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An Activation Failure: Factors Associated With Undertriage of Pediatric Major Trauma Victims

Jillian Gorski, MD, MS,[a,*] *Seth Goldstein, MD, MPhil,*[b] *Suhail Zeineddin, MD,*[b] *and Sriram Ramgopal, MD*[c]

[a] *Division of Pediatric Emergency Medicine, Department of Emergency Medicine, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin*

[b] *Department of Surgery, Ann & Robert H. Lurie Children's Hospital of Chicago, Northwestern University Feinberg School of Medicine, Chicago, Illinois*

[c] *Division of Emergency Medicine, Department of Pediatrics, Ann & Robert H. Lurie Children's Hospital of Chicago, Northwestern University Feinberg School of Medicine, Chicago, Illinois*

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ABSTRACT

Introduction: Undertriage of children contributes to poorer clinical outcomes. The objective of this study was to determine factors associated with undertriage of pediatric major trauma victims.

Methods: We performed a retrospective cross-sectional study of children (aged < 16 ys) using the 2021 American College of Surgeons National Trauma Data Bank. We identified children who met the definition of major trauma defined by the Standard Triage Assessment Tool. We performed multivariable logistic regression to determine factors associated with undertriage, defined as encounters which met criteria, but did not receive highest-level activation.

Results: Of 97,812 included children, 5.3% met major trauma criteria. Undertriage occurred in 34.4% of encounters with major trauma. Factors associated with undertriage included fall and striking mechanisms, missing blood pressure, private vehicle arrival, and incoming interfacility transfers. Hypotension, decreased level of consciousness, prehospital and in-hospital intubation, tachycardia, hypothermia, penetrating mechanism, presentation to a pediatric level 2 or adult level 1 trauma center relative to pediatric level 1 center, and arrival by flight were associated with lower odds of undertriage.

Conclusions: Many children with major trauma were undertriaged, particularly those presenting with lower-risk histories, such as private vehicle arrivals and fall mechanisms. Future work should seek to develop risk-stratification systems that can better identify children with major trauma, with an emphasis on those with blunt traumatic mechanisms.

* *Corresponding author*. Division of Pediatric Emergency Medicine, Department of Emergency Medicine, University of Wisconsin School of Medicine and Public Health, 600 Highland Avenue, Madison, WI 53792.

E-mail address: jkgorski@wisc.edu (J. Gorski).

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Introduction

Trauma is the leading cause of death among children in the United States.[1] Trauma activations ensure adequate bedside resources to address injuries. Of these, highest-level activations are defined as prompt (< 15 mins) arrival of the entire trauma team to the emergency department (ED), including the on-call attending trauma surgeon.[2] Appropriate activations are associated with improved outcomes, including time to imaging and transfusion, hospital length of stay, and survivability.[3-5] The American College of Surgeons (ACS) has defined eight minimum criteria (ACS-8), most of which are identifiable in the prehospital setting, that warrant the highest-level activation for all trauma centers[2] and correlate with morbidity risk.[6-8] Conversely, the concept of "major trauma" is an outcome measure used to describe victims with significant injuries or fatalities.[9-11] Recent studies have led to the development of definitions of major trauma that incorporate injury severity and/or interventions performed.[12-17] Using this framework, patients who meet major trauma criteria but do not undergo highest-level activation are considered to be undertriaged.[18-20]

There is evidence that trauma undertriage contributes to worse outcomes including mortality,[20-23] necessitating a system to accurately identify children with major trauma. One multicenter study demonstrated that undertriaged adult trauma victims meeting one of six previously defined criteria for highest level of activation were more likely to die from their injuries.[20] Despite evidence of improved outcomes by accurate risk stratification, variability exists in pediatric trauma activation protocols across centers, contributing to disparities in care.[24-29] Studies of injured children suggest that emphasizing physiologic (rather than mechanistic) criteria in concordance with clear, consensus-derived guidelines will improve overall sensitivity in the identification of major trauma.[6,30,31] Which physiologic, mechanistic, and demographic factors may positively or negatively influence the identification of children with major trauma remain unknown.

The primary objective of this study was to determine factors associated with undertriage of children with major trauma, using a large national sample.

