products in various capacities. The case study considered a pediatric trauma patient treated by military personnel in a remote combat zone. The other three considered civilian pediatric trauma patients taken from trauma registries and hospital databases that were created by adding multiple years together for a larger patient sample size. The included articles had information that either compared pediatric patients receiving prehospital transfusion or hospital transfusion upon initial arrival to the hospital. These articles also detailed patient outcomes as they were affected by the transfusions considering where those transfusions were given. No blinded, large prospective civilian studies, or randomized studies were identified; other than one prospective military case study, all were retrospective observational studies.

Study Design and Parameters

A military case study that was reviewed included a 13-year-old treated with FDP and so cannot be generalized to any other population.[21] The patient was treated with blood products in the prehospital environment (prior to transfer to a host-nation hospital) for multiple penetrating traumas with explosion exposure and open fractures by coalition forces.[21] FDP was used, which is not widely applied in the prehospital or hospital setting for blood transfusion. The patient was given 1 g of tranexamic acid in 500 mL of lactated ringer fluid through a peripheral intravenous line, but because of complications establishing another intravenous line, an intraosseous catheter was established to apply the FDP.[21]

The case study reported both a survival outcome and a long-term benefit subsequent to blood product receipt in the field. Once stabilized, the patient was transferred by a military medical team to a host-nation medical facility for further treatment. The patient ultimately recovered and went home three weeks later without major deficits and with a positive prognosis.[21] The study showed that FDP can be effectively and efficiently used in prehospital pediatric trauma patients through the intraosseous route (Table 1). However, no further conclusions can be made because the patient was lost for follow-up, as all civilian casualties in the combat zone of Afghanistan have to be stabilized and transferred to a host-nation facility.[21, 31]

Limitations of the case study include the treatment of just one 13-year-old patient, a factor that could introduce measurement and reporting biases. And although FDP is being used more and more to explore logistical and storage problems, it is not representative of blood products used in normal military, adult, or pediatric trauma blood transfusion operations.[10, 14, 20, 21] PRBCs and FFP, or even whole blood products, are used more commonly than FDP.[10, 20] The intraosseous administration route is also not well-studied or normally used in pediatric blood transfusion, again introducing the potential for measurement bias.[10, 14] Intravenous catheters are commonly used for fluid or blood application, and there are no other reports of prehospital blood administration in pediatrics through intraosseous catheter.[14, 21]

Table 1. Length of Stay (LOS) for Pediatric Patients Receiving Blood Products in the Prehospital Environment

Study	Sample Size	Blood Product Receipt Location	Type of Blood Product	Used Fluids in Addition to Blood Products	Population Age Range	Study Design	Average LOS (days)	Outcome/ Conclusion
Fahy et al. 2017	16 of 28	Prehospital in route	PRBC, Plasma (PLM)	Saline	1–18	Retrospective cohort	13.4	It is safe to give pediatric patients blood transfusions in the prehospital environment.
Hussmann et al. 2012	62	Prehospital (upon arrival)	PRBC, THR concentrate	Saline	1–15	Retrospective matched case control	28.45	Patients who receive high amounts of fluids for resuscitation in the prehospital environment have longer LOS, higher mortality, and lower coagulation capabilities.
Potter et al. 2015	16	Prehospital in route	PRBC, PLM	Saline	1–18	Retrospective cohort	9.3	Patients showed improved outcomes with three patients surviving unexpectedly. Hemoglobin levels rose, and acidosis decreased in patients who received prehospital blood products.
Rottenstreich et al. 2015*	1	Prehospital (military outpost stabilization before foreign-host hospitalization)	FDP	Lactated ringer	13	Military case study	21	Patient was stabilized and transferred to a host nation hospital. She was released home with a good prognosis three weeks later.

*Low sample size due to case study, no conclusions can be made

A prehospital retrospective study conducted in 2012 evaluated pediatric trauma patients aged 1 to 15 years old from hospitals in Germany and Austria. The hospitals voluntarily participated in the study, introducing selection bias (volunteer, availability, and hospital-patient biases). Bias was further introduced by German and Austrian hospitals from European trauma centers collaborating (367) due to data availability, a strategy to minimize variation by hospital and rescue system in place across this region of Europe.[28] The study pooled its patients from 1993 to 2010, also introducing reporting, assignment, and information biases. Reporting bias may have occurred due to information needing to be collected and classified over a 17-year period and taking 2 years more to publish the findings.[28] Also, information bias and assignment bias may have occurred by automating the case selection system in 2002, leading to potential misclassification of patients.[28]

The study was a retrospective registry study with a sample of 62 patients split into two categories of 31 each. Patients were between the ages of 1 and 15 and had treatment initiated in the prehospital environment. The study combined PRBCs and crystalloid fluid (CR) in some cases and then stratified cases into high-volume and low-volume matched groups. The German study considered prehospital blood product administration as being given PRBCs on arrival at the emergency department or at the end of transport. This study highlighted the lack of clear recommendations and guidance on fluid resuscitation or blood transfusion for severely injured children in Germany.[5, 12, 28, 29]

The study wanted to explore crystalloid and colloid (blood product) amounts received by prehospital pediatric trauma patients to assess patient outcome effects. To accomplish this, it focused on high-volume and low-volume prehospital fluid resuscitation groups.[28] Medical records data were used from the Trauma Register DGU of the German Trauma Society.

Differences between the low-volume and high-volume groups were analyzed with the McNemar test for dichotomous variables. The Wilcoxon sign-rank test was used to analyze ordinal categorical variables or non-normal continuous variables. A paired t-test was applied to analyze continuous variables. Results were presented descriptively with frequencies, percentages, means, and standard deviations (SDs).

The study accounted for confounders such as systolic blood pressure (SBP), abbreviated injury scale (AIS), HR, accident year, age, gender, trauma type, fluid type, respirations, chest tube placement, and prehospital intubation. Overall, the results showed that high amounts of prehospital fluid resuscitation led to increased patient mortality (low-volume group 19.4%, high-volume group 25.8%). Results also showed a worse long-term outcome, with higher probabilities of death (low-volume group 22.8%, high-volume group 29.4%). Authors also found a decrease in coagulopathy in patients receiving higher prehospital fluid totals (low-volume group prothrombin time [PT] 42.2 sec [SD 16.3], high-volume group PT 50.1 sec [SD 34.4]).

Findings further showed that patients in the high-volume group needed more units of blood (over 10 units on average) and THR concentrations (16.1%, or 3.2% more) during further treatment in the hospital setting compared to patients in the low-volume group.[28] Hospital LOS was longer in the low-volume group (33.6 days) than in the high-volume group (23.3 days), and the number of ventilator-free days was similar for both groups (18.1 days for low-volume; 14.6 days for high-volume).[28] Assessment of additional clinical parameters were needed upon arrival at the hospital, including HB, base deficit (BD), trauma and injury severity score (TRISS), and revised injury severity classification (RISC).[28] PT and partial thromboplastin time (PTT) were used to examine the effects of the fluids and their volumes on patient injury and status.[28]

This study had limitations in that measurement bias may have been introduced in a number of ways. There was documented use of adult resuscitation protocols in pediatric patients, and fluid and blood product resuscitation was seen as possibly too aggressive for pediatric patients.[16, 28, 29] Prehospital blood product administration was regarded as the receipt of PRBCs upon arrival to the ED (or the end of transport), and blood products were administered only after CR administration.[28] In addition, the protocol used this study did not have a fluid threshold like other protocols used to implement a blood transfusion (Table 2). Hospital indicators and procedures such as AIS, chest tube placement, and fluid type were used to evaluate pediatric outcomes, further introducing potential measurement bias.

Table 2. Strengths and Limitations by Study

Study	Strengths	Limitations
Fahy et al. 2017	Administration of prehospital blood products was found to be safe and efficient. There was an 80% survival probability after blood product administration in the prehospital environment. Lower LOS was found in patients given blood products in the prehospital setting. The study accounted for BD, HR, SBP, weight, lactate values, HCT level, HB level, international normalized ratio (INR), StO2, injury severity score (ISS), gender, and age.	Sample size of 16. Hospital indicators were used in the prehospital determination of blood product need. Patients were only transported by the hospital's helicopter service. Two types of blood products were carried by the helicopter. Hospital (nontrauma) protocols were used to determine blood product administration and need in traumatic pediatric patients. This was a single-center study and is nongeneralizable. The patient was only treated with hospital pediatric blood product administration protocols if under 40 kg. CRs were always given first per protocol in two 20 mL/kg boluses before blood product administration. PLM was the first blood product for administration, not PRBCs like other hospitals and services. Only PRBCs and PLM were evaluated.
Hussmann et al. 2012	The study explored the use of high and low volumes of fluid resuscitation in prehospital pediatric trauma patients. It was descriptive of patients in each category assessed. The study found that lower fluid resuscitations in the prehospital setting led to shorter LOSs. Increased mortality was found in the high-volume group. Coagulation was also found to be longer in higher-volume patients. Worse long-term outcomes and higher probabilities of death were found in the high-volume group. The study accounted for BP, AIS, HR, accident year, age, gender, trauma type, fluid type, respirations, chest tube placement, and prehospital intubation.	Sample size of 62 with 31 stratified by high- and low-volume groups. Adult resuscitation protocols were used in pediatric stabilization. CRs had to be administered per protocol before any blood products. Only PRBCs were evaluated. Receipt of blood was only applied upon arrival at the hospital. Hospital indicators were used for prehospital blood product administration.

Table 2 (continued)

Study	Strengths	Limitations
Potter et al. 2015	Exploration of the administration of two types of blood product in the prehospital setting. Improved HB level and LOS were noted in patients administered prehospital blood products. Patients also had a 75% predicted survival when administered prehospital blood products. The study accounted for mechanism of injury (MOI), transport time, sex, age, ISS, units of blood given, HB level, and indications of blood transfusion.	Sample size of 16. Only PLM and PRBCs were evaluated. CRs had to be given first per protocol for age-unspecified patients. The study was a single-center, single-helicopter-service study. Patients were only transported by the hospital's helicopter service. PLM was used first unless PRBCs were initiated by medical control of the previous facility. Medical control had to be contacted for PRBC administration. The study used an i-STAT device to evaluate hospital indicators such as lactic acid level (LL) and HB. CRs were always given first per protocol in two 20-mL/kg boluses before blood product administration. Prehospital protocol was developed, but not for pediatric patients specifically like adults.
Rottenstreich et al. 2015	Exploration of FDP. Positive stabilization results with FDP. Displayed success with blood product administration through intraosseous catheter administration.	Sample size of one. Patient was transferred after stabilization. Only PLM was evaluated. Use of a form of PLM that isn't widely used. The patient's blood products were not infused through intravenous catheter like other studies. Adult protocols were used for pediatric stabilization. Tranexamic acid (TXA) in 500 mL of lactated ringer fluid was administered, in addition to the FDP, which is not always used in penetrating traumas.

A pediatric prehospital retrospective study analyzed pediatric trauma patients aged 18 and under from a single regional academic medical center. The study analyzed patients from 2002 to 2014 with a sample size of 16 trauma patients and 12 nontrauma patients. Patient data were gathered from hospital registries and charting systems. The study used PRBC and/or FFP fluids with the goal of assessing the safety and efficacy of prehospital blood transfusion protocol. The helicopter team transporting patients carried three units of PRBC and three units of FFP blood products.[3] Analyses were performed using a two-sample t-test for continuous variables and Fisher's exact test for categorical variables.

The study accounted for confounders such as BD, HR, SBP, weight, lactate value, HCT level, HB level, INR, StO2, ISS, gender, and age. Results showed that most children needed further blood products during hospitalization or operative procedures after the initial prehospital blood product administration.[3] Trauma patients were more likely to need operative interventions (68.7%) and had a lower LOS (13.4 days) as compared to nontrauma patients. Pediatric trauma patients who received prehospital blood products held an 80% survival probability.[3] Additional clinical parameters such as LL, HB value, INR, and thromboelastography (TEG) were considered upon arrival at the hospital to determine further blood product administration (Table 3). The study concluded prehospital transfusions to be safe and efficiently effective in pediatric trauma patients, and more research is needed to determine improvement in overall outcomes.

As a limitation to this study, selection bias may have been be introduced because patients only came from the facility's helicopter service and no other prehospital services or units. Also, this study combined results of both trauma and nontrauma patients, introducing selection and measurement biases. The helicopter always had blood products and the means to administer them, which further limits the study. Measurement bias may have also been introduced because the two types of blood products were administered by the facility's designated in-hospital protocol.[3] Moreover, BD, LL, HCT, HB, and INR are not available for patients treated by every helicopter service, hospital, or EMS jurisdiction, making the results of this study nongeneralizable.[5, 11, 12, 31] Furthermore, CRs were given first in pediatric patients under age 14 before blood products could be administered per facility protocol.[3] Protocol also dictated that patients only be treated with in-hospital pediatric blood products if under 40 kg; over 40 kg, patients were treated using adult protocol.[3] The protocol also specified that PLM be given to patients before PRBC in the event of need, introducing measurement bias.[3, 11, 34]

Table 3. Additional Tests and Assessments Needed Upon Arrival at the Hospital Following Prehospital-Initiated Blood Transfusion

Procedures, Tests, and Labs	Fahy et al. 2017	Hussmann et al. 2012	Potter et al. 2015	Rottenstreich et al. 2015
ISS	X	X	X	X
INR	X		X	X
HR	X	X	X	X
Respiratory Rate (RR)	X	X	X	X
PT	X	X		
PTT	X	X		
HB	X	X	X	X
BD		X	X	
TRISS		X	X	
RISC		X		
SBP	X	X	X	X
LL	X		X	
TEG	X			
Point-of-Care Blood Gas Analysis (PBGA)			X	
Specific AIS				X
Serial Blood Gas Sample (SBGS)			X	
HCT	X			

Another prehospital retrospective study analyzed 16 pediatric trauma patients aged 18 and under from a single regional academic medical center and its helicopter service. The study looked only at patients flown to this facility from January 1, 2003 to December 31, 2012.[5] Data were gathered from trauma and flight registries. The study compared the administration of the two types of blood carried on the helicopter (type-O PRBCs and A+/A– FFP) using a prehospital transfusion protocol developed at the facility.[5] No other literature mentioned the use of a prehospital-specific blood transfusion protocol like the one developed for this study.[3, 5, 12, 21, 28] After accounting for MOI, transport time, sex, age, ISS, units of blood given, HB level, and blood transfusion indicators, the study found improved HB levels (from 9.4 to 11.1 mg/dL) and overall outcomes in patients given blood products (75% survival probability).[5] Patient LOS was also shorter than all other studies evaluated (9.3 days).[5]

