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# Association of Prehospital Transfusion With Mortality in Pediatric Trauma

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Supplemental content

**IMPORTANCE** Optimal hemostatic resuscitation in pediatric trauma is not well defined.

**OBJECTIVE** To assess the association of prehospital blood transfusion (PHT) with outcomes in injured children.

**DESIGN, SETTING, AND PARTICIPANTS** This retrospective cohort study of the Pennsylvania Trauma Systems Foundation database included children aged 0 to 17 years old who received a PHT or emergency department blood transfusion (EDT) from January 2009 and December 2019. Interfacility transfers and isolated burn mechanism were excluded. Analysis took place between November 2022 and January 2023.

**EXPOSURE** Receipt of a blood product transfusion in the prehospital setting compared with the emergency department.

**MAIN OUTCOMES AND MEASURES** The primary outcome was 24-hour mortality. A 3:1 propensity score match was developed balancing for age, injury mechanism, shock index, and prehospital Glasgow Comma Scale score. A mixed-effects logistic regression was performed in the matched cohort further accounting for patient sex, Injury Severity Score, insurance status, and potential center-level heterogeneity. Secondary outcomes included in-hospital mortality and complications.

**RESULTS** Of 559 children included, 70 (13%) received prehospital transfusions. In the unmatched cohort, the PHT and EDT groups had comparable age (median [IQR], 47 [9-16] vs 14 [9-17] years), sex (46 [66%] vs 337 [69%] were male), and insurance status (42 [60%] vs 245 [50%]). The PHT group had higher rates of shock (39 [55%] vs 204 [42%]) and blunt trauma mechanism (57 [81%] vs 277 [57%]) and lower median (IQR) Injury Severity Score (14 [5-29] vs 25 [16-36]). Propensity matching resulted in a weighted cohort of 207 children, including 68 of 70 recipients of PHT, and produced well-balanced groups. Both 24-hour (11 [16%] vs 38 [27%]) and in-hospital mortality (14 [21%] vs 44 [32%]) were lower in the PHT cohort compared with the EDT cohort, respectively; there was no difference in in-hospital complications. Mixed-effects logistic regression in the postmatched group adjusting for the confounders listed above found PHT was associated with a significant reduction in 24-hour (adjusted odds ratio, 0.46; 95% CI, 0.23-0.91) and in-hospital mortality (adjusted odds ratio, 0.51; 95% CI, 0.27-0.97) compared with EDT. The number needed to transfuse in the prehospital setting to save 1 child's life was 5 (95% CI, 3-10).

**CONCLUSIONS AND RELEVANCE** In this study, prehospital transfusion was associated with lower rates of mortality compared with transfusion on arrival to the emergency department, suggesting bleeding pediatric patients may benefit from early hemostatic resuscitation. Further prospective studies are warranted. Although the logistics of prehospital blood product programs are complex, strategies to shift hemostatic resuscitation toward the immediate postinjury period should be pursued.

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Hemorrhagic shock is one of the most common causes of preventable mortality in injured children.[1-5] Early hemorrhagic shock is challenging to identify, as children have a physiologic reserve that maintains normotension to the verge of circulatory collapse. Clinicians must be vigilant for signs of shock (altered mentation, tachycardia, and hypotension) in injured children and implement early hemostatic resuscitation as needed.[6,7] There is increasing adult literature showing restrictive prehospital crystalloid and early balanced blood product resuscitation in combat and civilian trauma improves outcomes.[8-16] Therefore, resuscitation practices are shifting away from crystalloid and toward initial resuscitation with blood products in injured adult patients.

However, prehospital blood product transfusion remains a rare practice in pediatric trauma due to a paucity of quality research to support the practice. Current literature suggests children in hemorrhagic shock benefit from fewer crystalloid boluses to prevent the deleterious effects of dilution and volume overload.[17-19] Further, small single-center studies have shown prehospital blood transfusion (PHT) is associated with improved makers of coagulopathy (international normalized ratio, fibrinogen) and shock (pediatric-adjusted shock index, lactate, and base deficit) with no differences in mortality or other clinical outcomes.[20-24] These studies suggest the safety and feasibility of PHT, but clinical benefit has yet to be elucidated. Given the paucity of high-quality research on early resuscitation strategies in injured children, the Pediatric Traumatic Hemorrhagic Shock Consensus Conference proposed several research priorities regarding pediatric traumatic hemorrhagic shock, which included improving recognition and identifying most effective treatment of hemorrhagic shock in children.[25] This current study aligns with this research priority and was performed to determine if PHT is associated with decreased mortality in injured children using a statewide trauma database.