Methods

Data source

We performed a retrospective cross-sectional study using the 2021 (January 1, 2021 through December 31, 2021) ACS National Trauma Data Bank (NTDB) Trauma Quality Improvement Program (TQIP) Participant Use File (PUF). The TQIP PUF contains deidentified ED patient encounter data aggregated annually from hundreds of US hospitals which voluntarily contribute data to the NTDB. This study was approved by the Institutional Review Board and was conducted in accordance with relevant guidelines from the ACS.

Eligibility criteria

We included encounters of injured children (aged < 16 ys). As the NTDB reports all infant ages (< 12 mons) as missing, we identified infants as those patients of missing age and male sex weighing < 10.5 kg and those of missing age and female or missing sex weighing < 9.5 kg.[32] We excluded children with primary injury mechanisms of burns and drownings, due to the rarity of these conditions in the database and inconsistent inclusion across contributing sites. We excluded children missing outcome data (activation level or ED disposition). Consistent with prior multicenter work evaluating major trauma criteria,[16,17] we excluded children with an ED disposition of transfer, due to the inability of the database to follow patient outcomes after leaving the institution, consistent with prior multicenter work evaluating major trauma criteria.[16,17]

Variables

We selected extractible factors meeting any of the following criteria: (1) objective extractible mechanistic or physiologic factors that have been used in pediatric trauma triage protocols,[24,30] (2) demographic or geographic factors that have shown to be subject to disparities in care,[26-29] and (3) important physiologic criteria selected *a priori* by our study team (e.g., age). We acquired the following from each encounter: demographics including weight (in kg; used to identify infants with missing age), age (in years, categorized as 0-3 ys, 4-7 ys, 8-11 ys, and 12-15 ys), sex (male, female, nonbinary, or missing), race/ethnicity (Non-Hispanic White race, Non-Hispanic Black race, Hispanic and/or Latino ethnicity, other or more than one race and ethnicity, and missing race and ethnicity), and primary payer (government, private, self-pay, not billed, other, missing); and clinical characteristics including presence of prehospital cardiac arrest, ED vital signs (blood pressure [BP], heart rate [HR], and temperature), Glasgow Coma Score (GCS; < 9, ≥ 9, and missing), injury mechanism (traffic/pedestrian accident, fall, environmental, firearm, cut/pierce, striking, other, missing), whether the patient was an incoming interfacility transfer or arrived from the scene, type of transport (private vehicle, ground transport, flight, other, and missing), and type of trauma center (pediatric level 1, pediatric level 2, adult level 1 not pediatric, adult level 2 or lower not pediatric, and unverified trauma center). Vital signs (BP and HR) were classified using a composite of Pediatric Advanced Life Support and Advanced Trauma Life Support (Supplemental Table 1), with separate categories for missing data. We characterized patients with a prehospital cardiac arrest as hypotensive, consistent with prior literature.[7] We classified temperature as fever (> 38°C), hypothermia (≤ 36°C), normal, or missing. We chose to include missing data as its own category rather than excluding these encounters or performing imputation, due to emerging evidence suggesting that these patients differ from the trauma population at large.[33-36]

We acquired data relevant to outcomes including ED and hospital disposition and data required to derive major trauma criteria (abbreviated injury scale data; provision and volume of blood product transfusion; ED and hospital length of stay; use and timing of endotracheal intubation; and use of the operating room, interventional radiology, or intensive care unit). We extracted whether highest-level trauma activation was performed, which is present within the NTDB as a dichotomous variable.

Outcomes

Our primary outcome of interest was undertriage, defined as an encounter which received lower-level trauma activation despite meeting the definition of major trauma. Major trauma was defined as a composite outcome of the Cribari Matrix (CM) and the Need for Trauma Intervention (NFTI), represented in both pediatric and adult literature via the Standard Triage Assessment Tool (STAT).[13,17] CM was defined as an injury severity score of $>$ 15 (maximum 75), calculated from individual abbreviated injury scale data.[37] NFTI was defined as the presence of any of the following interventions: administration of packed red blood cells or whole blood within 4 hs of hospital arrival, transfer from the ED to the operating room within 90 mins of hospital arrival, transfer from ED to interventional radiology, admission to the intensive care unit with an intensive care unit length of stay of $\geq$ 72 hs, performance of nonprocedural mechanical ventilation within 72 hs of hospital arrival, or mortality within 60 hs.[15,16] Adapting these criteria for NTDB, we defined red blood cell administration as the provision of at least 300 mL of packed red blood cells, at least 500 mL of whole blood, or at least 10 mL per kilogram of packed red blood cells and/or whole blood.[38] The interventional radiology criteria included angiography and were modified to identify all patients who underwent this procedure within 24 hs of ED arrival. The intensive care unit and mortality criteria were modified to use a cutoff of 3 ds if length of stay in hours was unavailable. Major trauma was defined by the presence of both positive CM and NFTI.[13]

Analysis

We described the overall characteristics of our sample, stratified by major trauma. We characterized the proportion of included children who received the highest level of activation as well as those who met major trauma criteria. We determined the proportion of those who met criteria for undertriage, with associated 95% confidence intervals (CIs).