Limitations in this study included selection bias based on only evaluating PRBC and PLM administration for patients in route to the facility by helicopter.[5] Patient sample size was also low: only 16 pediatric trauma patients receiving prehospital blood transfusions. This study has measurement bias because it is specific to the protocols used in the facility (making it not generalizable), no other literature exists to confirm the results, and protocol stated that PLM was to be used first before PRBCs in the event of prehospital blood transfusion implementation, which argues with other protocols around the country initiating PRBCs before or concurrently with PLM blood products.[11, 22, 25]

Similar to other mentioned studies, the protocol was not developed specifically for pediatric patients; this lack of pediatric-specific protocol also causes potential measurement bias.[3, 5, 12, 16, 28, 29] The study stated that, overall, if pediatric-specific indicators and protocols were available, they would be better than any adult protocol or facility-specific modification for pediatric patients.[7, 12, 13, 31] CRs were given first in age-unspecified pediatric patients before blood products could be administered per protocol of the facility.[5] However, this indication was for PRBCs specifically, with no specified indications for PLM given. Patients were given PRBCs based on provider judgement or other factors such as continued hemorrhage, anemia, anticoagulants, or the patient already being given PRBCs upon receipt.[5]

The indicators and vital signs used to determine pediatric blood transfusion in this study also differed from other studies. The study used an i-STAT device to gather LLs and HB values in the helicopter.[5] Other indicators considered were ISS, age, SBP, RR, and MOI/trauma type. If the patient's vitals were not responsive to CR fluid boluses, they were started on PLM. Measurements and predictions of survival came from the patient's TRISS, another element not used at other facilities—introducing measurement, selection, diagnostic, and reporting biases.[5, 28] Other hospitals use RISC, trauma-associated severe hemorrhage (TASH), and survival probability.[1–3, 5, 11, 22, 28]

DISCUSSION

This is the first literature review on the administration of blood products in a prehospital setting for pediatric trauma patients. Although research is limited, studies have focused on blood transfusion in the prehospital setting for pediatric patients and suggest that outcomes are improved when pediatric trauma patients are given prehospital blood products. Studies included in this review cannot be directly compared because of differences in definitions of prehospital blood transfusion. Similarly, protocols and indicators used in assessing and treating patients differed. Sample size was a major limitation, reducing the power of some studies. Several studies were unable to account for other variables, which may have confounded associations. Evidence for improved short-term survival is derived from four studies and may not translate to substantial long-term outcome improvement.

The military case study used a different method of blood product administration with intraosseous catheters versus venous catheters in the prehospital environment.[21] Definite conclusion cannot be made from this study; however, these exploratory interventions should be kept in mind because of their unique efficacy in trauma patients. Although extrapolation from this study is questionable, it was one of the first successful intraosseous blood transfusions with FDP documented in a pediatric patient. More research on this method of fluid and blood product administration in pediatric patients would be beneficial based on the success of this progressive case study.

An important variable to note is the use of FDP, which is not normally used in the civilian setting due to lack of access to type-AB FDP. Refrigeration units on helicopters and ambulances would be necessary in the civilian environment to support the transport of thawed plasma (FFP).[35] DP is used in military settings because refrigeration and cooling units to carry PRBCs or FFP are not available, and carrying FDP accommodates this need.[35] Moreover, FDP is carried in glass bottles and plastic bags that can withstand pressure.[35] Training is required for infusing blood products, recognizing adverse reactions, and trouble-shooting infusion issues due to high viscosity, which is different from normal blood products (PRBCs, FFP).[35] Furthermore, no literature exists to determine if using FDP in a civilian urban environment is possible or effective.[35]

The team in the case study carried FDP because it has few temperature and storage requirements and is being tested with troops to compare its effectiveness to normally used blood products.[21, 35] FDP could potentially be used in civilian prehospital blood product administration on ambulances because it can be kept at room temperature.[5, 21, 28] Currently, blood products are used when they are available on prehospital helicopters to replace massive blood loss and assist with the patient's ability to create blood cells of their own.[5, 11, 22, 25] Further research with FDP may have implications for standard-of-care practices in civilian populations because blood products could possibly be placed on all prehospital units. This is important because arguments against blood products for many ambulance EMS, especially ground EMS, involve difficulties with blood product storage and rotation.[8]

In the case study, 250 mL of FDP was paired with 1 g of tranexamic acid and 500 mL of lactated ringer fluids, per Israeli Defense Force protocol. This is not common practice in any prehospital emergency medical situation. Protocols used in the civilian setting call for TXA use in cases of penetrating trauma with the potential for massive blood loss and coagulopathy problems that received CRs in the field without the availability of blood products.[10, 21, 35] TXA and blood products can be used together; however, blood products are preferred as they assist in normalizing blood cell production.[8, 10, 12, 13, 18, 21, 31] TXA improves clotting factors by assisting in clot formation in a multiple penetrating trauma or a massive severe hemorrhage.[10] TXA is a short-term solution as opposed to blood products, which are a longer-term solution, so the military case study represents an unusual procedure on a more exploratory scale.[10, 21] Reproducing this case-study in a civilian population would be limited by hospital protocol.[3, 5] The patient success seen in this study by combining TXA and lactated ringer fluids may prove beneficial in the civilian arena with both adult and pediatric patients.[21, 31] Due to this successful discovery, this method warrants further research.

Current research has identified gaps in treatment methods for this field. Studies suggest a need for pediatric blood transfusion earlier in treatment, potentially in the prehospital environment.[3, 5, 8, 11, 25, 28] Each reviewed study used different protocols, including some that used modified versions of adult parameters; these inconsistencies introduce measurement, diagnosis, reporting, and selection biases, as well as confounders to outcome assessment. Patients and facilities were in different parts of the country, and patients were transported by unique means (facility helicopter), with advantages that are uncommon in ground EMS (blood products of any kind). Given the lack of protocols or guidelines for pediatric blood transfusion, further research is needed to inform clinicians about best practices—specifically, possible universal indicators and parameters for blood product administration.[3, 5, 12, 16, 28, 29]

Overall, studies reported reduced mortality, reduced hospital stay, reduced acidosis, and safe and efficient administration of prehospital blood products. The German study found that outcome benefits are specific to blood and fluid amount given in the prehospital environment.[28] Military studies have observed reduced mortality by administering blood products to a pediatric patient in the combat environment. The civilian studies examined all noted reduced mortality by administering blood products quickly and early, leading to decreased acidosis, decreased mortality, and established safety in the prehospital environment.[3, 5, 28]

It is important to acknowledge that military and civilian patients have different needs. The majority of studied civilian patients suffered blunt force trauma, which is more prevalent in pediatric patients than penetrating injuries, which are more common in adult patients.[3, 5, 12, 28] Thus, providers may not be adequately administering blood products to the majority of the patient population.[36] This points to measurement bias in the literature available because none of the protocols modified for pediatrics used blunt force trauma indicators when implementing blood transfusions; they used penetrating trauma indicators modified from adult protocols.

Consequently, a large number of children may be overlooked when using current blood transfusion protocols because they may not meet the criteria of having a penetrating trauma according to assessments of blood consumption, TASH, or McLaughlin.[2, 5, 7, 11, 12, 22, 28, 37] The absence of pediatric-specific indicators for trauma patients can result in obstructive complexity related to interpreting current protocols.[5] Methods for evaluating patient outcomes need to be standardized to avoid underestimation of the progress and influence of blood products in pediatric trauma patients.

Standardization for pediatric indicators would result in more consistent and accurate blood transfusion for these patients.[5] Prehospital blood transfusion protocols should also be present, as displayed in the pediatric prehospital helicopter study, to address the differences in equipment, environment, and presentation of patients needing blood transfusion.[5] Hospitals may benefit from a simple scoring system to activate blood transfusion in a pediatric patient for both prehospital and hospital settings. A scoring system would be a routine way to measure the efficacy and efficiency of blood transfusion using existing pediatric-specific indicators and ranges.[5, 12] However, further research is needed to establish pediatric-specific indicators and better understand outcomes and needs of blood transfusion in pediatric trauma patients.[5]

Current protocols for blood transfusion use adult parameters and indicators, but children (and different developmental stages) have different normal vital sign ranges.[38, 39] The civilian studies examined in this literature review focused on PRBC or FFP administration given the availability of storage methods on civilian prehospital helicopters and ambulances.[5, 11, 25, 28] The two prehospital studies using helicopter transport both reported on FFP and PRBC blood product administration, while the German study reported PRBC use. However, the only two blood products that can be carried on the prehospital apparatus at this time currently are PRBCs and

FFP.[5, 11, 25, 37] Therefore, limited knowledge can be gained on the impact of administering other blood products (PLTs, THR concentrations, and ALB concentrations) to pediatric trauma patients.

The sequence in which blood products were received was not equivalent among the institutions treating pediatric patients.[3, 5, 11, 12, 25, 37] Institutions tend to start with PRBCs, unless FFP is warranted by specified indicators or has already been initiated upon arrival of the transport mode.[11, 12, 25, 28] Nevertheless, the civilian studies examined in this literature review concluded administration to be safe and beneficial in pediatric patients, regardless of the cause of the trauma.[3, 5, 28] The limited literature in this area reveals that excessive administration occurs because of adult protocol usage.[16, 28, 29] Further research should consider the volume of blood products given to children (to expand on the findings of the German study) to verify efficiency. This may produce limitations that have yet to be addressed but that can only be explored upon investigation.[5, 11, 25]

LIMITATIONS

The literature review was limited to 30 years (1987 to 2017). However, only studies published in the last six years addressed prehospital administration of blood products to pediatric patients. The number of results returned was small from which to draw conclusions, even though the search included all major citation databases for medicine and public health, specialist books, and reference lists from included studies and was not limited by language. Statistical synthesis such as meta-analysis was not possible due to the limited amount of statistical data provided in the studies and the small sample sizes. Therefore, this review can provide at best only a preliminary indication of the need to better understand the disposition and overall mortality of pediatric trauma patients receiving prehospital blood products. The significant weakness represented by low quantity of studies and data reflects a gap in understanding pediatric trauma in patients under age 15.

The inclusion of a military case study in this review demonstrates lack of specified prehospital pediatric trauma blood product resuscitation literature. The military case study was an exploratory study and conclusions are not possible to be drawn from it at this time. However, multiple military studies to include the case study in this literature review display factors and evidence, even if tenuous, that must be included when interpreting the existing literature.[10, 14, 21, 31] Furthermore, the exploratory nature of the case study may have standard-of-care implications in civilian populations. The parameters for the three civilian studies varied, as did the adult indicators used to determine the need for more fluid in the treatment period. Heterogeneity assessment was not possible because of the small effect size given by limited literature available for a meta-analysis. The protocols used in the civilian studies in this review continued to rely on administering boluses of CRs before administering blood products. This evidences that increased fluid may cause increased mortality and morbidity after a penetrating trauma.[40]

CONCLUSION

The questions of whether FDP should be used in civilian resuscitation efforts, as well as if these should be the automatically used products in all future massive transfusion protocols (MTPs), remain unanswered. It is possible that more focused, pediatric-specific indicators could be used to improve outcomes. Additionally, creating specific prehospital or hospital blood product protocols for pediatric patients could be warranted. Exploratory research, possibly identifying lactated ringer fluids as a possible benefit to pediatric patients requires further research and inquiry. The literature on prehospital pediatric trauma blood transfusion is limited but presents several avenues for further exploration that may contribute to evidence-based guidance.

More evidence of indicators in pediatric cases is required. Using a pediatric dataset from Memorial Hermann Texas Medical Center (MHTMC) in Houston, Texas, we analyzed specific demographic and clinical factors associated with MT receipt and patient outcomes. Chapter Two describes the demographic and clinical factors that create a profile of a pediatric trauma patient given a blood transfusion during treatment at MHTMC, as well as explores what parameters, factors, and aspects are involved with blood transfusion for these patients. Chapter Three assesses the variables associated with blood transfusion within the hospital setting in critical pediatric trauma patients between 2011 and 2016. Chapter Four assesses the variables in the prehospital setting versus the hospital setting during the same time period. This allows for comparison and possible aggregation of blood transfusion indicators for a pediatric trauma patient in the prehospital setting versus the hospital setting—leading to potential exploration of more specific treatment guidelines and protocols.

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CHAPTER II

VARIABLES ASSOCIATED WITH BLOOD TRANSFUSION AT MEMORIAL HERMANN HOSPITAL TEXAS MEDICAL CENTER AMONG CRITICAL PEDIATRIC TRAUMA PATIENTS, 2011 TO 2016

INTRODUCTION

Massive blood loss due to trauma requires rapid recognition and treatment using established protocols to prevent death. Research in both military and civilian populations has led to the development and subsequent improvement of blood transfusion protocols for adult patients.[1–4] However, adult procedures and protocols for MT may not adequately address the needs of pediatric trauma patients.[5–8] In the absence of pediatric protocols, the implementation of MT in the prehospital environmental remains ambiguous.[6, 8]

There are several definitions for MT in medical literature that cover both adult and pediatric patients. For adults, MT is characterized as blood volume replacement of more than 50% of TBV in a three-hour period or the replacement of a TBV (1 L of blood) in 24 hours.[4, 9] In pediatrics, MT is characterized by either of the adult definitions or by the transfusion of greater than four units of PRBCs in one hour.[1, 4, 9] The United States military has been establishing new and more widely accepted standards for pediatric MT that replace TBVs based on a 10-mL/kg interval for patients under 40 kg and closer to a unit of blood for pediatric patients weighing 40 kg or greater.[2, 10–12]

Current MT implementation for pediatric patients typically uses adult protocols and guidelines, but the impact of this usage on the pediatric trauma patient population is unknown.[1, 7] Using adult guidelines for children may result in suboptimal patient outcomes due to differences in blood volume, physiology, and body weight.[4, 6] Adult protocols may also provide inadequate guidance related to HB and HCT level measurements in pediatric patients.[1, 6] Other clinical parameters like BP, HR, and laboratory results should be considered when deciding to implement blood transfusions in a pediatric patient.[1, 6] Additional research is needed on the use of MT in the prehospital environment among pediatric trauma patients.

In a literature review conducted on pediatric trauma and the receipt of blood products in the prehospital setting, only four studies were found, and no universal methods or indicators were identified specifically directing the activation of an MTP or blood transfusion in pediatric trauma.[1, 7] In the limited literature, the most utilized indicators for pediatric transfusion included ISS or AIS, SBP, HR, focused assessment with sonography in trauma (FAST), BD, INR, LL, PT, PTT, and other factors differing by hospital or prehospital service.[10, 13–15] The lack of consistency in the indicators used must be addressed to improve treatment of pediatric trauma patients in both the prehospital and hospital environments. To our knowledge, no study has adequately defined the pediatric population that receives blood products in the prehospital or hospital setting, nor is the subsequent impact on patient outcomes well understood.

