Which Trauma Severity Scores Are Useful in Predicting Pediatric Mortality?

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Background and Objectives: Trauma is the leading cause of death in children. Several trauma severity scores exist: the shock index (SI), age-adjusted SI (SIPA), reverse SI (rSI), and rSI multiplied by Glasgow Coma Score (rSIG). However, it is unknown which is the best predictor of clinical outcomes in children. Our goal was to determine the association between trauma severity scores and mortality in pediatric trauma.

Design and Methods: A multicenter retrospective study was performed using the 2015 US National Trauma Data Bank, including patients 1 to 18 years old and excluding patients with unknown emergency department dispositions. The scores were calculated using initial emergency department parameters. Descriptive analysis was carried out. Variables were stratified by outcome (hospital mortality). Then, for each trauma score, a multivariate logistic regression was conducted to determine its association with mortality.

Results: A total of 67,098 patients with a mean age of 11 ±5 years were included. Majority of the patients were male (66%) and had an injury severity score <15 (87%). Eighty-four percent of patients were admitted: 15% to the intensive care unit and 17% directly to the operating room. The mortality at hospital discharge was 3%.

There was a statistically significant association between SI, rSI, rSIG, and mortality ($P < 0.05$). The highest adjusted odds ratio for mortality corresponded to rSIG, followed by rSI then SI (8.51, 1.9, and 1.3, respectively).

Conclusion: Several trauma scores may help predict mortality in children with trauma, the best being rSIG. Introduction of these scores in algorithms for pediatric trauma evaluations can impact clinical decision-making.

Key Words: pediatric trauma, pediatric trauma scores, age-adjusted shock index, reverse shock index, shock index, GCS

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Trauma is the leading cause of death worldwide in children aged 1 to 18 years, with more than 9 million visits per year to US emergency departments (EDs) for nonlethal injuries.[1] Because the main cause of death from trauma is blood loss and hypovolemic shock, early recognition and management of hypovolemic shock are crucial. We have historically relied on vital signs in isolation, for example, tachycardia or hypotension, to determine the presence of shock.[2] Yet, relying on isolated vital signs may delay the diagnosis of shock in children who, for example, maintain normal blood pressure until they are in decompensated shock, hence leading to a higher mortality. Furthermore, most used trauma scores, such as the revised trauma scores, pediatric trauma scores, or injury severity score (ISS), are cumbersome to calculate at bedside.

Multiple different trauma severity scores based on vital signs and Glasgow Coma Score (GCS) have been used to predict outcomes in injured patients. These include the shock index (SI), age-adjusted SI (SIPA), reverse SI (rSI), and rSI multiplied by GCS (rSIG).

An SI, calculated by dividing the heart rate (HR) over systolic blood pressure (SBP), greater than 0.9 despite normal vital signs was studied initially in nontrauma patients as a prognostic factor for increased mortality, increased need for monitoring, and hence hospital and intensive care unit (ICU) admission.[3] Further studies showed its efficacy in adult trauma patients as a marker not only of mortality but of increased need for massive transfusions.[4,5] However, because cut-offs for normal vital signs differ between children and adults, SIPA was developed.[6] Four different cut-off categories by age were studied. These cut-off values correlated with higher mortality and transfusion rates, at all age categories, in blunt and penetrating injuries.[6,7]

Furthermore, because the SBP may be a stronger marker of hemodynamic instability in adults, it may be more intuitive to calculate a score with the SBP as the numerator. Therefore, the rSI, calculated by SBP divided by HR was introduced.[8,9] An rSI <1 in both adults and pediatric trauma patients correlated with a higher number of ED procedures, ICU admissions, and mortality.[8,9]

Finally, the rSIG, calculated by multiplying the rSI by the GCS emerged. It inversely correlated with in-hospital mortality at a cut-off of 14, meaning the higher the rSIG above 14, the lower the in-hospital mortality.[10]

A summary of these scores' calculations and cut-offs is shown in Table 1.

Although the 4 mentioned scores have been shown to predict worse outcomes in trauma patients at certain cut-offs, it is unclear which one is better as they have been studied in different populations. To date, there has been no study that assessed the simultaneous

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TABLE 1. Trauma Score Calculations and Corresponding Cut-offs

Trauma Score	Cut-offs
SI = HR/SBP	>0.9
SIPA = HR/SBP	>1.2 for ages 1–3 y
	>1.22 for ages 4–6 y
	>1.0 for ages 7–12 y
	>0.9 for ages 13–16 y
rSI = SBP/HR	<1
rSIG = SBP/HR × GCS	<14

Systolic blood pressure is in millimeter mercury (mm Hg).
For reference: SI,[3] SIPA,[6] rSI,[8,9] rSIG.[10]

performance of the 4 abovementioned trauma scores (SI, rSI, rSIG, and SIPA) in the pediatric population. Therefore, our aim was to study the association with mortality of the 4 trauma scores, side by side, in a large pediatric sample. In addition, we will describe other variables associated with mortality in children presenting to the ED with traumatic injuries.