Among patients with major trauma, we investigated factors (selected *a priori*) associated with undertriage using univariable and multivariable logistic regression. Factors in this model included endotracheal intubation (prehospital, in ED, or none), GCS, BP, HR, temperature, mechanism, race, ethnicity, payer type, sex, age, incoming interfacility transfer, transport mode, and trauma center level. Results were expressed as odds ratios of undertriage with 95% CI. Analyses were performed using StataSE 17 (StataCorp LLC; College Station, TX).

Additional analyses

Children's initial stabilization and secondary transfer has been scrutinized in both undertriage and overtriage research, with transfer itself acting as a surrogate for triage.[26,39,40] Due to the possibility of eliminating a clinically important cohort by excluding transfers to outside facilities, we performed sensitivity analyses to compare study results when including children from the outgoing transfer population. First, we expanded the inclusion criteria to include outgoing ED transfers, performing multivariable analysis of children meeting the major trauma outcome within this expanded cohort to determine factors associated with undertriage. Second, using this expanded cohort, we modified major trauma criteria to include outgoing transfers as a seventh "NFTI" intervention type, subsequently performing a multivariable analysis of children in the modified major trauma subset with the modified outcome.

Results

We included 97,812 encounters of 115,982 encounters for children in the 2021 NTDB TQIP PUF (Fig.). The most common mechanism for the sample was falls (42.9%) followed by traffic/pedestrian-related injuries (28.6%; Table 1). About half of encounters were for incoming interfacility transfers (48.6%). Most children were seen at pediatric trauma centers (43.9% level 1; 16.9% level 2). Ten thousand six hundred three encounters (10.8%) were triaged as a highest-level activation. There were 5156 children (5.3%) who met STAT (NFTI+ and CM + overlapping) criteria for major trauma, of which 1773 (34.4%) were undertriaged.

Univariable and multivariable analysis of the major trauma subset demonstrated multiple factors associated with undertriage (Table 2). Factors associated with higher odds of undertriage in multivariable analysis included missing BP documentation; fall, strike, or missing mechanism; incoming interfacility transfers; and private vehicle transport. Factors

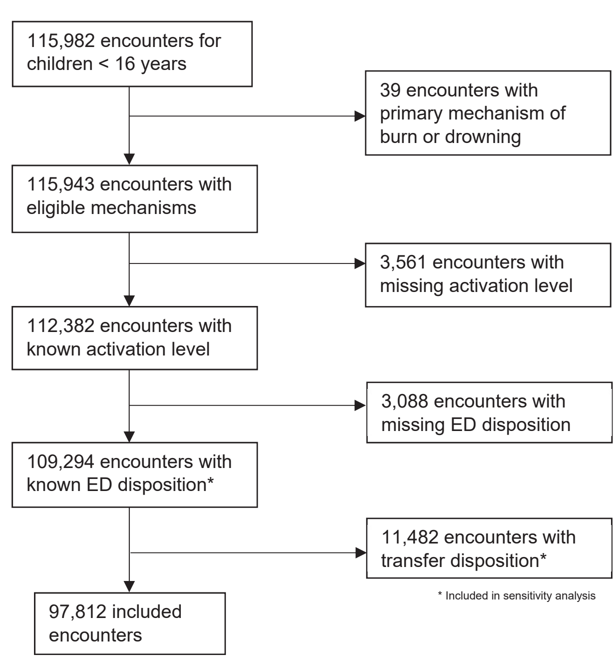

Fig. – Patient inclusion flowsheet.

Table 1 – Sample characteristics.