## Key Points

**Question** Is prehospital transfusion of blood products associated with outcomes in injured children?

**Findings** In a cohort study of a statewide trauma database, injured children who received prehospital blood product transfusions had significantly lower odds of 24-hour and in-hospital mortality compared with injured children who received a transfusion in the emergency department. For every unit of red blood cells transfused in the prehospital setting, children had 2 times increased odds of survival.

**Meaning** Bleeding children may benefit from early hemostatic resuscitation; strategies to shift hemostatic resuscitation to the immediate postinjury phase should be considered.

## Methods

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies. Research procedures and analyses were approved by the University of Pittsburgh institutional review board.

### Database

A retrospective review of the Pennsylvania Trauma Systems Foundation registry was performed. More than 50 trauma centers contribute data to this statewide trauma registry as a stipulation of trauma center accreditation. The Pennsylvania Trauma Systems Foundation database includes all patients with a diagnosis of trauma defined by *International Statistical Classification of Diseases, Tenth Revision, Clinical Modification* injury codes who were admitted to the hospital for at least 36 hours (or >24 hours if Injury Severity Score [ISS] >9) as well as all trauma deaths. This statewide trauma database was queried for children aged 0 to 17 years who received a red blood cell transfusion either in the emergency department (ie, emergency department blood transfusion [EDT]) or in the prehospital setting (ie, PHT) between January 2009 and December 2019. Isolated burn patients were excluded as were interfacility transfers (both admitted from and discharged to another trauma center) to decrease confounding as these children are more likely to have been resuscitated and stabilized prior to arrival at the definitive treatment facility.

Data collected included patient demographics, injury mechanism and ISS, Glasgow Coma Scale score (GCS), admission vital signs, ventilator days, and hospital and intensive care unit length of stay. Data on race were self-reported on admission. Severe traumatic brain injury was defined as Head Abbreviated Injury score of 3 or higher. Shock index was calculated as heart rate/blood pressure.[26] Prehospital vital signs were used when available; otherwise admission vital signs were included as baseline vital sign values. Prehospital data of interest included prehospital emergency medical service (EMS) professional level (ie, advance life support vs basic life support), scene and transport times, transport mode, and prehospital red blood cell transfusion volume (reported in units). If the PHT field was blank, there was assumed to be no transfusion. The primary outcome of interest was 24-hour mortality. Secondary outcomes included in-hospital mortality and in-hospital complications including venous thromboembolism (combined outcome of deep vein thrombosis and pulmonary embolism), sepsis, acute kidney injury, and acute respiratory distress syndrome as defined by standard registry definition.

### Missing Data

Missing data for relevant variables ranged from 0.2% (ISS) to 9.5% (race), with a mean of 1.1%. The propensity score analysis was used to balance the distribution of missingness between groups by including missing as a category for variables in the propensity score with missing data. A sensitivity analysis was performed using complete cases not including the missing category and demonstrated no significant differences in the outcomes studied. Thus, results for the full cohort that include the missing category are reported below.

### Propensity Score Matching

Since children who receive blood products in the prehospital setting may differ from those who undergo transfusion in the hospital, propensity score matching was used to address selection bias. A model was developed to predict the likelihood of PHT based on age, injury mechanism, shock index, and prehospital GCS. The propensity score model was developed based on variables that would be available to prehospital EMS professionals and potentially influence the decision to initiate blood transfusion. Matching was performed using a 3:1 nearest neighbor algorithm. Absolute standardized mean differences were used to assess the balance of covariates after matching; an absolute standardized mean differences less than 0.1 suggests a good balance between groups, representing lower rates of nonoverlap in the distribution of a given variable between the 2 groups.[27]

### Statistical Analysis

Data were summarized as median (IQR), counts, or percentage. A mixed-effects logistic regression model was constructed to determine the association between 24-hour survival and PHT compared with EDT. The model was adjusted for sex, ISS, and insurance status, as the propensity match already accounted for balance in the following covariates: age, injury mechanism, shock index, and prehospital GCS. The model included a random intercept for trauma facility to account for a potential center-level heterogeneity. An E-value was calculated to assess for potential unmeasured confounding.[28] These methods were also used to generate a mixed-effects logistic regression model with in-hospital mortality as the outcome.