Because few studies have explored the administration of blood products to critical pediatric trauma patients in the prehospital setting, we have little knowledge about the clinical and demographic factors that may be associated with the decision to administer blood products, as well as the type of blood products received.[16] Using a dataset of pediatric trauma patients receiving care at MHTMC in Houston, Texas, we describe and assess bivariate and crude association between demographic and clinical characteristics of critical pediatric trauma patients and receipt of blood products.

METHODS

Data Sources and Study Population

The dataset included pediatric trauma patients treated at MHTMC, an urban Level I trauma center with the highest volume of trauma patients in the Houston metropolitan area. All critically injured pediatric trauma patients aged 17 and under who were transported by either helicopter or ground ambulance to MHTMC between January 1, 2011 and December 31, 2016 were eligible for inclusion in the dataset. Patients of a critical classification were identified through vital signs, MOI, age, height, weight, blood loss, electronic reporting chart and narrative, and method of transport.

The study included 210 of 397 (53%) patients transported by the MHTMC EMS helicopter service, Memorial Hermann Life Flight (MHLF). MHLF is a large hospital-based helicopter EMS service managed and maintained by the MHTMC trauma and surgery services department. The service usually accounts for approximately 53% of the region’s critical pediatric trauma patient transports. During the study period, MHLF was staffed by a paramedic/nurse team and carried two units of type-O-negative PRBCs and two units of FFP on each mission. All orders for administration of blood products were from the medical director and MHTMC surgery department based on adult assessment of blood consumption (ABC) evaluation. This study was reviewed by the University of Texas Health Science Center Institutional Review Board (IRB) (HSC-GEN-12-0476) and the Texas A&M University IRB (18-0073) and was determined to be exempt.

The dataset contained electronic inputs from the MHTMC trauma registry, the blood bank database, the MHLF flight registry, and MHLF medical records. Patients included in the dataset were identified through electronic hospital record query. Demographic variables included race, sex, ethnicity, age, weight, height, transfer from other facility (yes/no), transport type (ground ambulance/helicopter), and trauma type/MOI (blunt/penetrating). Clinical factors included patient intubation (yes/no), mean arterial pressure (MAP), SBP, HR, and identifiable severe head injury (SHI) (yes/no). Other clinical factors considered were fluid types given (CR, PRBCs, FFP, PLTs, cryoprecipitate [CRYO], serum ALB products, and THR products), FAST (positive/negative), and the completion of FAST (yes/no). FAST was only included as an exploratory inferential diagnostic variable due to missing data for this variable in more than 50% of the total records. However, FAST completion (yes/no) was included to assess if those who had the procedure were more likely to receive blood products.

Missing Data

A total of 397 patients were included in the analyzed dataset. Observations were excluded if they were missing data for any variable. The variables with missing values were weight (3), height (15), MAP (13), SBP (9), HR (8), ethnicity (4), transport type (2), LOS (1), and intubation (1). These observations were treated as missing when descriptive and bivariate analyses were performed for each respective variable to report complete cases.

Statistical Analysis

The primary outcome was the receipt of blood products by a critical pediatric trauma patient at any point in the treatment process. Descriptive analyses were conducted to calculate frequencies, medians, and ranges, as well as bivariate associations between demographic and clinical factors and the outcome variable of blood products being received or not. Bivariate analyses were performed using logistic regression for each demographic and clinical variable and the binary outcome of whether blood products were received. Crude odds ratios (ORs) and 95% confidence intervals (CIs) were estimated. CIs that did not include the null value of 1.0 were interpreted as indicating statistical significance. All data analysis was conducted in SAS 9.4 (Cary, NC).

RESULTS

Of 397 critical pediatric trauma patients identified, 63% (252 of 397) received blood products in the prehospital or hospital environment. Table 4 summarizes the demographic characteristics of the critical pediatric trauma patients treated at MHTMC. Of the treated patients, 66% (262 of 397) were male. The median age was 12 (interquartile range [IQR] 4 to 16), although nearly half were between 13 and 17 (47%; 188 of 397). Forty-percent (160 of 397) of patients were White, and 39% (153 of 397) identified as other, including Native American, Asian, Pacific Islander, Native Hispanic, and mixed race.

The majority of patients came directly from emergency scenes (70%; 278 of 397) as opposed to interfacility transfer. Average patient weight and height were consistent with an average 12-year-old child.[17] Nearly two-thirds of patients (63%; 252 of 397) were transported by helicopter to MHTMC, and four-fifths had blunt force trauma as the MOI (79%; 314 of 397). More than two-thirds of patients were given fluids in the hospital setting (69%; 272 of 397). Overall, 73% (288 of 397) of patients survived their injuries with the treatment received. Patients who expired held a median of 12 hours, 36 minutes before death (range: 54 minutes to 1 day, 10 hours, 55 minutes).

Table 4. Demographic Profile of Critical Pediatric Trauma Patients at MHTMC (n = 397)

Variable		
Sex		
	Male, n, (%)	262 (66)
	Female, n, (%)	135 (34)
Age, years, median, (IQR)		12 (4–16)
Age Group		
	Infant (0–1) years, n, (%)	37 (9)
	Toddler (1–4) years, n, (%)	68 (17)
	Child (5–9) years, n, (%)	69 (17)
	Preteenager (10–12) years, n, (%)	35 (9)
	Teenager (13–17) years, n, (%)	188 (47)
Weight, kg, median, (IQR)*		48 (20–68)
Height, cm, median, (IQR)†		152 (107–170)
Interfacility Transfer		
	Yes, n, (%)	119 (30)
	No, n, (%)	278 (70)
Race		
	White, n, (%)	160 (40)
	Black, n, (%)	84 (21)
	Other§, n, (%)	153 (39)
Ethnicity‡		
	Non-Hispanic, n, (%)	238 (60)
	Hispanic, n, (%)	155 (39)
Transport Type¶		
	Ground, n, (%)	143 (36)
	Helicopter, n, (%)	252 (63)
Fluid Location		
	Prehospital, n, (%)	125 (31)
	Hospital, n, (%)	272 (69)
Trauma Type/MOI		
	Blunt Force Trauma, n, (%)	314 (79)
	Penetrating Trauma, n, (%)	83 (21)
Outcome		
	Survival Over 24 hours, n, (%)	288 (73)
	Death Within 24 hours, n, (%)	109 (27)
	Time to Death, median, (IQR), (days: hours: minutes)	00:12:36 (00:00:54–01:10:55)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*missing 3, n = 394; †missing 15, n = 382; ‡missing 4, n = 393; §Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; ¶missing 2, n = 395

Shown in Table 5, the clinical characteristics of critical pediatric trauma patients included MAP (median: 79 mmHg [IQR 63 to 93]) and SBP (median:110 mmHg [IQR 85 to 128]). Almost three-quarters of all patients were intubated (70%; 277 of 396). Less than half were classified as having a severe head trauma (45%; 177 of 397) based on the AIS values assigned during treatment. The patients had a median ISS of 25 (IQR 16 to 33) after assessment, and 226 (57%) had FAST completed at some point during treatment. More than 60% of the FASTs were negative (63%; 143 of 226). Blood products were received by 252 of 397 (63%) critical pediatric trauma patients at some point during treatment. The most frequently used fluids were PRBC blood products (42%; 168 of 397) and CR fluids (37%; 145 of 397).

Table 5. Clinical Profile of Critical Pediatric Trauma Patients at MHTMC (n=397)

Variable		
MAP, mmHg, median, (IQR)*		79 (63–93)
SBP, mmHg, median, (IQR)†		110 (85–128)
HR, bpm, median, (IQR)‡		111 (88–138)
Intubation§		
	Yes, n, (%)	277 (70)
	No, n, (%)	119 (30)
SHI		
	Yes, n, (%)	177 (45)
	No, n, (%)	220 (55)
Blood Product Use		
	Yes, n, (%)	252 (63)
	No, n, (%)	145 (37)
FAST		
	Completed, n, (%)	226 (57)
	Positive¶, n, (%)	79 (35)
	Negative¶, n, (%)	147 (65)
	Not Completed, n, (%)	171 (43)
ISS, median, (IQR)		25 (16–33)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*missing 13, n = 384; †missing 9, n = 388; ‡missing 8, n = 389; §missing 1, n = 396; ¶close to 50% of FAST results were missing for assessment, and inconclusive results existed that were excluded, so the results are exploratory

The dataset included 252 patients who received treatment with blood products (prehospital or hospital) and 145 who were not given blood products during treatment (Table 6). Compared with males who received no blood products (65%; 94 of 145), there were more males who received blood products (67%; 169 of 239). The median age of the patients receiving blood products was only slightly higher than the overall median age (12.5; IQR 4 to 16). Teenagers (126 of 252) and Whites (98 of 252) received the largest number of blood transfusions. Approximately two-thirds of patients who received blood products came directly from emergency scenes (66%; 166 of 252), nearly four-fifths of patients who did not receive any blood products came directly from emergency scenes (77%; 112 of 145) as opposed to interfacility transfer.

Pediatric trauma patients who received blood products had a lower median MAP (75 mmHg; IQR 57 to 89) and a lower median SBP (105 mmHg; IQR 80 to 125) compared with those not receiving blood products (median MAP of 87 mmHg, IQR 72 to 98; median SBP of 118 mmHg, IQR 101 to 136) (Table 6). Patients who did not receive blood products had a higher median HR (113 bpm; IQR 90 to 138) than those receiving blood products (111 bpm; IQR 85 to 138). The percentage of patients intubated was higher in the group receiving blood products (74%; 186 of 252). Children with injuries classified as a severe head trauma made up about half of the patient population not receiving blood products (49%; 71 of 145), based on the AIS number assigned during treatment. PRBC was the most-used blood product for patients given blood products (67%; 168 of 252). These data are shown on Table 7.

Table 6. Demographic Profile of Critical Pediatric Trauma Patients at MHTMC Who Received Blood Products (n = 252) and Who Did Not (n = 145)

Variable	Blood Products n = 252	No Blood Products n = 145
Sex		
Male, n, (%)	169 (67)	94 (65)
Female, n, (%)	83 (34)	51 (35)
Age, years, median, (IQR)	12.5 (4–16)	11 (4–15)
Age Group		
Infant (0–1) years, n, (%)	26 (10)	11 (8)
Toddler (1–4) years, n, (%)	40 (16)	28 (19)
Child (5–9) years, n, (%)	39 (15)	30 (21)
Preteenager (10–12) years, n, (%)	21 (8)	14 (10)
Teenager (13–17) years, n, (%)	126 (50)	62 (43)
Weight, kg, median, (IQR)*	50 (19–68)	43 (20–64)
Height, cm, median, (IQR)†	155 (104–170)	152 (107–168)
Interfacility Transfer		
Yes, n, (%)	86 (34)	33 (23)
No, n, (%)	166 (66)	112 (77)
Race		
White	98 (39)	62 (43)
Black	57 (23)	27 (18)
‡Other	97 (38)	56 (39)
Ethnicity¶		
Non-Hispanic, n, (%)	152 (60)	90 (62)
Hispanic, n, (%)	100 (40)	55 (38)
Transport Type#		
Ground, n, (%)	93 (37)	51 (35)
Helicopter, n, (%)	159 (63)	94 (65)
Fluid Location		
Prehospital, n, (%)	79 (31)	46 (32)
Hospital, n, (%)	173 (69)	99 (68)
Trauma Type/MOI		
Blunt Force Trauma, n, (%)	197 (78)	118 (81)
Penetrating Trauma, n, (%)	55 (22)	27 (19)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016

*Blood: missing 2, n = 250, No Blood: missing 1, n = 144; †Blood: missing 9, n = 243, No Blood: missing 6, n = 139; ‡Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; ¶Blood: missing 1, n = 251, No Blood: missing 3, n = 142; #Blood: missing 1, n = 251; No Blood: missing 1, n = 144

Table 7. Clinical Profile of Critical Pediatric Trauma Patients at MHTMC Who Received Blood Products (n = 252) and Who Did Not (n = 145)

Variable	Blood Products n = 252	No Blood Products n = 145
MAP, mmHg, median, (IQR)*	75 (57–89)	87 (72–98)
SBP, mmHg, median, (IQR)†	105 (80–125)	118 (101–136)
HR, bpm, median, (IQR)‡	111 (85–138)	113 (90–138)
Intubation§		
Yes, n, (%)	186 (74)	91 (63)
No, n, (%)	66 (26)	54 (37)
Identified SHI		
Yes, n, (%)	106 (42)	71 (49)
No, n, (%)	146 (58)	74 (51)
FAST		
Completed, n, (%)	144 (57)	83 (57)
Positive¶, n, (%)	32 (22)	12 (15)
Negative¶, n, (%)	49 (34)	32 (38)
Not Completed, n, (%)	108 (43)	62 (43)
Fluid Type Given		
CR, n, (%)	-	145 (100)
PRBCs, n, (%)	168 (67)	-
FFP, n, (%)	75 (30)	-
PLTs, CRYO, ALB, THR,# n, (%)	9 (3)	-

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Blood: missing 8, n=244, No Blood: missing 4, n=141; †Blood: missing 7, n=245, No Blood: missing 2, n=143; ‡Blood: missing 5, n=234, No Blood: missing 3, n=142; §Blood: missing 1, n=251; ¶close to 50% of FAST results were missing for assessment, and inconclusive results existed that were excluded, so the results are exploratory

Crude ORs and 95% CIs are reported in Table 8. Patients who were intubated were more likely to have been given blood products compared to patients not intubated (OR = 1.61; 95% CI: 1.04, 2.51). Also more likely to receive blood products were patients with lower MAPs (MAP ≤ 59: OR = 4.04; 95% CI: 1.95, 8.37), lower SBPs (SPB ≤ 89: OR = 3.69; 95% CI: 2.02, 6.76), and lower HRs (HR ≤ 59: OR = 5.12; 95% CI: 1.67, 15.70). Patients who arrived directly from the scene and not by interfacility transfer were less likely to receive blood products (OR =

0.58; 95% CI: 0.36, 0.92). Patients with high MAPs (≥90) and high SBPs (≥130) were also less likely to receive blood products (MAP: OR = 0.57; 95% CI: 0.36, 0.90; SBP: OR = 0.53; 95% CI: 0.32, 0.88), compared to patients with low MAPs (≤59) and low SBPs (≤89) (MAP: OR = 4.04; 95% CI: 1.95, 8.37; SBP: OR = 3.69; 95% CI: 2.02, 6.76).