Factor	Count (% of category)		
	All	Major trauma per STAT	Not major trauma
n	97,812	5156	92,656
Intubation			
None	94,314 (96.4)	2717 (52.7)	91,597 (98.9)
Intubated prior to ED arrival	1713 (1.8)	1182 (22.9)	531 (0.6)
Intubated in ED	1785 (1.8)	1257 (24.4)	528 (0.6)
GCS			
GCS $\geq$ 9	88,317 (90.3)	2490 (48.3)	85,827 (92.6)
GCS eight or lower	3542 (3.6)	2468 (47.9)	1074 (1.2)
Missing GCS	5953 (6.1)	198 (3.8)	5755 (6.2)
Blood pressure			
Normal or elevated blood pressure	85,695 (87.6)	3954 (76.7)	81,741 (88.2)
Hypotension	1877 (1.9)	1041 (20.2)	836 (0.9)
Missing blood pressure	10,240 (10.5)	161 (3.1)	10,079 (10.9)
Heart rate			
Normal heart rate	70,709 (72.3)	2298 (44.6)	68,411 (73.8)
Bradycardia	4371 (4.5)	664 (12.9)	3707 (4.0)
Tachycardia	19,447 (19.9)	2068 (40.1)	17,379 (18.8)
Missing heart rate	3285 (3.4)	126 (2.4)	3159 (3.4)
Temperature			
Normal temperature	85,847 (87.8)	3196 (62.0)	82,651 (89.2)
Hypothermia	3306 (3.4)	923 (17.9)	2383 (2.6)
Fever	765 (0.8)	116 (2.2)	649 (0.7)
Missing temperature	7894 (8.1)	921 (17.9)	6973 (7.5)
Mechanism			
Traffic related	27,961 (28.6)	2661 (51.6)	25,300 (27.3)
Fall	41,995 (42.9)	642 (12.5)	41,353 (44.6)
Natural/environmental	4595 (4.7)	69 (1.3)	4526 (4.9)
Firearm	2915 (3.0)	709 (13.8)	2206 (2.4)
Cut/pierce	2588 (2.6)	49 (1.0)	2539 (2.7)
Struck by/against	8897 (9.1)	225 (4.4)	8672 (9.4)
Other	3325 (3.4)	47 (0.9)	3278 (3.5)
Missing mechanism	5536 (5.7)	754 (14.6)	4782 (5.2)
Race and ethnicity			
Non-Hispanic White	52,710 (53.9)	2214 (42.9)	50,496 (54.5)
Non-Hispanic Black	10,380 (10.6)	569 (11.0)	9811 (10.6)
Hispanic ethnicity	17,905 (18.3)	1344 (26.1)	16,561 (17.9)
Other race or ethnicity	14,646 (15.0)	834 (16.2)	13,812 (14.9)
Missing race and ethnicity	2171 (2.2)	195 (3.8)	1976 (2.1)
Payer type			
Government	47,920 (49.0)	2765 (53.6)	45,155 (48.7)
Private	41,622 (42.6)	1784 (34.6)	39,838 (43.0)
Self-pay	5014 (5.1)	363 (7.0)	4651 (5.0)
Not billed	73 (0.1)	9 (0.2)	64 (0.1)
Other	1584 (1.6)	104 (2.0)	1480 (1.6)
Missing payer type	1599 (1.6)	131 (2.5)	1468 (1.6)
Sex*			
Male	60,256 (61.6)	3285 (63.7)	56,971 (61.5)
Female	35,430 (36.2)	1809 (35.1)	33,621 (36.3)

(continued)

Table 1 – (continued)

Factor	Count (% of category)		
	All	Major trauma per STAT	Not major trauma
Nonbinary	41 (0.0)	1 (0.0)	40 (0.0)
Missing sex	2085 (2.1)	61 (1.2)	2024 (2.2)
Age category			
0-3 ys	18,868 (19.3)	1176 (22.8)	17,692 (19.1)
4-7 ys	30,202 (30.9)	1128 (21.9)	29,074 (31.4)
8-11 ys	19,877 (20.3)	803 (15.6)	19,074 (20.6)
12-15 ys	28,865 (29.5)	2049 (39.7)	26,816 (28.9)
Incoming interfacility transfer			
Transfer	47,514 (48.6)	1972 (38.2)	45,542 (49.2)
Not a transfer	50,298 (51.4)	3184 (61.8)	47,114 (50.8)
Transport type			
Ground transport	54,962 (56.2)	3024 (58.7)	51,938 (56.1)
Personal vehicle	33,589 (34.3)	326 (6.3)	33,263 (35.9)
Flight transport	8557 (8.7)	1752 (34.0)	6805 (7.3)
Other transport	375 (0.4)	38 (0.7)	337 (0.4)
Missing transport type	329 (0.3)	16 (0.3)	313 (0.3)
Trauma center level			
Pediatric level 1	42,963 (43.9)	2041 (39.6)	40,922 (44.2)
Pediatric level 2	16,496 (16.9)	884 (17.1)	15,612 (16.8)
Adult level 1[*]	8517 (8.7)	679 (13.2)	7838 (8.5)
Adult level 2 or lower[*]	7868 (8.0)	468 (9.1)	7400 (8.0)
Unverified trauma center	21,968 (22.5)	1084 (21.0)	20,884 (22.5)