The number needed to treat to reduce 24-hour and in-hospital mortality was calculated using the following formula: 1 / absolute risk reduction or 1 / (EDT mortality rate) − (PHT mortality rate). All analyses were performed using Stata version 16 (StataCorp). Analysis took place between November 2022 and January 2023.

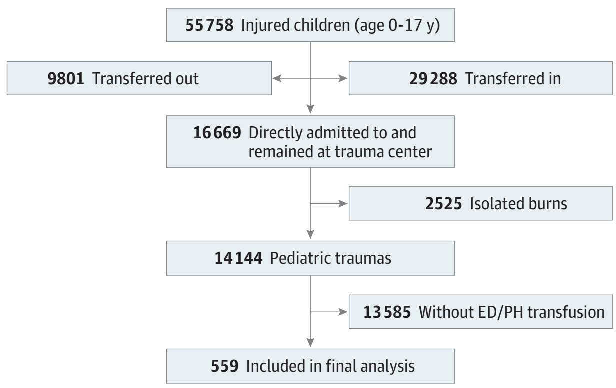
## Results

After applying the exclusion criteria, 559 children were included in the final analysis (**Figure**). In this cohort, 70 children (13%) received a prehospital blood transfusion and 489 (87%) received an EDT. At baseline, the PHT group had higher rates of shock, blunt vs penetrating trauma, and were more likely to identify as White (PHT: 52 [76%]) vs EDT: 247 [53%]). There was no difference in age, sex, GCS, or rate of severe traumatic brain injury (**Table 1**). While more children who received a PHT were transported by helicopter EMS compared with ground EMS, there was no difference in prehospital EMS professionals level of care (PHT advance life support crew, 65 [93%] vs EDT advance life support crew, 379 [96%]; Table 1). The unadjusted analysis results can be found in the eTable in Supplement 1.

### Propensity Match and Mixed-Effects Logistic Regression Model

From the total cohort of 559 individuals, propensity matching resulted in a weighted cohort of 207 children that included 68 of 70 recipients of PHT. The matching procedure

**Figure. Study Population Flowchart**




Children younger than 18 years who received a red blood cell transfusion in the emergency department (ED) or prehospital (PH) setting from the Pennsylvania Trauma Systems Foundation registry were analyzed. Isolated burn patients and interfacility transfers were excluded.

produced well balanced groups, with all absolute standardized differences less than 0.15 for each variable used in the propensity score (eFigures 1 and 2 in Supplement 1). Demographic and injury characteristics for the postmatch cohort can be found in **Table 2**. Postmatched 24-hour (11 [16%] vs 38 [27%]) and in-hospital mortality (14 [21%] vs 44 [32%]) were lower in the PHT cohort compared with the EDT cohort, respectively. In the mixed-effects logistic regression model adjusting further for ISS, sex, and insurance (**Table 3**), there was reduced odds of 24-hour mortality in the matched cohort for recipients of PHT compared with EDT (adjusted odds ratio [OR], 0.46; 95% CI, 0.23-0.91). The E-value for this was 3.80, meaning residual confounding could explain the observed association if there was an unmeasured covariate having an OR exceeding 3.80. The strongest associations in the model were PHT with an OR of 0.45 (95% CI, 0.23-0.91) followed by public insurance with an OR of 0.77 (95% CI, 0.52-1.13), meaning it would be unlikely that an unmeasured or unknown confounder would have a substantially greater effect on mortality than these known risk factors. For in-hospital mortality, there also was reduced odds of death in the matched cohort for recipients of PHT compared with EDT (adjusted OR, 0.51; 95% CI, 0.27-0.97). The E-value for this in-hospital mortality model was 3.33. In the matched cohort, both 24-hour mortality (11 [16%] vs 38 [27%]) and in-hospital (14 [21%] vs 44 [32%]) mortality were lower in the PHT group. The number needed to treat to reduce 24-hour mortality was 6 (95% CI, 3-10) and the number needed to treat to reduce in-hospital mortality was 5 (95% CI, 3.2-9.7).