Table 8. Crude ORs and 95% CIs for the Association Between Receipt of Blood Products and Demographic and Clinical Variables

Variable	Crude OR	95% CI	P-Value
Sex			
Male, n, (%)	1.12	0.73, 1.73	0.59
Female, n, (%)	1	-	-
Age			
Infant (0–1) years, n, (%)	1.16	0.54, 2.51	0.7
Toddler (1–4) years, n, (%)	0.7	0.40, 1.24	0.23
Child (5–9) years, n, (%)	0.64	0.36, 1.12	0.12
Preteenager (10–12) years, n, (%)	0.74	0.35, 1.55	0.42
Teenager (13–17) years, n, (%)	1	-	-
Interfacility Transfer			
No	0.58	0.36, 0.92	**0.02**
Yes	1	-	-
Race			
White, n, (%)	1	-	-
Black, n, (%)	1.34	0.76, 2.33	0.31
*Other, n, (%)	1.05	0.66, 1.66	0.83
Ethnicity†			
Non-Hispanic, n, (%)	1	-	-
Hispanic, n, (%)	1.1	0.72, 1.67	0.67
Transport Type‡			
Ground, n, (%)	1	-	-
Helicopter, n, (%)	0.95	0.62, 1.45	0.81
Fluid Location			
Prehospital, n, (%)	0.98	0.63, 1.52	0.94
Hospital, n, (%)	1	-	-

Table 8 (continued)

Variable	Crude OR	95% CI	P-Value
Trauma Type/MOI			
Blunt Force Trauma, n, (%)	0.86	0.51, 1.43	0.55
Penetrating Trauma, n, (%)	1	-	-
Intubation[§]			
Yes, n, (%)	1.61	1.04, 2.51	**0.03**
No, n, (%)	1	-	-
SHI Suspected			
Yes, n, (%)	1		-
No, n, (%)	1.32	0.88, 1.99	0.18
FAST			
Completed, n, (%)	1.02	0.68, 1.55	0.91
Not Completed, n, (%)	1	-	-
ISS			
≥24, n, (%)	1.41	0.85, 2.35	0.18
23–16, n, (%)	1.07	0.58, 1.95	0.83
≤15, n, (%)	1	-	-
MAP, mmHg[¶]			
≥90, n, (%)	0.57	0.36, 0.90	**0.02**
89–60, n, (%)	-	-	-
≤59, n, (%)	4.04	1.95, 8.37	**0.0002**
SBP, mmHg[#]			
≥130, n, (%)	0.53	0.32, 0.88	0.01
129–90, n, (%)	-	-	-
≤89, n, (%)	3.69	2.02, 6.76	**<0.0001**
HR, bpm**			
≥140, n, (%)	1.40	0.78, 2.50	0.26
139–100, n, (%)	1.26	0.76, 2.08	0.37
99-60, n, (%)	-	-	-
≤59, n, (%)	5.12	1.67, 15.70	**0.004**
Weight, kg[††]			
≥46, n, (%)	-	-	-
45–29, n, (%)	1.15	0.56, 2.37	0.70
28–17, n, (%)	0.78	0.45, 1.35	0.37
≤16, n, (%)	0.98	0.57, 1.67	0.94

Table 8 (continued)

Variable	Crude OR	95% CI	P-Value
Height, cm[‡‡]			
≥151, n, (%)	-	-	-
150–134, n, (%)	2.20	0.86, 5.64	0.10
133–103, n, (%)	0.60	0.34, 1.06	0.08
≤102, n, (%)	0.99	0.59, 1.68	0.98

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; [†]Blood: missing 1, No Blood: missing 3, n=393; [‡]Blood: missing 1, No Blood: missing 1, n = 395; [§]Blood: missing 1 n=396; [¶]Blood: missing 9, No Blood: missing 4, n = 384; [#]Blood: missing 7, Blood: missing 2, n = 388; **Blood: missing 5, No Blood: missing 3, n=389; [††]Blood: missing 2, No Blood: missing 1, n = 394; [‡‡]Blood: missing 9, No Blood: missing 6, n = 382

DISCUSSION

This descriptive study summarizes the use of blood products at MHTMC in the treatment of critical pediatric trauma patients between 2011 and 2016. We describe the demographic and clinical characteristics of pediatric trauma patients treated at a major urban Level I trauma center. The receipt of blood products in pediatric patients is rare, with only 5 to 15% of all pediatric patients requiring blood transfusion and less than 2.5% requiring blood transfusion in critical trauma events.[16–18] To our knowledge, this dataset of 252 pediatric trauma patients transfused represents the largest civilian experience with assessment of pediatric indicators of blood transfusion in trauma.[5, 19] To potentially improve outcomes for pediatric trauma patients, we focused on exploring crude associations between clinical and demographic variables and pediatric blood transfusions. These are relatively simply yet important demographic and clinical indicators that may be useful for improving the speed and accuracy of the recognition of a pediatric trauma patient in need of a blood transfusion.[19] Our study found that MAP, intubation, HR, and the direct transport of the patients from the injury scene, rather than transfer, had statistically significant crude associations with blood transfusion in critical pediatric trauma patients.

Our analysis identified potential clinical and demographic criteria that should be further investigated in pediatric blood transfusion indication. We wanted to explore indicators that could be evaluated universally across institutions. A goal of our study is to influence provider decision-making when initiating an appropriate procedure, transferring patients to other departments, or transferring them to another facility. Our results show that demographic variables are important to consider in blood transfusion indication.

The results of diagnostic and laboratory tests, along with other variables, should be used as validation for the decision to transfuse a pediatric patient. Our findings conveyed 32% higher odds for patients with no sign of SHI receiving blood products, further supporting clinical knowledge that SHI trauma patients, adult or pediatric, are not given blood products.[11, 20] This practice is widely acknowledged based on the adverse effects of HB, worsened outcomes, longer stays in intensive care units, and patients not having a surgical or operative need. [11, 20]

MAP is associated with blood transfusion due to its correlation with overall body and brain perfusion.[7, 21] This would be a helpful indicator in the case of a critical hemorrhage.[7, 20] Additionally, it may be why MAP is currently used in surgical and anesthetic environments for all patients.[7, 21] Today, the commonly used threshold of MAP for a patient is a value over 60 mmHg.[8] An MAP with a value above 60 mmHg adequately perfuses both the brain and the body to sustain life.[7, 8] Average MAP values of pediatric patients are not significantly different from those of adult patients because the value represents a mean for the body's perfusion.[7, 21] Conversely, pediatric SBPs are different and cannot be generalized in the same way since SBP varies by developmental age group and body type. [1, 7, 14, 19, 21] Therefore, an indicator should be used that is more generalizable across populations and more homogeneous compared to other range-based values.[7, 21]

We found patient intubation to be associated with blood receipt. A prehospital study conducted in Germany found that intubation is a key indicator for prehospital severity in trauma and the need for blood product administration.[5] Additionally, the study stated that most patients needing intubation have lower correlating Glasgow Coma Scale (GCS) scores (≤8 out of 15).[4, 5] Research has found that a GCS of eight or below is indicative of critical injury requiring blood transfusion.[4, 20] There are hemodynamic instabilities associated with lower GCS scores requiring intubation due to respiratory decompensations that can occur, which indicate forms of advanced shock in patients.[4, 5, 20] Therefore, intubation should be an indicator included in blood transfusion determination.

Our analysis also showed that ISS is associated with the use of blood products, a finding that is also supported by the literature.[4] A military study showed that ISS and GCS are correlated with the severity of a patient's injuries and the need for advanced interventions such as blood transfusion.[4] Results from our study support these findings and suggest that intubated patients are approximately twice as likely to receive a blood transfusion. Further, our study shows that as ISS values increase, so do the odds for needing blood products. This means that patients with higher ISS values are more critical and require more services and resources during treatment.[4]

Our results show that a patient transported from the scene of a trauma is less likely to receive blood products than an interfacility transfer patient. This could be due to many factors depending on the facility of admission. Patients are often taken to the facility that is closest geographically to the injury site, and the facility starts life-saving blood transfusions and treatments as needed.[5, 13, 19] The facility, however, may not have appropriate resources, like a blood bank or high trauma level, to treat a critical pediatric patient with a severe hemorrhage.[5, 13, 19, 22] When an original-admission facility is underequipped for blood product needs, transfer to a Level I trauma center often occurs, which is where blood treatments are most often administered.[3, 5, 13, 19, 22]

The results also show that patients with lower HRs are more than five times more likely to need blood products than others in the study. Indicators such as tachycardia and hypotension tend to be traditionally used in emergency rooms as sensitive indicators of advanced trauma.[23] Adult patients with HRs outside the normal range of 70 to 89 bpm are generally in shock according to the shock index and require further care due to higher injury severity.[23] However, a seven-year-old patient with an HR of 115 may be classified as within normal limits while being in stage III shock because of individual differences in resting and abnormal HRs.[15] Furthermore, it has been found that when used in a shock index, HR is more informative than when used as a lone indicator; HR should be used with SBP or MAP to more accurately indicate trauma or hemorrhage severity.[24]

Recent research has correlated pediatric age and HR and the tissue they have to perfuse adequately.[14, 25] This indicates that older (larger) children are more likely to need blood products when they have critical injuries compared to younger (smaller) children of school age.[14, 25] It follows, then, that height and weight are important indicators in determining amount of and need for blood product receipt in pediatric patients.[9] Infants under three months old have TBVs of approximately 90 mL/kg, while those more than three months old have TBVs of approximately 70 mL/kg.[9] These parameters could prove to be helpful when determining and maintaining appropriate blood volumes in pediatric patients.

Our data show that MOI is not a significant factor in the receipt of blood products. However, blunt force trauma injuries should be given special consideration when treating critical pediatric trauma patients with blood products because it is the most common MOI for all critical pediatric trauma patients treated at MHTMC.[6, 17] The current focus on implementing blood transfusions primarily in response to penetrating injuries, as well as current scoring processes (e.g., TASH, ABC, etc.), may be missing blunt force trauma patients who could benefit from transfusion.[26–29] This would allow for further accuracy and consideration of blood product use for a population that is overlooked by the inappropriate use of adult MTP scoring totals.[3, 17, 26–28, 30]

Additional studies are needed to determine the effect of FAST as an indicator of blood transfusion and MT in pediatric trauma patients. More complete data are needed on FAST because it is not available at every facility. Additional research is also needed to better understand the potential influence of CR and lactated ringer fluids combined with the administration of blood products. Future research should also include improving our understanding of the potential impact of certain blood types on the mortality of pediatric and adult trauma patients.

LIMITATIONS

This study has several important limitations. All patients included in this dataset were treated at a single trauma center in Houston, Texas, and therefore our findings are not generalizable. However, this dataset included a relatively large number of pediatric trauma patients from a six-year period that included patients transported to the hospital by ambulance and helicopter. Although the dataset was relatively complete, some records were missing data for variables including MAP, SBP, HR, weight, height, intubation, FAST outcome values, and ethnicity. FAST results were not available for each patient, but if a FAST was completed on a patient, data were available and complete. Not all patients received MT; some received different types of blood products over a period of time that may have included a hospital stay after the trauma, subsequent surgeries, and procedures required for recovery.

In this study, patients that had CR fluids administered with blood products were included with the patients who received blood products only. The majority of prehospital responding units, such as MHLF, carry only PRBCs and PLM, while the hospital has access to a blood bank and more diagnostics to give blood products not used in the prehospital environment (e.g., CRYO, ALB serum, and THR treatments). Further research will be required to look at the possible impact of the administration of CR fluids with blood products in critical pediatric trauma patients. Patients included in this dataset had different treatment providers. Therefore, the protocols used and decisions made for the administration of blood products may have differed.

Additionally, our analyses were retrospective and could only describe the demographic and clinical characteristics of those receiving blood transfusions in the prehospital and hospital environments. We do not know if there were patients who received a transfusion when they did not need one or vice versa. Although the dataset included data on patients who received CR fluids and expanders before, during, and after blood product administration, we did not include these data in our analyses due to the completeness of data. Since most prehospital services carry only CR fluids, the receipt of CR fluids should be considered separately in future research. Finally, we focused on early outcomes rather than long-term or chronic outcomes on survival or quality-of-life implications.

CONCLUSION

Critical pediatric trauma patients who received blood products in the prehospital or hospital environment were more likely to have been intubated and had lower MAPs, SBPs, and HRs. More complex statistical models should be developed as part of future research to calculate adjusted associations between clinical and demographic variables and the receipt of blood products in the prehospital or hospital environment.