ED = emergency department; GCS = Glasgow coma score; STAT = standard triage assessment tool.
[*] Adult trauma centers lacking pediatric verification.

associated with lower odds of this outcome included endotracheal intubation (both pre-ED and in-ED), low GCS, hypotension, bradycardia, hypothermia or missing temperature, firearm or cut/pierce mechanism of injury, flight or other miscellaneous transport, and pediatric level 2 or adult level 1 trauma center (relative to pediatric level 1 trauma center). Race, ethnicity, payer type, sex, and age were not associated with undertriage in multivariable analysis.

When including children transferred to outside facilities in sensitivity analyses, an additional 11,482 encounters were included (with a combined cohort of 109,294 children). Of these, 5.0% (5493 children) met criteria for major trauma (33.6% undertriaged). In multivariable analysis examining the odds of undertriage for children meeting the major trauma definition in the expanded cohort, all prior significant variables and directionality were observed, with the addition of younger age (0-3 ys) as a factor associated with higher odds of undertriage. When modifying the definition of the major trauma outcome (6231 children, an additional 738 children) to include outgoing transfers as a seventh intervention type, 5.7% met major trauma criteria (38.6% undertriaged). In multivariable analysis of this cohort with the modified outcome, younger age was not associated with undertriage and “other transport type” was no longer significantly associated with this outcome. In both analyses, unverified trauma centers were significantly associated with lower odds of undertriage, differing from the main analysis.

Discussion

We performed a cross-sectional study of injured children to quantify undertriage rates and evaluate factors associated with undertriage. We identified potentially modifiable factors associated with undertriage of the most critically ill subset of traumatically injured children.

Many factors associated with lower odds of undertriage were injury-related characteristics which align closely with the ACS-8. This finding demonstrates the relative success of trauma triage algorithms as well as heightened awareness among frontline trauma teams of higher-risk conditions (low GCS, penetrating injuries, hypotension, prehospital intubation, and respiratory compromise requiring intubation).[2] Further physiologic risk factors were protective against undertriage, including bradycardia and hypothermia, although it is possible that these effects were secondary to overall awareness of the critical, periarrest, or postarrest state.

Several important patient-level factors were associated with undertriage. For example, while a low proportion of children with fall and strike mechanisms met major trauma criteria, these patients were more frequently undertriaged. Patients with these conditions may be subject to anchoring and availability biases, leading to an impaired recognition of their critical status.[41] One possible solution to improve

Table 2 – Factors associated with undertriage for children with major trauma.