## Discussion

In this cohort study using a statewide trauma database, injured children who received a prehospital blood transfusion had decreased 24-hour and in-hospital mortality after propensity matching for age, injury mechanism, shock, and GCS

Table 1. Demographics and Injury Characteristics of the Prehospital vs Emergency Department Transfusion Group

| Characteristic | No. (%) Emergency department transfusion (n = 489) | No. (%) Prehospital transfusion (n = 70) |
|---|---|---|
| Age, median (IQR), y | 14 (9-17) | 14 (9-16) |
| Sex | | |
| Female | 152 (31) | 24 (34) |
| Male | 337 (69) | 46 (66) |
| Race | | |
| Asian/Pacific Islander | 7 (2) | 2 (3) |
| Black | 186 (40) | 12 (18) |
| White | 247 (53) | 52 (76) |
| Other[a] | 22 (5) | 2 (3) |
| Mechanism of injury | | |
| Blunt | 277 (57) | 57 (81) |
| Penetrating | 212 (43) | 13 (19) |
| Injury Severity Score, median (IQR) (n = 558) | 25 (16-36) | 14 (5-29) |
| Prehospital data | | |
| Transport EMS professional: ALS (n = 463) | 379 (96) | 65 (93) |
| Transport mode (n = 409) | | |
| GEMS | 232 (68) | 36 (52) |
| HEMS | 107 (32) | 34 (48) |
| Scene time GEMS, median (IQR) (n = 241) | 9 (7-13) | 13 (8-15) |
| Transport time GEMS, median (IQR), min (n = 241) | 13 (9-20) | 20 (11-27) |
| Scene time HEMS, median (IQR), min (n = 137) | 22 (15-28) | 26 (22-34) |
| Transport time HEMS, median (IQR), min (n = 138) | 17 (13-24) | 21 (15-27) |
| Admission vital signs | | |
| Temperature, median (IQR) | 36.2 (35.6-36.7) | 36.6 (36.1-36.9) |
| Shock[b] | 204 (42) | 39 (55) |
| Glasgow Coma Scale score, median (IQR) | 14 (3-15) | 15 (3-15) |
| Transfusions, median (IQR), RBC unit | | |
| Prehospital | NA | 2 (1-2) |
| In emergency department | 2 (1-4) | 0 (0-2) |
| Total | 2 (1-4) | 2 (2-4) |

Abbreviations: ALS, advance life support; EMS, emergency medical services; GEMS, ground emergency medical services; HEMS, helicopter emergency medical services; NA, not applicable; RBC, red blood cell.

[a] Other was a variable in the database.

[b] Shock defined by shock index (heart rate/systolic blood pressure).

and adjusting for sex, ISS, insurance, and center-level variation. These data suggest bleeding pediatric patients benefit from early hemostatic resuscitation. Although the logistics of prehospital blood product programs are complex, strategies to shift hemostatic resuscitation toward the immediate post injury period should be pursued. Multicenter, prospective studies on PHT in injured children are needed to confirm these findings in children with hemorrhagic shock.

Death from hemorrhagic shock typically occurs soon after injury, emphasizing the need for prompt diagnosis and treatment.[29-31] Damage control resuscitation emphasizes rapid hemorrhage control, minimizing crystalloid, and early use of balanced blood product resuscitation.[32] Time to intervention is key. In bleeding adults, the risk of mortality increases by 5% for every 1-minute delay in transfusing blood products.[33] While no data quantify the mortality risk in children when resuscitation is delayed, the present study indicates reducing the time to transfusion may be sufficient to improve outcomes in children with severe traumatic bleeding.

More children in the PHT group were transported by air, and those who were had statistically longer scene times by a median of 4 minutes. While this seemingly small difference is perhaps not clinically significant, this raises the question of scoop and run vs stay and play in prehospital EMS care. In children, there may be a particular benefit of prompt recognition and treatment of shock as it is poorly tolerated and a sign of impending circulatory collapse. Transfusion may be considered an intervention that, when applied expeditiously in the setting of hemorrhagic shock, can be lifesaving. The ability to transfuse blood products in the prehospital setting to severely injured children at the expense of a few additional minutes, to obtain intravenous access and infuse products, may improve survival. This hypothesis, generated by the study data presented above, needs to be studied in a prospective and rigorous fashion.

The low incidence of PHT in pediatric trauma in this database and nationwide, as well as the lack of standardized practice guidelines, is likely multifactorial. Shock can be challenging to identify in children due to compensatory mechanisms that maintain normotension and differences in normal vital sign ranges by age groups. Other challenges include the infrequency of severe pediatric trauma requiring transfusion limiting the experience of any 1 health care professional, the challenge of obtaining intravenous access in children, and the need for weight-based dosing protocols. Despite these barriers, the finding that PHT was associated with improved survival in this cohort can inform state officials, EMS professionals, and trauma systems on the importance of transfusing injured children in the prehospital setting so that appropriate education, training, and protocols can be enacted.