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CHAPTER III

VARIABLES ASSOCIATED WITH PREHOSPITAL VERSUS HOSPITAL BLOOD TRANSFUSIONS AT MEMORIAL HERMANN HOSPITAL TEXAS MEDICAL CENTER AMONG CRITICAL PEDIATRIC TRAUMA PATIENTS, 2011 TO 2016

INTRODUCTION

When making decisions for pediatric MT, relying on adult protocols could mean considering factors that may not be clinically relevant for giving blood products to a critical pediatric trauma patient. The indicators used to implement blood transfusion protocols depend on the hospital, treatment team, other providers and overall experience with pediatric MTPs.[1, 2] At various facilities and with various services (e.g., ground and air ambulance), the data used as part of the decision to start a blood transfusion in pediatric patients vary. Data may include ISS, AIS, SBP, HR, GCS score, FAST, BD, INR, "BIG" score for child injury (BD + [2.5 × INR] + [15 – current GCS]), LL, PT, PTT, and other factors that differ by hospital.[1, 3–6]

There is no universally recommended, accepted or agreed-upon number or type of variables for indicating blood transfusion or MT in critical pediatric trauma patients.[1, 7, 8] In adult populations, scoring systems have been developed and implemented.[9–12] Scoring systems allow providers to use indicators based on selected clinical parameters to indicate blood transfusion in severely injured adult patients.[9–12] Prehospital clinical indicators are needed to guide decision-making for blood transfusion in critical pediatric trauma patients.[1, 7]

Some hospitals in the United States use a scoring protocol called ABC to indicate the need for a blood transfusion in adult patients. [9–12] Currently, SBP is used in almost all adult protocols to indicate perfusion in trauma patients.[11, 12] Specifically, SBP greater than 140 indicates high blood pressure, and less than 90 indicates low blood pressure and possible hemorrhage.[9, 11, 12] Other clinical indicators for transfusion might include an HR greater than 100 bpm, a FAST that is positive, or the presence of a penetrating trauma.[9, 11] These four components—SBP, HR, FAST, and penetrating trauma—are used to calculate a total score, with a blood transfusion being implemented with the presence of at least two of the components.[9–11]

Several scoring tools are used in adults including ABC, TASH, McLoughlin score, and others.[11, 12] None of these protocols apply specifically to pediatrics. If applied, adult parameters are used for guiding the decision-making around blood transfusions.[1, 10, 13] This may be detrimental to the health of the patient. For example, children may receive a transfusion unnecessarily, not receive a transfusion when needed, or receive an excessive transfusion.[1, 5, 7, 8, 14] Research has not focused on development of protocols or scoring scales for blood transfusion in pediatric patients.[1, 2, 7, 8]

There are several important reasons that pediatric-specific guidance is imperative.[1, 2, 8, 10] In pediatric patients, HB and HCT level measurements are inadequate, acceptable SBP range changes by developmental stage, HR ranges differ, and most critical injuries in pediatric trauma are the result of blunt force.[3, 5, 7, 8, 13, 15] Adult scoring tools are currently the only ones available for critical pediatric trauma patients receiving blood products, but the impact of using them on the prehospital critical pediatric trauma patient population is currently unknown.[2, 15, 16] In the absence of universal pediatric blood transfusion protocols, there remains ambiguity about the need for transfusions when treating pediatric patients in critical trauma situations, both in prehospital and hospital settings.[1, 7, 8] Since the pediatric trauma population differs from the adult trauma population in a number of ways, it is important to identify factors that may be associated with improved survival and implementation of blood transfusion among pediatric trauma patients, both in prehospital and hospital settings.[7, 8]

While pediatric blood transfusion has become more widely studied over the last decade, there remains little published research on prehospital blood transfusion within the pediatric trauma population.[1, 3, 7] In general, pediatric patients receiving prehospital blood transfusions in route to a Level I trauma center have positive outcomes.[1, 3, 10, 13] For example, recent research has shown that patients receiving prehospital blood transfusions have a decreased need for further transfusion upon arrival at facilities.[3, 5, 10, 13] There have also been few reported adverse reactions to blood products in prehospital pediatric patients.[1, 3, 10] Studies have also demonstrated improved hospital-arrival vital signs, shorter LOSs, and increased positive overall survival outcomes based on the receipt of early blood transfusion, especially in critical traumatic injuries.[1, 3, 5, 10, 13] Even with increased research on pediatric blood transfusion and new studies in the prehospital context, there remain discrepancies and a lack of guidance on accurate indicators to identify pediatric patient need for blood transfusions.[1, 3, 13] We hypothesized that demographic and clinical variables are associated with receipt of prehospital blood products in pediatric trauma patients.

METHODS

Data Sources and Study Population

The dataset included pediatric trauma patients treated at MHTMC, an urban Level I trauma center with the highest volume of trauma patients in the Houston metropolitan area. Eligible for inclusion in the dataset were all critically injured pediatric trauma patients aged 17 and under who were transported by either helicopter or ground ambulance to MHTMC between January 1, 2011 and December 31, 2016. Patients of a critical classification were identified through vital signs, MOI, age, height, weight, blood loss, electronic reporting chart and narrative, and method of transport.

The study included 144 of 252 (57%) patients transported by MHLF, a large hospital-based helicopter EMS service managed and maintained by the MHTMC trauma and surgery services department. The service usually accounts for approximately 53% of the region's critical pediatric trauma patient transports. During the study period, MHLF was staffed by a paramedic/nurse team and carried two units of type-O-negative PRBCs and two units of FFP on each mission. All orders for administration of blood products came from the medical director and MHTMC surgery department based on adult ABC evaluation. This study was reviewed by the University of Texas Health Science Center IRB (HSC-GEN-12-0476) and the Texas A&M University IRB (18-0073) and was determined to be exempt.

The dataset contained variables from the MHTMC trauma registry, blood bank database, MHLF flight registry, and MHLF medical records. Patients included in the dataset were identified through electronic hospital record query. Demographic variables included race, sex, ethnicity, age, weight, height, transfer from other facility (yes/no), transport type (ground ambulance/helicopter), and trauma type/MOI (blunt/penetrating). Clinical factors included patient intubation (yes/no), MAP, SBP, HR, and identifiable SHI (yes/no). Other clinical factors considered were fluid types given (CR, PRBCs, FFP, PLTs, CRYO, serum ALB products, and THR products), FAST (positive/negative), and the completion of FAST (yes/no). FAST was only included as an exploratory inferential diagnostic variable due to missing data for this variable in more than 50% of the total records. However, FAST completion (yes/no) was included to assess if those who had the procedure were more likely to receive blood products.

Missing Data

A total of 252 patients were included in the analyzed dataset. Observations were excluded if they were missing data for any variable. The variables with missing values were weight (2), height (9), MAP (9), SBP (7), HR (5), ethnicity (1), transport type (1), and intubation (1). These observations were treated as missing when descriptive and bivariate analyses were performed for each respective variable to report complete cases.

Statistical Analysis

The primary outcome was the receipt of blood products by a critical pediatric trauma patient during either the prehospital or in hospital period. Descriptive analyses were conducted to calculate frequencies, medians, and ranges, as well as bivariate associations between demographic and clinical factors and the outcome variable of prehospital blood products being received or not. Bivariate analyses were performed using logistic regression for each demographic and clinical variable and the binary outcome of whether blood products were received. Crude ORs and 95% CIs were estimated. CIs that did not include the null value of 1.0 were interpreted as indicating statistical significance. All data analysis was conducted in SAS 9.4 (Cary, NC).

RESULTS

Of 397 critical pediatric trauma patients identified, 63% (252 of 397) received blood products in the prehospital or hospital environment (Table 9). Of the treated patients who received blood products, 67% (169 of 239) were male. The median age was 12.5 (IQR 4 to 16), although half were between 13 and 17 (50%, 126 of 252). Average patient weight and height were consistent with an average 12-year-old child.[17] Thirty-nine percent (98 of 252) of patients were White, and 38% (97 of 252) identified as other, including Native American, Asian, Pacific

Islander, Native Hispanic, and mixed race, and were most likely to receive blood products. The majority of patients came directly from emergency scenes (66%; 166 of 252) as opposed to interfacility transfer. Nearly two-thirds of patients (63%; 159 of 252) were transported by helicopter to MHTMC, and four-fifths had blunt force trauma as the MOI (78%; 197 of 252). More than two-thirds of patients were given fluids in the hospital setting (69%; 173 of 252). Overall, 65% (164 of 252) of patients survived their injuries with the treatment received. Patients who expired held a median of 14 hours, 41 minutes before death (range: 54 minutes to 1 day, 10 hours, 55 minutes).

Table 9. Demographic Profile of Critical Pediatric Trauma Patients at MHTMC Who Received Blood Products (n = 252)

Variable		**Blood Products** n = 252
Sex		
	Male, n, (%)	169 (67)
	Female, n, (%)	83 (33)
Age, years, median, (IQR)		12.5 (4–16)
Age Group, years		
	Infant (0–1) years, n, (%)	26 (10)
	Toddler (1–4) years, n, (%)	40 (16)
	Child (5–9) years, n, (%)	39 (15)
	Preteenager (10–12) years, n, (%)	21 (8)
	Teenager (13–17) years, n, (%)	126 (50)
Weight, kg, median, (IQR)*		50 (19–68)
Height, cm, median, (IQR)[†]		155 (104–170)
Interfacility Transfer		
	Yes, n, (%)	86 (34)
	No, n, (%)	166 (66)
Race		
White		98 (39)
Black		57 (23)
[‡]Other		97 (38)

Table 9 (continued)

Variable		**Blood Products** n = 252
Ethnicity¶		
	Non-Hispanic, n, (%)	152 (60)
	Hispanic, n, (%)	100 (40)
Transport Type#		
	Ground, n, (%)	93 (37)
	Helicopter, n, (%)	159 (63)
Fluid Location		
	Prehospital, n, (%)	79 (31)
	Hospital, n, (%)	173 (69)
Trauma Type/MOI		
	Blunt Force Trauma, n, (%)	197 (78)
	Penetrating Trauma, n, (%)	55 (22)
Clinical Outcome		
	Survival Over 24 hours, n, (%)	164 (65)
	Death Within 24 hours, n, (%)	88 (35)
	Time to Death, median, (IQR), (hours: minutes)	14:41 (11:43–19:52)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Blood: missing 2, n = 250; †Blood: missing 9, n = 243; ‡Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; ¶Blood: missing 1, n = 251; #Blood: missing 1, n = 251

As shown in Table 10, pediatric trauma patients who received blood products had a median MAP of 75 mmHg (IQR 57 to 89) and a median SBP of 105 mmHg (IQR 80 to 125). Patients who received blood products had a median HR of 111 bpm (IQR 85 to 138). Almost three-quarters of patients who received blood products were intubated (74%; 186 of 252). Children with injuries classified as a severe head trauma received blood products less often than those with noticeable head traumas (58%; 146 of 252), based on the AIS number assigned during treatment. PRBC was the most-used blood product (67%; 168 of 252).

Table 10. Clinical Profile of Critical Pediatric Trauma Patients Receiving Blood Products at MHTMC (n = 252)

Variable		**Blood Products** n = 252
MAP, mmHg, median, (IQR)*		75 (57–89)
SBP, mmHg, median, (IQR)†		105 (80–125)
HR, bpm, median, (IQR)‡		111 (85–138)
Intubation§		
	Yes, n, (%)	186 (74)
	No, n, (%)	66 (26)
Identifiable SHI		
	Yes, n, (%)	106 (42)
	No, n, (%)	146 (58)
FAST		
	Completed, n, (%)	144 (57)
	Positive¶, n, (%)	32 (22)
	Negative¶, n, (%)	49 (34)
	Not completed, n, (%)	108 (43)
Fluid Type Given		
	CR, n, (%)	-
	PRBCs, n, (%)	168 (67)
	FFP, n, (%)	75 (30)
	PLTs, CRYO, ALB, THR,# n, (%)	9 (3)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Blood: missing 8, n = 244; †Blood: missing 7, n = 245; ‡Blood: missing 5, n = 234; §Blood: missing 1, n = 251; ¶Close to 50% of the FAST results were missing for assessment, and there were inconclusive results excluded, so the results are exploratory

The dataset included 79 patients who received prehospital blood products and 173 who received hospital blood products at MHTMC (Table 11). Patients who received blood products were mostly male (67% of prehospital recipients, 53 of 79; 68% of hospital recipients, 117 of 173). The median age was higher for patients who received hospital blood products than those who received prehospital blood products (13 for hospital, IQR 5 to 16; 11 for prehospital, IQR 4 to 15). Fifty-nine percent (47 of 79) of patients who came directly from emergency scenes received prehospital blood products while 69% (120 of 173) of patients who came directly from emergency scenes received hospital blood products.

Table 11. Demographic Profile of Critical Pediatric Trauma Patients at MHTMC Who Received Prehospital (n = 79) and Hospital (n = 173) Blood Products

Variable	Prehospital Blood Products n = 79	Hospital Blood Products n = 173
Sex		
Male, n, (%)	53 (67)	117 (68)
Female, n, (%)	26 (33)	56 (32)
Age, years, median, (IQR)	11 (4–15)	13 (5–16)
Age Group		
Infant (0–1) years, n, (%)	5 (6)	21 (12)
Toddler (1–4) years, n, (%)	20 (25)	20 (12)
Child (5–9) years, n, (%)	13 (16)	26 (15)
Preteenager (10–12) years, n, (%)	7 (9)	14 (8)
Teenager (13–17) years, n, (%)	34 (43)	92 (53)
Weight, kg, median, (IQR)*	41 (17–61)	51 (20–69)
Height, cm, median, (IQR)†	145 (103–165)	160 (110–170)
Interfacility Transfer		
Yes, n, (%)	32 (41)	53 (31)
No, n, (%)	47 (59)	120 (69)
Race		
White, n, (%)	35 (44)	63 (36)
Black, n, (%)	17 (22)	40 (23)
‡Other, n, (%)	27 (34)	70 (40)
Ethnicity¶		
Hispanic, n, (%)	32 (41)	69 (40)
Non-Hispanic, n, (%)	47 (59)	103 (60)
Transport Type#		
Ground, n, (%)	5 (6)	87 (50)
Helicopter, n, (%)	74 (94)	85 (49)
Trauma Type/MOI		
Blunt force trauma, n, (%)	60 (76)	137 (79)
Penetrating trauma, n, (%)	19 (24)	36 (21)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016.
*Prehospital blood: missing 1, n = 78; Hospital blood: missing 1, n = 172; †Prehospital blood: missing 6, n = 73; Hospital blood: missing 3, n = 170; ‡Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; ¶Hospital blood: missing 1, n = 172; #Hospital blood: missing 1, n = 172

As shown on Table 12, pediatric trauma patients who received prehospital blood products had a lower median MAP (62 mmHg; IQR 33 to 83) and a lower median SBP (86 mmHg; IQR 60 to 120) compared with those who received hospital blood products (median MAP of 77 mmHg, IQR 64 to 91; median SBP of 110 mmHg, IQR 85 to 126). Patients who received hospital blood products had a higher median HR (116 bpm; IQR 95 to 143) than those receiving prehospital blood products (103 bpm; IQR 62 to 126). The percentage of patients intubated was higher in the group receiving prehospital blood products (80%; 63 of 79). Children with injuries classified as a severe head trauma comprised over half of the patient population receiving hospital blood products (60%; 104 of 173), based on the AIS number assigned during treatment. PRBC was the most-used blood product (67%; 168 of 252).

Crude ORs and 95% CIs are reported in Table 13. Compared to children aged 13 to 17, pediatric trauma patients between 1 and 4 years old were more likely to receive prehospital blood products (OR = 2.71; 95% CI: 1.30, 5.64). Patients transported by helicopter were also more likely to receive prehospital blood products (OR = 15.14; 95% CI: 5.84, 39.30). Patients with lower MAPs (MAP ≤59: OR = 3.37; 95% CI: 1.79, 6.37), lower SBPs (SPB ≤89: OR = 2.68; 95% CI: 1.48, 4.87), and lower HRs (HR ≤59: OR = 3.78; 95% CI: 1.45, 9.86) were also more likely to receive prehospital blood products. Patients who arrived directly from the scene were less likely to receive blood products (OR = 0.65; 95% CI: 0.37, 1.13) than interfacility transfers, and intubated patients were more likely to receive prehospital blood products (OR = 1.61; 95% CI: 0.85, 3.06).