Factor	Adjusted OR (95% CI)	
	Univariable	Multivariable
Intubation		
None	Ref	Ref
Intubated prior to ED arrival	**0.11 (0.09-0.14)**	**0.36 (0.27-0.47)**
Intubated in ED	**0.17 (0.14-0.20)**	**0.39 (0.32-0.49)**
GCS		
GCS ≥ 9	Ref	Ref
GCS eight or lower	**0.10 (0.09-0.12)**	**0.22 (0.18-0.28)**
Missing GCS	0.79 (0.59-1.06)	0.72 (0.51-1.02)
Blood pressure		
Normal or elevated blood pressure	Ref	Ref
Hypotension	**0.23 (0.19-0.27)**	**0.73 (0.57-0.94)**
Missing	**2.13 (1.54-2.92)**	**1.79 (1.10-2.91)**
Heart rate		
Normal heart rate	Ref	Ref
Bradycardia	**0.33 (0.27-0.40)**	0.92 (0.69-1.21)
Tachycardia	**0.61 (0.54-0.70)**	**0.75 (0.64-0.88)**
Missing	**0.55 (0.37-0.81)**	0.78 (0.42-1.43)
Temperature		
Normal temperature	Ref	Ref
Hypothermia	**0.33 (0.28-0.40)**	**0.75 (0.60-0.93)**
Fever	1.00 (0.69-1.46)	1.38 (0.86-2.23)
Missing	**0.29 (0.24-0.34)**	**0.70 (0.55-0.89)**
Mechanism		
Traffic related	Ref	Ref
Fall	**3.12 (2.62-3.73)**	**1.70 (1.36-2.13)**
Natural/environmental	**1.79 (1.10-2.90)**	1.03 (0.59-1.82)
Firearm	**0.16 (0.12-0.22)**	**0.15 (0.11-0.22)**
Cut/pierce	**0.26 (0.10-0.67)**	**0.17 (0.07-0.46)**
Struck by/against	**2.43 (1.85-3.20)**	**1.62 (1.15-2.28)**
Other	0.71 (0.36-1.40)	0.79 (0.36-1.75)
Missing	**2.60 (2.20-3.07)**	**2.05 (1.59-2.66)**
Race and ethnicity		
Non-Hispanic White	Ref	Ref
Non-Hispanic Black	0.99 (0.82-1.20)	1.18 (0.93-1.51)
Hispanic ethnicity	**0.53 (0.45-0.61)**	0.87 (0.71-1.07)
Other race or ethnicity	**0.82 (0.69-0.96)**	0.81 (0.66-1.00)
Missing	**0.63 (0.45-0.86)**	0.98 (0.66-1.46)
Payer type		
Government	Ref	Ref
Private	1.07 (0.95-1.21)	0.94 (0.79-1.10)
Self-pay	**0.47 (0.36-0.61)**	0.78 (0.56-1.10)
Not billed	0.23 (0.03-1.84)	0.25 (0.02-2.43)
Other	**0.52 (0.33-0.83)**	0.62 (0.35-1.10)
Missing	0.90 (0.62-1.30)	0.83 (0.52-1.33)
Sex*		
Male	Ref	Ref
Female	1.03 (0.91-1.16)	0.94 (0.81-1.09)
Missing	1.09 (0.64-1.84)	1.37 (0.70-2.70)
Age category		
0-3 ys	**2.30 (1.98-2.67)**	1.26 (0.99-1.60)
4-7 ys	**1.23 (1.05-1.44)**	1.04 (0.85-1.28)
8-11 ys	**1.37 (1.15-1.63)**	1.08 (0.87-1.34)
12-15 ys	Ref	Ref
Incoming interfacility transfer	**1.76 (1.56-1.98)**	**1.73 (1.46-2.04)**
Transport type		
Ground transport	Ref	Ref
Personal vehicle	**4.49 (3.50-5.76)**	**2.96 (2.12-4.13)**
Flight transport	**0.75 (0.66-0.85)**	**0.70 (0.59-0.83)**
Other transport	**0.11 (0.03-0.44)**	**0.18 (0.04-0.83)**
Missing	1.14 (0.41-3.15)	0.40 (0.12-1.31)
Trauma center level		
Pediatric level 1	Ref	Ref
Pediatric level 2	0.90 (0.76-1.06)	**0.74 (0.60-0.91)**
Adult level 1†	**0.52 (0.43-0.63)**	**0.58 (0.45-0.74)**
Adult level 2 or lower†	0.91 (0.74-1.12)	0.94 (0.72-1.23)
Unverified trauma center	**0.77 (0.66-0.90)**	0.82 (0.67-1.00)

Bold text = significant ($P < 0.05$).
CI = confidence interval; ED = emergency department; GCS = Glasgow Coma Score; OR = odds ratio; Ref = reference.
* Insufficient count for nonbinary.
† Adult trauma centers lacking pediatric verification.

recognition of these patients includes increasing emphasis on the importance of physiologic (e.g., tachycardia) over mechanistic criteria (e.g., height of fall) in the design of trauma triage algorithms.[6,30] As there is limited literature on mechanistic risk factors for children with blunt trauma, trauma improvement initiatives should be mindful of the variability that exists in blunt trauma as well as the false reassurances that occur when relying on mechanism within triage criteria.