Adult data have shown prehospital blood transfusions are a lifesaving intervention for stabilizing and treating major hemorrhage in military and civilian populations until surgical services are available.[8,12,14-16] In a retrospective review of military combat casualties undergoing medical evacuation, Shackelford et al[14] found PHT was associated with decreased 24-hour (adjusted hazard ratio, 0.26; 95% CI, 0.08-0.84; $P = .02$) and 30-day (hazard ratio, 0.39; 95% CI, 0.16-0.92; $P = .03$) mortality in study individuals with acute bleeding or shock. In a multicenter retrospective review, Holcomb et al[34] found prehospital plasma and red blood cell transfusions were associated with improved acid-base status on admission and decreased 24-hour blood product use after controlling for arrival systolic blood pressure, injury mechanism, base deficit, rapid thromboelastography-activated clotting time, and prehospital crystalloid volume. They also found a reduction in the risk of 6-hour mortality (OR, 0.23; 95% CI, 0.06-0.89; $P = .03$) with minimal blood product waste (1.9%). In the PAMPer trial,[15]

Table 2. Demographics and Injury Characteristics of Postpropensity-Matched Prehospital Transfusion Group vs Emergency Department Transfusion Group

| Characteristic | Matched cohort (n = 207) | Emergency department transfusion (n = 139) | Prehospital transfusion (n = 68) |
|---|---|---|---|
| Age, median (IQR), y | 14 (8-16) | 14 (7-16) | 14 (9-16) |
| Sex, No. (%) | | | |
| Female | 78 (38) | 54 (39) | 24 (35) |
| Male | 129 (62) | 85 (61) | 44 (65) |
| Race, No. (%) | | | |
| Asian/Pacific Islander | 3 (1) | 2 (1) | 1 (1) |
| Black | 51 (25) | 39 (28) | 12 (18) |
| White | 135 (65) | 84 (60) | 51 (75) |
| Other[a] | 10 (5) | 8 (6) | 2 (3) |
| Missing | 8 (4) | 6 (4) | 2 (3) |
| Mechanism of injury, No. (%) | | | |
| Blunt | 162 (78) | 106 (76) | 56 (82) |
| Penetrating | 45 (22) | 33 (24) | 12 (18) |
| Shock index, median (IQR) | 1 (1-2) | 1 (1-2) | 1 (1-2) |
| Prehospital Glasgow Coma Scale score, median (IQR) | 15 (3-15) | 15 (3-15) | 15 (3-15) |
| Injury Severity Score, median (IQR) | 21 (10-34) | 25 (14-35) | 14 (6-29) |
| Insurance, No. (%) | | | |
| Public/self-pay | 85 (42) | 58 (43) | 27 (40) |
| Commercial | 119 (58) | 78 (57) | 41 (60) |

[a] Other was a variable in the database.

230 injured adults were randomized to 2 units of plasma vs standard of care before arrival to a trauma center. This study showed 30-day mortality was lower in the plasma group compared to the standard of care group (23.2% vs 33%; *P* = .03). In a combined analysis of the COMBAT and PAMPer trials, 626 injured adults with hemorrhagic shock who received prehospital plasma had significant survival benefits (hazard ratio, 0.65; 95% CI, 0.47-0.90; *P* = .01).[13]

Pediatric data are limited by small observational or retrospective studies. Early military and civilian studies showed PHT is feasible and safe.[20,35] A retrospective review of 16 children who received prehospital red blood cells or plasma via civilian air ambulance found improvements in hemoglobin, base deficit, and unexpected survivors.[22] More recently, Shirek et al[24] performed a single-center retrospective review of injured children arriving to a pediatric trauma center within 4 hours of injury who received prehospital blood (38 children) vs prehospital crystalloid plus blood product transfusion within 6 hours of hospital arrival (38 children). Children who received a PHT had significantly improved lactate (−62% vs −8%; *P* = .038) and hemoglobin (*P* = .04) levels on arrival and received less crystalloid within 12 hours of admission (52.3 mL/kg vs 86.6 mL/kg; *P* = .017). There were no differences in complications or other clinical outcomes. In a propensity-matched cohort of 17 civilian pediatric trauma patients, Van Dijck et al[23] found improved coagulation indices in children who received PHT with higher fibrinogen levels (239 vs 148; *P* = .007) and more rapid correction of international normalized ratio (6.4 vs 19.1 hours; *P* = .042). Additionally, children in the PHT group received significantly less crystalloid (4.3 mL/kg vs 16.9 mL/kg; *P* = .004) and significantly more plasma (3 vs 1 unit; *P* = .004).