Table 12. Clinical Profile of Critical Pediatric Trauma Patients at MHTMC Who Received Prehospital (n = 79) and Hospital (n = 173) Blood Products

Variable	Prehospital Blood Products n = 79	Hospital Blood Products n = 173
MAP, mmHg, median, (IQR)*	62 (33–83)	77 (64–91)
SBP, mmHg, median, (IQR)†	86 (60–120)	110 (85–126)
HR, bpm, median, (IQR)‡	103 (62–126)	116 (95–143)
Intubation§		
Yes, n, (%)	63 (80)	122 (71)
No, n, (%)	16 (20)	50 (29)
Identifiable SHI		
Yes, n, (%)	37 (47)	104 (60)
No, n, (%)	42 (53)	69 (40)
FAST		
Completed, n, (%)	48 (61)	95 (55)
Positive¶, n, (%)	14 (30)	17 (18)
Negative¶, n, (%)	14 (29)	35 (36)
Not Completed, n, (%)	31 (39)	78 (45)
Fluid Type Given		
PRBCs, n, (%)	59 (75)	109 (63)
FFP, n, (%)	20 (25)	55 (32)
PLTs, CRYO, ALB, THR, n, (%)	-	9 (5)

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Prehospital blood: missing 1, n = 78; Hospital blood: missing 8, n=165; †Hospital blood: missing 7, n = 166; ‡Prehospital blood: missing 1, n = 78; Hospital blood: missing 4, n = 169; §Hospital blood: missing 1, n = 172; ¶Close to 50% of the FAST results were missing for assessment, and there were inconclusive results excluded, so the results are exploratory

Table 13. Crude ORs and 95% CIs for the Relationship Between Receipt of Prehospital Blood Products and Demographic and Clinical Variables

Variable	Crude OR	95% CI	P-Value
Sex			
Male, n, (%)	0.98	0.55, 1.72	0.93
Female, n, (%)	1.00	-	-
Age			
Infant (0–1) years, n, (%)	0.64	0.22, 1.84	0.41
Toddler (1–4) years, n, (%)	2.71	1.30, 5.64	**0.008**
Child (5–9) years, n, (%)	1.35	0.62, 2.93	0.44
Preteenager (10–12) years, n, (%)	1.35	0.50, 3.64	0.55
Teenager (13–17) years, n, (%)	1.00	-	-
Interfacility Transfer			
No	0.65	0.37, 1.13	0.12
Yes	1.00	-	-
Race			
White, n, (%)	1.00	-	-
Black, n, (%)	0.76	0.38, 1.54	0.45
*Other, n, (%)	0.69	0.38, 1.27	0.23
Ethnicity†			
Non-Hispanic, n, (%)	1.00	-	-
Hispanic, n, (%)	1.02	0.59, 1.75	0.95
Transport Type‡			
Ground, n, (%)	1.00	-	-
Helicopter, n, (%)	15.14	5.84, 39.30	**<0.0001**
Trauma Type/MOI			
Blunt Force Trauma, n, (%)	0.83	0.44, 1.56	0.56
Penetrating Trauma, n, (%)	1.00	-	-
Intubation§			
Yes, n, (%)	1.61	0.85, 3.06	0.14
No, n, (%)	1.00	-	-
SHI Suspected			
Yes, n, (%)	1.00		-
No, n, (%)	0.75	0.44, 1.29	0.30
FAST			
Completed, n, (%)	1.24	0.72, 2.14	0.43
Not Completed, n, (%)	1.00	-	-

Table 13 (continued)

Variable		Crude OR	95% CI	P-Value
ISS				
	≥24, n, (%)	1.15	0.58, 2.30	0.69
	16–23, n, (%)	1.04	0.45, 2.41	0.93
	≤15, n, (%)	1.00	-	-
MAP, mmHg¶				
	≥90, n, (%)	0.85	0.40, 1.79	0.66
	60–89, n, (%)	-	-	-
	≤59, n, (%)	3.37	1.79, 6.37	**0.0002**
SBP, mmHg#				
	≥130, n, (%)	1.05	0.46, 2.41	0.91
	90–129, n, (%)	-	-	-
	≤89, n, (%)	2.68	1.48, 4.87	**0.001**
HR, bpm**				
	≥140, n, (%)	0.63	0.27, 1.44	0.27
	100–139, n, (%)	0.91	0.45, 1.84	0.80
	60–99, n, (%)	-	-	-
	≤59, n, (%)	3.78	1.45, 9.86	**0.007**
Weight, kg††				
	≥46, n, (%)	-	-	-
	29–45, n, (%)	1.56	0.65, 3.74	0.31
	17–28, n, (%)	1.48	0.70, 3.10	0.30
	≤16, n, (%)	1.37	0.69, 2.72	0.37
Height, cm‡‡				
	≥151, n, (%)	-	-	-
	150–134, n, (%)	1.40	0.55, 3.56	0.48
	103–133, n, (%)	1.73	0.78, 3.83	0.18
	≤102, n, (%)	1.32	0.67, 2.62	0.42

Data from MHTMC Flight and Trauma Registry data, 2011 to 2016
*Other includes Native American, Asian, Pacific Islander, Native Hispanic races, and mixed race; †Hospital: missing 1, n = 251; ‡Hospital: missing 1, n = 251; §Hospital: missing 1, n = 251; ¶Prehospital: missing 1, Hospital: missing 8, n = 243; #Hospital: missing 7, n = 245; **Prehospital: missing 1, Hospital: missing 4, n=247; ††Prehospital: missing 1, Hospital: missing 1, n = 250; ‡‡Prehospital: missing 6, Hospital: missing 3, n = 243

DISCUSSION

This descriptive study summarizes the experience of critical pediatric trauma patients who were evaluated and received prehospital or hospital blood products between 2011 and 2016 at MHTMC. We analyzed the demographic and clinical characteristics of pediatric trauma patients receiving blood products at a major urban Level I trauma center and explored bivariate associations between demographic and clinical characteristics and the receipt of blood products in the prehospital or hospital context. The receipt of blood products in pediatric patients is rare, with approximately 2% of pediatric trauma patients requiring blood transfusion in critical trauma events.[1–3, 15, 16] To our knowledge, this is one of the largest studies to assess demographic and clinical factors for prehospital versus hospital pediatric blood transfusion.[4]

Our study explored demographic and clinical variables that can be assessed in the prehospital setting to make a quick decision on blood transfusion.[1] The appropriate use of prehospital blood products in a pediatric trauma patient aids triage and treatment upon arrival at the ED. Demographic and basic clinical factors are fairly easy to collect and may improve understanding of whether a pediatric trauma patient would benefit from a prehospital blood transfusion.[1] Our study found the following to be associated with prehospital blood transfusion in critical pediatric trauma patients: MAP ≤ 59 mmHg, SBP (from which MAP is derived) ≤ 89 mmHg, transport type (by helicopter), age (1 to 4 years), and HR ≤ 59 bpm. These demographic and clinical variables are typically evaluated universally across institutions and services, but the specific goal of our study is to influence the decision-making of flights crews, paramedics, nurses, midlevel practitioners, and physicians—those identifying blood transfusion need before arrival at the hospital.

A lower MAP value (≤59 mmHg) may be associated with prehospital blood transfusion. In the study, patients in this range had more than three times the odds of receiving prehospital blood products compared to those with a higher MAP. This may be because an MAP above 65 mmHg perfuses both the brain and the body of the patient adequately to sustain life—a helpful indicator in the case of a critical hemorrhage.[18, 19] Additionally, it may be why MAP is currently used in surgical and anesthetic environments for all patients, especially pediatrics.[18, 19] Importantly, pediatric average MAP values are not as significantly different from those of adults as SBP values are because MAP is a mean for the body's perfusion and not a range of possible normal values.[18, 19] A lower SBP (≤89 mmHg) may be associated with prehospital blood transfusion. However, the SBP of a pediatric patient is not a generalizable mean or median value; it is an irregular range for different ages and body types and so cannot be relied on as a fixed protocol.[19, 20] Blood transfusion indicators should be more generalizable and homogeneous across populations.[18, 19]

Patients with lower heart rates (≤59 bpm) had more than three times the odds of receiving prehospital blood products compared to those with higher HRs. In traumatic events, lower HR can be an indication of low blood volume or perfusion, shock, and decompensation of the body.[9, 11, 12, 21–23] Indicators such as tachycardia and hypotension are traditionally used in emergency rooms as more sensitive indicators of advanced trauma because they occur when the body is trying to compensate for a severe hemorrhage.[15, 16, 21–23] But pediatric trauma patients have different vital sign ranges and developmental stages than adults, leading to different compensation mechanisms and physical presentations.[2, 3, 7, 8, 14, 16, 17] For example, according to the shock index, adult patients with HRs outside the normal range of 70 to 89 bpm are generally in shock and require further care due to higher injury severity.[21] However, a seven-year-old patient with a heart rate of 115 may be classified as within normal limits while being in stage III shock because of individual differences in resting and abnormal heart rates.[22]

Recent research has correlated pediatric age and HR and the tissue they have to perfuse adequately.[8, 14, 17] Age in this study was also associated with prehospital blood transfusion. Children aged 1 to 4 had 2.5 times the odds of receiving prehospital blood than the teenage reference group. Toddlers and younger children may need blood products sooner than adolescent and adult patients due to lower sodium and potassium levels.[8] These patients also need more oxygen-carrying capacity in the blood for development.[8] And because smaller children are not completely developed, there are also procoagulant factors and differences in blood volume and surface/tissue area to be perfused.[8] Infants and children older than three months have TBVs of approximately 70 mL/kg.[8] These considerations point to a physiological factor—larger and older children with higher TBVs and fully developed coagulant factors and proteins are better able to compensate for longer periods of time.[8, 14, 16]

Height and weight have shown to be important factors in dictating blood product receipt, as well as amount needed, in pediatric patients.[1, 8, 11, 16, 24, 25] Older adolescents with blunt force trauma injuries whose height and weight may be comparable to adult patients may need to be assessed differently for blood product administration in the prehospital environment. Our results showed that as pediatric weight increases, so do patient odds of receiving prehospital blood products. Increased height also increased these odds (by 42%), but the specific range of 3 ft. 4 in. to 4 ft. 4 in. had 73% higher odds of receiving prehospital blood products. This range is the average height of a toddler to a school-aged child.[17] Therefore, toddlers and school-aged children may need blood products earlier in treatment due to differences in physiologic development.[8]

In this study, intubated patients had higher odds of receiving prehospital blood products. A German prehospital study demonstrated that intubation is a key indicator for prehospital trauma severity and the need for blood product administration.[5] Most patients needing intubation have lower correlating GCS scores (8 or less out of 15).[5, 26] Research has found that a GCS of eight or below is indicative of needing respiratory assistance (intubation) and critical injury requiring blood transfusion.[4, 26] There are hemodynamic instabilities associated with lower GCS scores requiring intubation due to respiratory decompensation that can occur, which indicate forms of advanced shock in patients.[4, 5, 26] Therefore, intubation should be an indicator to determine blood transfusion.

Our results showed that the odds of a patient receiving a prehospital blood transfusion were 15 times higher when the patient was transported to the hospital by helicopter. This may be because ground EMS agencies do not carry all blood products, so a flight crew is inherently more likely to give blood products prehospital.[1, 3, 10, 13] Currently, only two ground EMS agencies in the United States have the capability to carry blood products (both in the Houston area).[27] However, almost all EMS helicopter services, including MHLF, carry blood products that can be used when a patient is critically injured .[1, 3, 10, 13, 28] Flight teams, however, administer blood products to pediatric trauma patients using adult indicators modified by hospital MT protocols.[1]

Pediatric trauma patients at MHTMC have blunt force trauma as the MOI more than any other mechanism.[5, 25] Unintentional injury is the leading cause of death in patients under age 20, and motor vehicle crashes and falls are leading injury classifications in the blunt force trauma category.[25] Accordingly, a shift should be made from focusing on scoring tools such as ABC, TASH, and McLaughlin to include blunt force trauma for MT protocol initiation.[9, 12, 25] This shift would allow for further accuracy and consideration of blood product use for a population that is overlooked by the inappropriate use of adult MTP scoring totals.[1, 2, 11, 12]

Additional studies are needed to determine the effect of FAST as an indicator of blood transfusion and MT in pediatric trauma patients. While FAST is carried on MHLF aircraft for use in traumatic situations, it is not available at every facility.[3, 9, 10] Additional research is also needed to better understand the potential influence of CR and lactated ringer fluids combined with blood product administration. Future research should also focus on understanding the potential impact of certain blood types on the mortality of pediatric and adult trauma patients.

LIMITATIONS

This study has several important limitations. All patients included in this dataset were treated at a single trauma center in Houston, Texas, and therefore our findings are not generalizable. However, this dataset included a relatively large number of pediatric trauma patients from a six-year period that included patients transported to the hospital by ambulance and helicopter. Although the dataset was relatively complete, some records were missing data for variables including MAP, SBP, HR, weight, height, intubation, FAST outcome values, and ethnicity. FAST results were not available for each patient, but if a FAST was completed on a patient, data were available and complete. Not all patients received MT; some received different types of blood products over a period of time that may have included a hospital stay after the trauma, subsequent surgeries, and procedures required for recovery.

In this study, patients who had CR fluids administered with blood products were included with the patients who received blood products only. The majority of prehospital responding units, such as MHLF, carry only PRBCs and PLM, while the hospital has access to a blood bank and more diagnostics to give blood products not used in the prehospital environment (e.g., CRYO, ALB serum, and THR treatments). Further research will be required to look at the possible impact of the administration of CR fluids with blood products in critical pediatric trauma patients. Patients included in this dataset had different treatment providers. Therefore, the protocols used and decisions made for the administration of blood products may have differed.

Additionally, our analyses were retrospective and could only describe the demographic and clinical characteristics of those receiving blood transfusions in the prehospital and hospital environment. We do not know if there were patients who received a transfusion when they did not need one or vice versa. Although the dataset included data on patients who received CR fluids and expanders before, during, and after blood product administration, we did not include these data in our analyses due to the completeness of data. Since most prehospital services carry only CR fluids, the receipt of CR fluids should be considered separately in future research. Finally, we focused on early outcomes rather than long-term or chronic outcomes on survival or quality-of-life implications.

CONCLUSION

Critical pediatric trauma patients who received prehospital blood products came directly from emergency scenes, were preteenagers, were more frequently intubated, and had lower heights, weights, MAPs, SBPs, and HRs than critical pediatric trauma patients who received blood products in-hospital. Patients who received blood products in the prehospital environment were the most severely injured overall and survived their injuries only 48% of the time compared to 75% of patients who received blood products in the hospital setting. More complex statistical models should be developed as part of future research to calculate adjusted associations between clinical and demographic variables and the receipt of blood products in the prehospital or hospital environment.