Private vehicle arrival was associated with undertriage of children. There are a number of reasons for this phenomenon, including the lack of prehospital physical assessments that could potentially flag for high-risk physiologic risk factors, as well as the representativeness heuristic, where "walk-in" patients are judged to be lower acuity due to pre-existing stereotypes. Given that the ACS highest-level activation criteria apply to the broader trauma population and not just emergency medical services arrivals, children with traumatic injuries should be subject to uptriage as physiologic data are collected during early ED assessments. Similarly, the association of missing vital signs (BP, temperature) with undertriage speaks to the importance of early assessments in ensuring patients are adequately triaged; prior evidence shows that patients with missing vital signs may actually carry higher risk of morbidity and mortality than their counterparts.[35,36] Future work is needed to improve both compliance with and accuracy of early triage assessments and subsequent decisions surrounding activation level to assist with the recognition of those at highest risk of acute interventional needs and decompensation.

We additionally identify systems-level factors associated with undertriage. Notably, level 1 adult and level 2 pediatric trauma centers imparted lower odds of undertriage compared to level 1 pediatric trauma centers. One possible explanation is that level 1 adult trauma centers are accustomed to higher rates of major trauma in the adult trauma population (and thus trauma population overall),[15] therefore maintaining a higher index of suspicion for serious injury. Alternatively, there may be a higher overall acuity for major trauma patients seen at level 1 adult and level 2 pediatric trauma centers, making these patients easier to identify, given that regional protocols mandate that patients in extremis be seen at the closest available trauma center.[42] These findings may also be due to differences in utilization patterns between general and pediatric EDs.[43-45] Trauma team activation is associated with improved trauma-related outcomes,[3-5] and full activation translates to prompt expertise at the bedside, which may prove useful for the initial stabilization and transport decisions for centers that see a lower volume of children. Conversely, incoming interfacility transfers had higher odds of undertriage relative to those arriving from the scene. These findings suggest that developers of pediatric trauma triage algorithms and trauma teams alike should maintain a high index of suspicion that children who may have responded to initial resuscitative measures at outside facilities may continue to have further interventional and subspecialty needs upon arrival, warranting full trauma team activation.

Despite prior literature showing racial, ethnic, and income/payer disparities in trauma care,[26-29] our study did not reveal any statistically significant difference in triage rates within these categories. We suspect that racial disparities in trauma triage may be offset by geographic disparities affecting rural, predominantly White children as described in the literature.[26,27] Future work is needed to elucidate individual factors including urbanicity on trauma triage and associated outcomes, as well as evaluate the effect of race and ethnicity on other aspects of children's trauma care and outcomes.

We found similar undertriage rates and similar odds of undertriage for individual factors when both including and excluding outgoing interfacility transfers and expand upon prior work by using STAT, a rigorous definition for major trauma in children. Given that pediatric trauma teams and pediatric readiness have been shown to be essential to children's survival, appropriate transfer of critically ill children to a pediatric trauma center has itself been used as a surrogate for undertriage in prior multicenter work.[26,39,46-51] We demonstrate that novel metrics including NFTI and STAT can be evaluated in both outgoing transfer exclusionary and inclusionary samples. Future studies may seek to determine whether activation level influences pediatric transfer when controlling for injury factors, bridging a gap that exists between these two unique triage definitions.

This study was subject to limitations. The NTDB is based on a convenience sample of hospitals that contribute data and may therefore lack external validity. Given the retrospective, observational nature of our study, there is a possibility of inaccurate or missing data used to generate predictors and outcomes. As infant age is intentionally withheld from the NTDB, we used conservative assumptions to include a more comprehensive subset of children for the sample. Our study's focus on undertriage did not allow us to investigate factors associated with overtriage, including overutilization of helicopter transport,[52,53] which has emerged as a growing issue in pediatric trauma. Despite these limitations, we were able to offer significant insights on undertriage using the largest multicenter database of pediatric trauma patients available.

We demonstrated undertriage rates by activation level for children presenting to a diverse sample of trauma center types, affirming prior work establishing STAT as a feasible criterion for major trauma in children. Several factors, including fall and strike mechanisms, private vehicle arrivals, missing BP, and incoming interfacility transfers, were associated with undertriage. Additional work is required to develop and disseminate robust physiologic criteria for the classification of trauma in children, improve compliance with extant national guidelines, and improve systems-level factors to ensure the prompt triage and care of children with major trauma.

Supplementary Materials

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jss.2024.12.008.

Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

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CRediT authorship contribution statement

Jillian Gorski: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Seth Goldstein:** Writing – review & editing, Methodology, Conceptualization. **Suhail Zeineddin:** Writing – review & editing, Methodology, Conceptualization. **Sriram Ramgopal:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

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