Table 3. Mixed-Effects Logistic Regression Model Showing a Significant Association Between Prehospital Transfusion and Reduced 24-Hour and In-Hospital Mortality vs Emergency Department Transfusion in a Propensity-Matched Cohort

| Variable[a] | Odds ratio (95% CI) |
|---|---|
| **24-h Mortality** | |
| Prehospital transfusion | 0.46 (0.23-0.91) |
| Injury Severity Score | 1.04 (1.02-1.05) |
| Sex | |
| Female | 1 [Reference] |
| Male | 0.98 (0.65-1.48) |
| Insurance | |
| Public/self-pay | 1 [Reference] |
| Commercial | 0.77 (0.52-1.13) |
| **In-hospital mortality** | |
| Prehospital transfusion | 0.51 (0.27-0.97) |
| Injury Severity Score | 1.04 (1.03-1.06) |
| Sex | |
| Female | 1 [Reference] |
| Male | 0.90 (0.60-1.26) |
| Insurance | |
| Public/self-pay | 1 [Reference] |
| Commercial | 0.67 (0.46-0.97) |

[a] The model included a random effect for trauma facility to account for a potential center-level effect. The propensity match accounts for balance in age, injury mechanism, shock index, and prehospital Glasgow Coma Scale score.

There also were no differences in clinical outcomes, although the study was underpowered to detect a difference in mortality. Coagulation assays and crystalloid volumes were not available for analysis in the Pennsylvania Trauma Systems

Foundation database, although these are important covariates and outcomes to include in future trials.

### Limitations

The major limitation of this study is the small sample size due to the infrequency of PHTs in children. This prevented robust subgroup analyses in cohorts of interest (traumatic brain injury, very young age, and transport mode). Despite this limitation, this study represents the largest cohort to date on PHT practices in injured children. Given the nature of the statewide database, it was not possible to determine the timing of transfusion initiation or the transfusion criteria used prior to administering blood in the prehospital setting. Additionally, certain covariates of interest were not available for analysis. While crystalloid volumes were recorded, the wide-ranging categories (none, <500 mL, 500-2000 mL, and >2000 mL) have limited applicability in children (eg, receipt of 500 mL vs 2000 mL would have a substantially different impact in a 20-kg child). Administration of tranexamic acid and other hemostatic adjuncts were not included in the database. These variables will need to be further elucidated in future studies. Finally, this statewide database may not represent all centers and there likely was diversity in the practices and protocols across sites; however, the multicenter nature of the study lends to real-life application and generalization of the study results.

## Conclusion

In summary, PHT is rare in injured children. In this study, lower odds of 24-hour and in-hospital mortality were observed in injured children who received blood transfusions proximate to the time of their injury. PHTs in children have been shown to be safe and feasible in prior studies. These data expand on this concept in a statewide cohort nearly 3 times the size of the existing pediatric studies on PHTs and show that this intervention has the potential to improve survival in pediatric trauma. Although prehospital pediatric transfusions can be logistically challenging, requiring coordination between blood banks, emergency medical staff, and accepting trauma facilities to ensure blood products are available and not going to waste, many systems have overcome these challenges through multidisciplinary collaborative efforts. Future multicenter, prospective studies are needed to confirm these findings and define criteria for PHTs in children prior to broad-spread implementation of PHT programs.

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*Concept and design:* Abou-Khalil, Gaines, Leeper.
*Acquisition, analysis, or interpretation of data:* Morgan, Strotmeyer, Richardson, Gaines, Leeper.
*Drafting of the manuscript:* Morgan.
*Critical revision of the manuscript for important intellectual content:* All authors.
*Statistical analysis:* Morgan, Strotmeyer, Leeper.
*Administrative, technical, or material support:* Richardson, Gaines.
*Supervision:* Gaines, Leeper.