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CHAPTER IV

CORRELATIONS BETWEEN DEMOGRAPHIC AND CLINICAL VARIABLES AND MEAN ARTERIAL PRESSURE AMONG CRITICAL PEDIATRIC TRAUMA PATIENTS AT MEMORIAL HERMANN TEXAS MEDICAL CENTER, 2011 TO 2016

INTRODUCTION

MAP is used in many aspects of emergency medical care to assess whether a patient is profusing sufficiently.[1] MAP values can help to inform treatment teams about metabolic changes and to monitor variations in calcium, magnesium, and potassium levels during and after transfusion, especially in infants.[1–4] MAP is typically a factor in the use of MT in surgical patients; however, in settings outside of surgical environments, SBP is more commonly used as part of the decision to transfuse.[1, 3, 4] In addition to MAP, other variables such as weight, H), and SHI indications may be used as indicators of when or when not to initiate MT, particularly in the pediatric population.[1, 5–9] SBP and HR ranges may not work as well in pediatric patients as part of a quick scoring system used in the hospital or prehospital environment, such as TASH, ABC, or McLoughlin.[6, 10–13] Using these variables as part of pediatric assessment for MT requires memorization of eight different ranges of SBPs and five different HR ranges for scores to be accurate in a critical pediatric trauma patient that requires an MT or blood transfusion.[6, 10, 13]

While still evident, fluctuations in MAP tend to be smaller than the fluctuations in SBP.[1, 9, 13, 14] There is also a more accurate and simple formula to figure out what MAP in a pediatric patient should be (1.5 × age in years + 55 for the average MAP in patients from 1 to 17 years of age) to know if MT is required.[9] For example, a five-year-old pediatric patient with a 93/42 BP would not meet the criteria for MT using the ABC scoring system because the SBP (93) is not under or at 90 mmHg.[11, 12, 15, 16] However, considering the patient's calculated MAP from that BP (59) would indicate a lack of perfusion in any patient.[1, 13] Furthermore if using the above formula and factoring in the patient's age (five years), a value of 63 is calculated for the patient's normal MAP. This MAP would translate to an adult BP of 100/45, which, when using adult indicators, would still be considered within the normal range.[11, 15, 16]

MAP is associated with blood transfusion due to its relationship with overall body and brain perfusion.[1, 9] Because of this, MAP is currently used in surgical and anesthetic environments for all patients, including pediatric patients rather than SBP alone.[1, 9] An MAP greater than 59 mmHg adequately perfuses both the brain and the body of the patient.[9, 17] This is important because the body spends two-thirds as much time in diastole during a single cardiac cycle/heart beat then it does in systole.[17] This warrants accounting for the diastole in all situations that involve perfusion, circulation, blood flow, and hypovolemia.

A pediatric patient's average MAP values are typically similar to the average values of an adult patient due to the value being an overall summary of the body's perfusion.[1, 9] To better understand factors correlated with MAP in pediatric trauma patients, we analyzed a dataset composed of pediatric trauma patients treated at MHTMC. MHTMC is an urban Level I trauma center with the highest volume of trauma patients in the Houston metropolitan area. We hypothesize that MAP will be strongly correlated with other pediatric demographic and clinical variables used in the determination of blood transfusions in pediatric trauma patients.

METHODS

Data Sources and Study Population

The dataset included pediatric trauma patients treated at MHTMC, an urban Level I trauma center with the highest volume of trauma patients in the Houston metropolitan area.

Eligible for inclusion in the dataset were all critically injured pediatric trauma patients aged 17 and under who were transported by either helicopter and ground ambulance to MHTMC between January 1, 2011 and December 31, 2016. Patients that were of a critical classification were identified through vital signs, MOI, age, height, weight, blood loss, electronic reporting charts and narratives, and methods of transport.

The study included 210 of 397 (53%) patients transported by MHLF, the MHTMC EMS helicopter service. MHLF is a large hospital-based helicopter EMS service managed and maintained by MHTMC trauma and surgery services department. The service regularly accounts for approximately 53% of the region's critical pediatric trauma patient transports. During the study period, MHLF was staffed by a paramedic/nurse team and carried two units of type-O-negative PRBCs and two units of FFP on each mission. All orders for administration of blood products were from the medical director and MHTMC surgery department based on an evaluation using the adult ABC scoring tool used at MHTMC. This study was reviewed by the University of Texas Health Science Center IRB (HSC-GEN-12-0476) and the Texas A&M University IRB (18-0073) and was determined to be exempt.

The dataset contained electronic inputs from the MHTMC trauma registry, the blood bank database, the MHLF flight registry, and MHLF medical records. Patients included in the dataset were identified through electronic hospital record query. Demographic variables included race, sex, ethnicity, age, weight, height, transfer from other facility (yes/no), transport type (ground ambulance/helicopter), and trauma type/MOI (blunt/penetrating). The clinical factors included patient intubation (yes/no), MAP, fluid location (prehospital or hospital), HR, and identifiable SHI (yes/no). Other clinical factors considered were fluid types given (CR, PRBCs, FFP, PLTs, CRYO, serum ALB albumin products, and THR products) and FAST completion (yes/no).

Missing Data

A total of 384 patients were included in the dataset analyzed. Observations were excluded if they were missing data for any variable. The variables that had missing values, in addition to those excluded by the focus variable of MAP (13), were weight (3), height (14), HR (3), ethnicity (4), and transport type (2). These observations were treated as missing when correlation and comparative distribution analyses were performed for each respective variable to report complete cases.

Statistical Analysis

The primary variable of interest is the MAP (continuous) of a critical pediatric trauma patient during the treatment process. MAP was assessed for normality with univariate analysis, and its distribution was not normal. The non-normal distribution of MAP and the nine outliers present in the dataset between MAP and other continuous variables violated the assumptions to use a Pearson correlation analysis. However, the points could not be excluded from the data because it was not possible to verify if the observations were bad or if they were just due to random variation in the population. Therefore, Spearman correlation analysis was conducted to calculate a more robust nonparametric correlation matrix to outliers among the continuous demographic factors, clinical factors, and MAP values. A Mann-Whitney test was performed to compare the underlying distributions and measure the central tendencies for the distribution of MAP with respect to the dichotomous variables in the dataset. This test was used because of the independent variables not being normally distributed and having two levels while the dependent variable (MAP) was continuous.

The Kruskal-Wallis test was used to compare the differences in distributions of categorical variables (race and fluid type) with respect to MAP. A correlation analysis was performed to assess the association between each of the continuous demographic variables and MAP, adjusting for sex. Similar correlation analysis was done for the continuous clinical variables as well. Correlations between MAP and the demographic and clinical variables were interpreted for statistical significance using the intraclass correlation coefficient (ICC). ICC ranges used for interpretation were less than 0.20 (poor), 0.20 to 0.40 (moderate), 0.40 to 0.75 (good), and greater than 0.75 (excellent).[18] A p-value of less than 0.05 was considered statistically significant, and all data analysis was conducted in SAS 9.4 (Cary, NC).

RESULTS

Presented in Table 14 are estimates of correlation between MAP and demographic variables and estimates of correlation between MAP and clinical variables of critical pediatric trauma patients at MHTMC. There was a moderate correlation between age, weight, and height and MAP values ($s = 0.264$, $p = <0.0001$; $s = 0.270$, $p = <0.0001$; $s = 0.213$, $p = <0.0001$). A poor correlation was also identified between patient MAP values and the HR of critical patients ($s = 0.047$, $p = 0.361$).

Table 14. Correlation Between Demographic and Clinical Variables and MAP of Critical Pediatric Trauma Patients Treated at MHTMC from 2011 to 2016

Variable	n	Spearman ρ	P-Value
Age	384	0.264	**<0.0001**
Weight	381	0.270	**<0.0001**
Height	370	0.213	**<0.0001**
HR	381	0.047	0.361

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

A Mann-Whitney test was conducted to assess the differences in the underlying distributions between MAP for each of the levels of categorical variables (Table 15). There was a statistically significant difference between the underlying distributions of MAP by transport type (helicopter/ground), whether a severe head injury is indicated (yes/ no), and intubation (yes/ no) of a patient ($z = 2.72$, $p = 0.007$; $z = –2.24$, $p = 0.02$; $z = 4.38$, $p = <0.0001$). There were no other statistically significant differences in distributions and medians of other demographic and clinical variables. A Kruskal-Wallis test was conducted in order to assess the differences in distribution between the multilevel categorical variables of race and fluid type. The results show that there was a significant difference between the underlying distributions of MAP values between at least one of the different levels of fluid type ($X^2 = 31.2$, df = 3, $p = <0.0001$).

Table 15. Differences in Underlying Distributions and Medians in Demographic and Clinical Variables and the MAP of Critical Pediatric Trauma Patients Treated at MHTMC from 2011 to 2016

Variable	n	Mann-Whitney Z	P-Value Two-Sided
Sex	384	–1.44	0.15
Transport Type	382	2.72	**0.007**
Trauma Type/MOI	384	–1.17	0.24
FAST Completed	384	–1.35	0.17
Indicated SHI	384	–2.24	**0.02**
Ethnicity	380	–0.29	0.77
Interfacility Transfer	384	–1.64	0.1
Intubation	384	4.38	**<0.0001**
Variable	**n**	**Kruskal-Wallis X^2**	**P-Value**
Race	384	1.78	0.41
Fluid Type	384	31.2	**<0.0001**

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

We repeated the correlation analysis done previously, adjusting for sex (Table 16). This was done to identify any differences between genders in variable indicators with respect to MAP that may play a role in determining blood transfusion. MAP was not normally distributed due to having a left skew of the data (–0.79). The MAP variables also had an M-value of 180.5 and a p-value of <0.0001, showing that the median MAP was significantly different from zero. There were also identified outliers in each of the continuous variables in the analysis, so a Spearman correlation estimate was used. There was a moderate correlation identified between age and weight and MAP value (s = 0.264, p = <0.0001; s = 0.270, p = <0.0001; s = 0.213, p = <0.0001). In addition, a poor correlation was identified between patient MAP values, height, and the heart rate of critical patients (s = 0.194, p = 0.002; s = 0.056, p = 0.377).

Table 16. Correlation Between Demographic and Clinical Variables and MAP of Critical Male Pediatric Trauma Patients Treated at MHTMC from 2011 To 2016

Variable	n	Spearman ρ	P-Value
Age	254	0.246	**<0.0001**
Weight	251	0.254	**<0.0001**
Height	245	0.194	**0.002**
HR	252	0.056	0.377

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

A Mann-Whitney test was conducted to assess differences in the underlying distributions of MAP and the categorical demographic and clinical variables for male pediatric patients (Table 17). There were statistically significant differences between the underlying distributions and median MAP values by transport types (helicopter/ground), and intubation status (yes/no) ($z = 2.45$, $p = 0.01$; $z = 2.92$, $p = 0.003$). There were no other statistically significant differences identified in other demographic and clinical variables in male pediatric patients. However, there were significant differences in distributions and median MAP values between trauma type and SHI indication ($z = –1.81$, $p = 0.07$; $z = –1.70$, $p = 0.09$). A Kruskal-Wallis test was conducted to assess the differences in distribution between the multilevel categorical variables of race and fluid type. The results show that there was a significant difference between the underlying distributions and median MAP values between at least one of the different levels of fluid type ($X^2 = 18.77$, $df = 3$, $p = 0.0003$).

Table 17. Differences in Underlying Distributions and Medians in Demographic and Clinical Variables and MAP of Critical Male Pediatric Trauma Patients Treated at MHTMC from 2011 to 2016

Variable	n	Mann Whitney Z	P-Value Two-Sided
Transport Type	252	2.45	**0.01**
Trauma Type/MOI	254	-1.81	0.07
FAST Completed	254	-1.20	0.23
Indicated SHI	254	-1.70	0.09
Ethnicity	253	0.33	0.74
Interfacility Transfer	254	-1.45	0.15
Intubation	254	2.92	**0.003**
Variable	**n**	**Kruskal-Wallis X^2**	**P-Value**
Race	254	1.18	0.55
Fluid Type	254	18.77	**0.0003**

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

Table 18 shows estimates of correlation between MAP and demographic variables and estimates of correlation between MAP and clinical variables of female critical pediatric trauma patients at MHTMC. There was a moderate correlation identified between age, weight, and height and MAP value (s = 0.278, p = 0.001; s = 0.276, p = 0.001; s = 0.217, p = 0.015). Additionally, a poor correlation was also identified between patient MAP value and HR (s = 0.037, p = 0.674).

Table 18. Correlation Between the Demographic and Clinical Variables and MAP for Critical Female Pediatric Trauma Patients Treated at MHTMC from 2011 To 2016

Variables	n	Spearman ρ	P-Value
Age	130	0.278	**0.001**
Weight	130	0.276	**0.001**
Height	125	0.217	**0.015**
HR	129	0.037	0.674

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

A Mann-Whitney test was conducted to assess differences in the underlying distribution of MAP and the demographic and clinical variables for female pediatric patients (Table 19). There was a statistically significant difference between the underlying distributions and median MAP values based on intubation status (yes/no) ($z = 3.58$, $p = 0.0003$). There were no other statistically significant differences identified in other demographic and clinical variables in female pediatric patients. However, there was a marginally significant difference in the distribution and median MAP values for indications of an SHI ($z = -1.70$, $p = 0.09$). A Kruskal-Wallis test was conducted to assess the differences in distribution between the multilevel categorical variables of race and fluid type. The results show that there was a significant difference between the underlying distributions and median MAP values for at least one of the different levels of fluid type ($X^2 = 13.22$, df = 2, $p = 0.001$).

Table 19. Differences in Underlying Distributions and Medians in Demographic and Clinical Variables and the MAP of Female Critical Pediatric Trauma Patients Treated at MHTMC from 2011 to 2016

Variable	n	Mann-Whitney U	P-Value Two-Sided
Transport Type	130	1.22	0.22
Trauma Type/MOI	130	–0.47	0.64
FAST Completed	130	–0.62	0.53
Indicated SHI	130	–1.70	0.09
Ethnicity	127	–0.85	0.39
Interfacility Transfer	130	–0.83	0.41
Intubation	130	3.58	**0.0003**
Variable	**n**	**Kruskal-Wallis H**	**P-Value**
Race	130	2.56	0.28
Fluid Type	130	13.22	**0.001**

Data from MHTMC Flight and Trauma Registry data 2011 to 2016

DISCUSSION

This study assessed correlations between MAP and demographic and clinical variables that may be used in determining pediatric blood transfusion for critical trauma situations. Our results showed a moderate overall correlation between MAP and age, weight, and height in critical pediatric trauma patients. However, there were no statistically significant correlations between MAP and the other variables. This is possibly because pediatric patients all go through the same stages of development no matter how large or small they become from their individual growth.[19–21] The underlying distributions and medians showed statistically significant differences between groups with respect to transport type, SHI indication, intubation, and blood product type. These variables may be significantly correlated with MAP because they all have different individual probabilities to influence a patient's receipt of blood products indirectly.

When the analyses were stratified by sex, the results were similar for both males and females with respect to the variables age, height, and weight. Females had slightly higher correlations for all three variables. Pediatric trauma patient data from both genders had poor correlations with HR, possibly meaning that HRs do not vary with MAP due to physiological differences between male and female development.[19–21] Little prior research has examined potential correlations between MAP and other variables that may be used in determining whether a blood transfusion is needed for pediatric trauma patients.

Our study explored demographic and clinical variables that could be assessed in the prehospital setting and used to make a relatively quick decision for blood transfusion.[5] Weight and height have previously been associated with SBP, which is typically used to derive MAP (MAP = [{2 × diastolic blood pressure} + SBP] / 3).[17, 19, 20, 22] In pediatric patients, increases in body size are typically associated with increases in the amount of tissue and muscle to perfuse.[19]

Additionally, prior research has demonstrated that pediatric females have more body fat and tissue to perfuse and start development at higher height and weight percentiles than males do during development phases.[21] This may explain the slightly stronger correlation between MAP, age, height, and weight in female patients than in male patients in our results. Age also had a direct correlation with MAP, which is reasonable since the age of a pediatric patient would tend to be highly correlated with a patient's height weight, and body size.[19–22]

Intubation status was also significantly correlated with MAP. Intubation status was statistically significant in both strata (z = 3.58, p = 0.0003 to z = 2.92, p = 0.003 in males). Female pediatric patients over 1 week in age have lungs that are more responsive to hormones than males.[23] Female toddlers have smaller lungs than male toddlers but have larger airways in relation to lung surface area than males.[24] In a prehospital study conducted in Germany, intubation was found to be a key correlate for prehospital severity in trauma.[7]

Females have also been shown to have less airway resistance than males, regardless of height.[25] Furthermore, the maximum flow rate at 50% lung volume increases after deep inspiration in females as compared to males.[26] Females also have higher forced expiratory flow rates when accounting for forced vital capacity.[27, 28] Overall, females have been found to have lower respiratory pressures than males, with decreases in airway resistance up to 18 years old.[29, 30] However, forced expiratory volume in 1 second, as well as overall forced vital capacity, is higher in females than in males.[29, 30] Therefore, females have more tissue to perfuse than males and a higher need for oxygen, which may explain the higher correlation of their MAP with intubation. Additionally, research has found patients with a GCS score of eight or below to be indicative of necessity for respiratory assistance (intubation) and of critical injury that may inherently include a low MAP.[31, 32]

Fluid type was also found to have a statistically significant difference in the underlying distribution and median MAP between its groups (PRBCs, PLM, PLTs, CRYO, THR serums, and ALB serums). Pediatric females have a greater need for iron, and iron deficiency is more common in adolescent females, which could lead to them needing more PRBC blood products, which carry approximately 200 to 250 mg of iron per unit.[30, 33] Additionally, PRBC blood products are used more frequently per protocol in most Level I trauma institutions that use scoring tools or MTPs.[5, 6, 11, 15] Also, PRBC products are used more than other products because it is one of only two types of blood product (PRBCs/PLM) typically carried in the prehospital setting due to refrigeration and storage needs.[2, 5–8, 11, 15, 34]

Transport type was significantly correlated with MAP, overall and for male pediatric patients. This may be because the most severely injured pediatric patients are transported by helicopter, which regularly carry blood products.[5–7, 15, 34] Patients whose injuries are severe enough for helicopter transport are more likely to be males, who may have severe hemorrhages and lower MAPs than females.[35] Adolescent males are 2.5 times as likely to die from unintentional injury than females[35, 36] This creates a demand for helicopter transport when a patient is critically injured or has a need for services that cannot be locally provided by the EMS units available from nearby hospitals that may not have the equipment and resources to treat a critically injured patient.[5, 34, 37]

Overall, SHIs were significantly correlated with MAP. SHIs can dictate or alter the decision to provide blood products to a trauma patient.[34] In the hospital, all anatomic injuries are scored to include SHI, and these scores are considered before the administration of blood products since hospital data has shown that head trauma patients may be negatively affected by blood products.[38] Blood products are not given for an SHI because they may affect HB levels, worsen outcomes, lengthen stays in intensive care units, and increase mortality in patients with a confirmed SHI; further, at times, patients just do not have a surgical or operative need.[7, 31, 38] However, in the prehospital setting, there is often no way to confirm that a patient has an SHI.[31, 38] Additional study is needed to better understand the influence that may or may not be present from other demographic and clinical parameters on pediatric MAP values. Future studies should focus on more clearly understanding the associations between clinical and demographic indicators, the receipt of a blood transfusion, and patient outcomes in pediatric patients.

LIMITATIONS

This study has several important limitations. All patients included in this dataset were treated at a single trauma center in Houston, Texas, and therefore our findings are not generalizable. However, this dataset included a relatively large number of pediatric trauma patients from a six-year period with patients transported to the hospital by ambulance and helicopter. Although the dataset was relatively complete, some records were missing data for variables including MAP, SBP, HR, weight, height, intubation, transport type, and ethnicity. We used the prehospital and initial arrival measurements of the variables included in the study and did not follow the changes in these variables over the complete time the patient had contact with EMS. We also did not attempt to correlate the values for demographic or clinical variables with patient long- or short-term outcomes. Using the available data, we were unable to evaluate mortality as we have no data for any variables after arrival at the hospital. We were also unable to evaluate different stages of shock, hypovolemia, deviations in distribution, and correlation with need for blood transfusion since the measures used for correlation and median analyses were cross-sectional. Future studies with longitudinal and continuous measurement of possible pediatric indicators of blood transfusion are recommended. Additionally, our analyses were retrospective and could only describe the correlation between demographic and clinical characteristics in the prehospital and hospital environment at MHTMC.

CONCLUSION

Critical pediatric trauma patient MAPs showed a moderate overall correlation with age, weight, and height. More complex statistical models should be developed as part of future research to better understand adjusted associations between clinical and demographic variables and the receipt of blood products among pediatric trauma patients.

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CHAPTER V

CONCLUSIONS AND FUTURE RESEARCH

CURRENT RESEARCH SUMMARY

Currently, the most widely accepted protocols for active and severe hemorrhage suggest giving patients MT immediately upon arrival at a hospital.[1–3] Most hospitals start damage control soon after initial intake or as soon as an attending provider makes the decision to start MTP.[4, 5] Once a blood transfusion or MT is initiated, life-saving blood products are given to patients to help mitigate lethal hemorrhage.[5–8]

The purpose of MT use immediately upon arrival at a hospital is to improve patient outcomes; thus, MT has become a recommendation in almost all severe hemorrhage patients. Evidence has demonstrated that earlier administration of MT may lead to a better prognosis for patients.[1, 5, 9, 10, 11] Over the last 7 years, there has been an increasing focus on the ways we can improve response to severe hemorrhage in critical pediatric trauma patients and subsequent health outcomes. However, there is limited research and information on how to respond to severe hemorrhage in critical pediatric trauma patients.

There are a limited number of peer-reviewed research articles that address the prehospital administration of blood products in critical pediatric trauma patients. Those articles, although informative, are typically case studies or include only a small number of patients. Therefore, they lack the ability to define the pediatric population and describe the profiles of the patients who may benefit most from receiving blood transfusion in the prehospital environment.[10] The research available that does address prehospital blood transfusion does so predominantly through the use of adult indicators and in-hospital factors.[10–13] The indicators being used in overall pediatric trauma MTP execution are the same ones present in different scoring scales (e.g., ABC, TASH, McLoughlin score) used to implement MT in adult severe hemorrhage and trauma patients.[2, 8, 14]

This study sought to identify demographic and clinical factors of pediatric trauma cases receiving both in-hospital and prehospital blood transfusions. This descriptive study also considered the variables that may be relevant to the indication of prehospital and in-hospital blood transfusion in critical pediatric trauma patients. This study also explored variables that are most influential in the process of receiving blood products in pediatric patients. Further exploration was accomplished on MAP and its correlation with other variables used in the determination of blood transfusion in pediatric patients.

CHAPTER SUMMARY POINTS

In Chapter I, a review of the literature found only four relevant articles, including a military operation, that addressed critical hemorrhage in pediatric trauma patients in the prehospital setting. All four studies used indicators, interventions, diagnostics, and tests that are more common in the hospital setting, as opposed to the prehospital setting, to initiate blood transfusions. Blood products used in the prehospital environment were mostly PRBCs, with the military operation using FDP. Even with small sample sizes, outcomes such as LOS were improved in these studies among patients who received blood products in the prehospital environment.

In these studies, inconsistent procedures and tests were used in each case to determine the continued need for blood transfusion upon arrival at a hospital facility The studies used different protocols, different versions of the same protocol, and exploratory methods to establish efficacy and efficiency of the use of prehospital blood products. Overall, there were no generalizable conclusions that could be made about how the average child would respond to blood products in the prehospital or hospital environment because there was no standard/universal protocol or indicators used in the studies. The need for universal or standardized pediatric-specific indicators was called for by a preliminary prehospital study, but further research is needed to explore their development.[10]

In Chapter II, a descriptive profile of a pediatric trauma patient receiving prehospital or in-hospital blood transfusion was created using a dataset of critical pediatric trauma patients treated at MHTMC between January 1, 2011 and December 31, 2016. Though the data were from a single trauma center, they included 397 critical pediatric trauma patients who received blood products during treatment at MHTMC in Houston, Texas, either prehospital or in-hospital.

In the dataset, patients had a median age of 12 years old (IQR 4 to 16). More than half (63%) of the patients were transported by helicopter. The patients had a median MAP of 79 (IQR 63 to 93), median SBP of 110 (IQR 85 to 128), and median HR of 111 (IQR 88 to 138). Most patients had blunt force trauma injuries (79%) and were transported directly from the scene of an emergency (70%). Patients had a median weight of 48 kg (IQR 20 to 68) and a median height of 152 cm (IQR 107 to 170). Patients were intubated almost three-quarters of the time (70%) and were most commonly given PRBCs (42%, 168 of 397). Patients received blood products over three-quarters of the time (63%, 252 of 397) and usually did not have SHIs (55%, 220 of 397). Three-quarters of patients in the dataset survived their traumatic injuries (73%). If they did expire, it was within a median of 12 hours, 36 minutes of injury.

The demographic and clinical profile of these patients can be utilized to better understand the demographic and clinical characteristics of pediatric trauma patients receiving blood transfusions at MHTMC. The profile of patients receiving blood products in the hospital versus the prehospital setting could inform further research and possibly have practice-based implications. These include what variable should be considered as part of the decision to implement blood transfusion and MT in critical pediatric trauma patients. Further prospective research is needed to explore the effects of using standardized clinical or demographic variables to implement blood transfusion in pediatric patients.

In Chapter III, the descriptive profile of patients was further developed to assess clinical and demographic characteristics of pediatric trauma patients who specifically received a transfusion in the prehospital versus in-hospital setting. Further research is needed to assess which variables may be important to the development of a scoring model for MT in pediatric patients. The adult scoring method, known as ABC, which is currently used to initiate a blood transfusion in adults and pediatric patients at MHTMC, is likely not optimal for pediatric trauma patients.[1] Age, transport type, MAP, and HR were statistically significant predictors of receipt of blood products in the prehospital environment. This supported our hypothesis that there are other variables beyond those included in ABC that should be considered in the decision to give a blood transfusion to a critical pediatric trauma patient in the prehospital environment.

In Chapter IV, we assessed evidence of correlation between the underlying distributions and median MAPs and all the other indicators in critical pediatric trauma patients. This method was employed because MAP is not currently used for determining blood transfusion in pediatric trauma patients. There was a statistically significant correlation between MAP, weight, height, indicated SHI, transport type, intubated patients, fluid type used, and receipt of blood transfusion. There were also differences in the statistically significant indicators in female versus male patients. These results supported our hypothesis that other variables such as MAP should be further explored as part of the decision to initiate blood transfusion in pediatric trauma patients.

Moreover, these results depart from the adult indicators used in the ABC method—SBP, HR, positive FAST, and penetrating trauma—currently used at MHTMC to initiate a blood transfusion.[1] Further research is needed to assess the possible benefits and challenges of using MAP as part of scoring scales.[2, 8, 14]

DIRECTIONS FOR FURTHER RESEARCH

Moving forward, there are many opportunities for future research related to prehospital and in-hospital pediatric blood transfusion. More research is needed to assess the use of a set of possible universal indicators and their subsequent generalization across the pediatric population. These variables could be used to help identify individuals that may be predisposed to the possible need of blood transfusion in emergency situations. Also, further research is needed using more complex modeling to control for potential confounding and effect measure modification.

Having a set of validated variables to indicate the need for pediatric trauma transfusion would improve our understanding of the role played by factors such as physiology, age, and hemodynamic differences. Standalone pediatric blood transfusion protocols are also needed. Further research could look at the use of such protocols in medical emergencies, as well as in response to diseases, chronic condition treatment, and other settings. Additional research is also needed to identify variables that could be incorporated into new scoring scales that could be used in the pediatric environment that would be comparable to those currently used in the adult environment (ABC, TASH, McLoughlin).[1, 2, 8] This would improve the generalizability of results related to the overall impact of prehospital and in-hospital blood transfusion on outcomes including survival of pediatric patients.

Larger datasets from multiple hospitals could also inform the study of outcomes of pediatric patients who receive prehospital blood transfusion Variables such as LOS may be used to more accurately assess the validity of any new pediatric-specific blood transfusion protocol. Other questions that could be answered include those related to the amount of blood needed to stabilize a patient or the most appropriate timing for a pediatric trauma patient to receive blood products. A multicenter study testing a new protocol or scoring tool with standardized indicators to assess efficacy and effectiveness administering blood products to pediatric patients could be implemented to assess whether pediatric protocols are more effective than adult protocols.

Finally, further research is needed to determine if blood products are more appropriate for use in certain pediatric trauma types, such as motor vehicle collisions, gunshot wounds, and falls. Once we know the general efficacy and effectiveness of pediatric blood transfusion in response to different types of trauma, the types of blood product used could be studied. For example, do pediatric trauma patients with SHIs have better outcomes when receiving PBRCs over PLTs or PLM? Much more work is needed to maximize the positive impact of prehospital blood transfusion in the pediatric trauma population.

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