**Conflict of Interest Disclosures:** None reported.

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### REFERENCES

1. Davis JS, Satahoo SS, Butler FK, et al. An analysis of prehospital deaths: who can we save? *J Trauma Acute Care Surg*. 2014;77(2):213-218. doi:10.1097/TA.0000000000000292

2. Fox EE, Holcomb JB, Wade CE, Bulger EM, Tilley BC; PROPPR Study Group. Earlier endpoints are required for hemorrhagic shock trials among severely injured patients. *Shock*. 2017;47(5):567-573. doi:10.1097/SHK.0000000000000788

3. Kwon AM, Garbett NC, Kloecker GH. Pooled preventable death rates in trauma patients: meta analysis and systematic review since 1990. *Eur J Trauma Emerg Surg*. 2014;40(3):279-285. doi:10.1007/s00068-013-0364-5

4. Drake SA, Holcomb JB, Yang Y, et al. Establishing a regional trauma preventable/potentially preventable death rate. *Ann Surg*. 2020;271(2):375-382. doi:10.1097/SLA.0000000000002999

5. West BA, Rudd RA, Sauber-Schatz EK, Ballesteros MF. Unintentional injury deaths in children and youth, 2010-2019. *J Safety Res*. 2021;78:322-330. doi:10.1016/j.jsr.2021.07.001

6. Leeper CM, McKenna C, Gaines BA. Too little too late: hypotension and blood transfusion in the trauma bay are independent predictors of death in injured children. *J Trauma Acute Care Surg*. 2018;85(4):674-678. doi:10.1097/TA.0000000000001823

7. Nystrup KB, Stensballe J, Bøttger M, Johansson PI, Ostrowski SR. Transfusion therapy in paediatric trauma patients: a review of the literature. *Scand J Trauma Resusc Emerg Med*. 2015;23:21. doi:10.1186/s13049-015-0097-z

8. Brown JB, Guyette FX, Neal MD, et al. Taking the blood bank to the field: the design and rationale of the Prehospital Air Medical Plasma (PAMPer) trial. *Prehosp Emerg Care*. 2015;19(3):343-350. doi:10.3109/10903127.2014.995851

9. Guyette FX, Sperry JL, Peitzman AB, et al. Prehospital blood product and crystalloid resuscitation in the severely injured patient: a secondary analysis of the prehospital air medical plasma trial. *Ann Surg*. 2021;273(2):358-364. doi:10.1097/SLA.0000000000003324

10. Powell EK, Hinckley WR, Gottula A, Hart KW, Lindsell CJ, McMullan JT. Shorter times to packed red blood cell transfusion are associated with decreased risk of death in traumatically injured patients. *J Trauma Acute Care Surg*. 2016;81(3):458-462. doi:10.1097/TA.0000000000001078

11. Sheppard FR, Schaub LJ, Cap AP, et al. Whole blood mitigates the acute coagulopathy of trauma and avoids the coagulopathy of crystalloid resuscitation. *J Trauma Acute Care Surg*. 2018;85(6):1055-1062. doi:10.1097/TA.0000000000002046

12. Malsby RF III, Quesada J, Powell-Dunford N, et al. Prehospital blood product transfusion by U.S. army MEDEVAC during combat operations in Afghanistan: a process improvement initiative. *Mil Med*. 2013;178(7):785-791. doi:10.7205/MILMED-D-13-00047

13. Pusateri AE, Moore EE, Moore HB, et al. Association of prehospital plasma transfusion with survival in trauma patients with hemorrhagic shock when transport times are longer than 20 minutes. *JAMA Surg*. 2020;155(2):e195085. doi:10.1001/jamasurg.2019.5085

14. Shackelford SA, Del Junco DJ, Powell-Dunford N, et al. Association of prehospital blood product transfusion during medical evacuation of combat casualties in Afghanistan with acute and 30-day survival. *JAMA*. 2017;318(16):1581-1591. doi:10.1001/jama.2017.15097

15. Sperry JL, Guyette FX, Brown JB, et al; PAMPer Study Group. Prehospital plasma during air medical transport in trauma patients at risk for hemorrhagic shock. *N Engl J Med*. 2018;379(4):315-326. doi:10.1056/NEJMoa1802345

16. Deeb AP, Guyette FX, Daley BJ, et al. Time to early resuscitative intervention association with mortality in trauma patients at risk for hemorrhage. *J Trauma Acute Care Surg*. 2023;94(4):504-512. doi:10.1097/TA.0000000000003820

17. Polites SF, Moody S, Williams RF, et al. Timing and volume of crystalloid and blood products in pediatric trauma: an Eastern Association for the Surgery of Trauma multicenter prospective observational study. *J Trauma Acute Care Surg*. 2020;89(1):36-42. doi:10.1097/TA.0000000000002702

18. Polites SF, Nygaard RM, Reddy PN, et al. Multicenter study of crystalloid boluses and transfusion in pediatric trauma: when to go to blood? *J Trauma Acute Care Surg*. 2018;85(1):108-112. doi:10.1097/TA.0000000000001897

**19**. Schauer SG, April MD, Becker TE, Cap AP, Borgman MA. High crystalloid volumes negate benefit of hemostatic resuscitation in pediatric wartime trauma casualties. *J Trauma Acute Care Surg*. 2020;89(2S Suppl 2):S185-S191. doi:10.1097/TA.0000000000002590

**20**. Fahy AS, Thiels CA, Polites SF, et al. Prehospital blood transfusions in pediatric trauma and nontrauma patients: a single-center review of safety and outcomes. *Pediatr Surg Int*. 2017;33(7):787-792. doi:10.1007/s00383-017-4092-5

**21**. Moors XRJ, Bouman SJM, Peters JH, et al. Prehospital blood transfusions in pediatric patients by a helicopter emergency medical service. *Air Med J*. 2018;37(5):321-324. doi:10.1016/j.amj.2018.05.008

**22**. Potter DD, Berns KS, Elsbernd TA, Zietlow SP. Prehospital use of blood and plasma in pediatric trauma patients. *Air Med J*. 2015;34(1):40-43. doi:10.1016/j.amj.2014.07.037

**23**. Van Dijck CP, Stansbury LG, Latimer AJ, et al. Hemostatic resuscitation of pediatric trauma patients during air medical transport: a retrospective matched cohort study. *Air Med J*. 2021;40(5):344-349. doi:10.1016/j.amj.2021.04.004

**24**. Shirek G, Phillips R, Shahi N, et al. To give or not to give? blood for pediatric trauma patients prior to pediatric trauma center arrival. *Pediatr Surg Int*. 2022;38(2):285-293. doi:10.1007/s00383-021-05015-9

**25**. Russell RT, Bembea MM, Borgman MA, et al. Pediatric traumatic hemorrhagic shock consensus conference research priorities. *J Trauma Acute Care Surg*. 2023;94(1S Suppl 1):s11-s18. doi:10.1097/TA.0000000000003802

**26**. Nordin A, Coleman A, Shi J, et al. Validation of the age-adjusted shock index using pediatric trauma quality improvement program data. *J Pediatr Surg*. 2017;S0022-3468(17)30645-0. doi:10.1016/j.jpedsurg.2017.10.023

**27**. Austin PC, Stuart EA. Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies. *Stat Med*. 2015;34(28):3661-3679. doi:10.1002/sim.6607

**28**. Haneuse S, VanderWeele TJ, Arterburn D. Using the E-value to assess the potential effect of unmeasured confounding in observational studies. *JAMA*. 2019;321(6):602-603. doi:10.1001/jama.2018.21554

**29**. Demetriades D, Murray J, Charalambides K, et al. Trauma fatalities: time and location of hospital deaths. *J Am Coll Surg*. 2004;198(1):20-26. doi:10.1016/j.jamcollsurg.2003.09.003

**30**. Theodorou CM, Galganski LA, Jurkovich GJ, et al. Causes of early mortality in pediatric trauma patients. *J Trauma Acute Care Surg*. 2021;90(3):574-581. doi:10.1097/TA.0000000000003045

**31**. McLaughlin C, Zagory JA, Fenlon M, et al. Timing of mortality in pediatric trauma patients: a National Trauma Data Bank analysis. *J Pediatr Surg*. 2018;53(2):344-351. doi:10.1016/j.jpedsurg.2017.10.006

**32**. Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma*. 2007;62(2):307-310. doi:10.1097/TA.0b013e3180324124

**33**. Meyer DE, Vincent LE, Fox EE, et al. Every minute counts: time to delivery of initial massive transfusion cooler and its impact on mortality. *J Trauma Acute Care Surg*. 2017;83(1):19-24. doi:10.1097/TA.0000000000001531

**34**. Holcomb JB, Donathan DP, Cotton BA, et al. Prehospital transfusion of plasma and red blood cells in trauma patients. *Prehosp Emerg Care*. 2015;19(1):1-9. doi:10.3109/10903127.2014.923077

**35**. Lauby RS, Cuenca CM, Borgman MA, et al. An analysis of outcomes for pediatric trauma warm fresh whole blood recipients in Iraq and Afghanistan. *Transfusion*. 2021;61(suppl 1):S2-S7. doi:10.1111/trf.16504