METHODS

Study Design and Population

This was a retrospective study using the 2015 US National Trauma Data Bank (NTDB), the largest trauma registry in the United States, containing records from more than 900 facilities. This registry includes all hospitals accredited to treat trauma by the American College of Surgeons. Trauma patients are included in the dataset when they meet the International Classification of Diseases (ICD) codes criteria pertaining to specific injuries (excluding superficial injuries). The databank includes prehospital information, patient demographics, injury details and severity, ED and hospital information, diagnosis, and outcome, among other variables.[11–13]

We included patients between 1 and 18 years old from the 2015 NTDB. We excluded patients with undetermined outcomes, including those with unknown ED disposition, who left against medical advice, who transferred to another hospital, with unknown hospital disposition, and who had interhospital facility transfer.

Institutional review board approval was not needed.

Outcome Measure

Our primary outcome was overall hospital (ED or inpatient) mortality in injured pediatric patients presenting to the ED.

Definitions

We calculated the 4 different trauma severity scores (SI, SIPA, rSI, and rSIG) using the available initial ED parameters as shown in Table 1.

Data Collection

From the NTDB, we retrieved data on patient demographics and characteristics (age, sex, ethnicity, and presence of chronic disease), hospital demographics (hospital teaching status, number of beds in the facility, number of trauma surgeons, and mode of transportation to the ED), patient ED vital signs (HR, SBP, respiratory rate [RR], and GCS), injury-related information (mechanism and type of trauma), the ISS, injury intentionality, and our outcome of interest (mortality to hospital discharge).

Data Analysis

Categorical variables were summarized by calculating the frequencies and percentages, whereas the continuous variables were presented as mean ± standard deviation. The variables having more than 10% missing values as indicated by the descriptive analysis (whether patient used alcohol, 13.2%; whether patient used drug, 12.1%; the patient's ethnicity, 10.8%) were treated with multiple imputation procedures to provide accurate estimates. Hence, an automatic imputation method was conducted, and 5 imputed datasets were produced. The Student *t*-test and the Pearson χ^2 test were used to assess the significance of the statistical association between the independent variables (continuous and categorical) and the 2 groups (hospital mortality, yes/no) of the outcome. To assess the association between each trauma score and hospital mortality after controlling for all potential confounding factors, we performed several separate multivariate analyses using a stepwise selection procedure. Thus, a unique logistic regression model was conducted for each trauma score to assess its association with hospital mortality after adjusting for all patients' demographics and clinical characteristics. More particularly, for each model, the score of interest was included into it in addition to all statistically associated variables with hospital mortality and all clinically meaningful factors. These variables were listed under Table 5 as footnotes. It is worth noting that any variable taken into consideration in the trauma score calculation was not adjusted while conducting the multivariate analysis of this score. For instance, GCS was not included in the model in which rSIG was the main independent factor, but it was involved in the models that primarily controlled for the SI or rSI.

The logistic regression models had an excellent discrimination between deceased and survived patients as shown by the obtained values of the area under the curve that was equal to 0.965 (95% confidence interval [CI], 0.960–0.970; $P < 0.001$), 0.966 (95% CI, 0.961–0.970; $P < 0.001$), 0.950 (95% CI, 0.945–0.955; $P < 0.001$), and 0.968 (95% CI, 0.962–0.974; $P < 0.001$) for the models in which one of the adjusted confounding factors was ED SI, ED rSI, rSIG, and ED SI for patients aged 13 to 18 years, respectively. Statistical significance was considered at the 0.05 level. Analyses were performed using the SPSS statistical package (version 24.0; IBM, Chicago, IL).

RESULTS

Population and Hospital Demographics

The 2015 US National Trauma Data Bank collected data for 917,865 ED trauma visits. We included patients between 1 and 18 years old (n = 125,740). We excluded patients for whom the study outcome could not be determined. These included patients with unknown ED disposition (not known/not recorded) (n = 4836, 3.9%), who left against medical advice (n = 75, 0.1%), who were transferred to another hospital (n = 10,567, 8.4%), who had unknown hospital disposition (n = 20, 0%), and who had interhospital facility transfer (n = 45,993, 36.5%).

A total of 67,098 patients with a mean age of 11 ± 5 years were included. The majority of the patients were male (43,974, 65.6%), seen in a university hospital (35,634, 53.1%) and in the Southern US regions (27,469, 40.9%). Most injuries were blunt (52,216, 77.8%) and unintentional (56,808, 84.7%). Almost 30% of the injuries were equally due to motor vehicle collision

(19,253) and falls (19,532). Upon presentation to the ED, most patients had an ISS <15 (58,432, 87.1%), a GCS >13 (58,511, 87.2%), and an SBP >90 mm Hg (60,560, 90.2%) (Table 1).

The overall mortality rate was 3.1% (2093): 1.9% (1297) at ED discharge and 1.2% (796) at hospital discharge. Most patients (83.6%, 56,080) were admitted. Of these, 45% (30,120) were admitted to the general ward, 15% (10,217) to the ICU, and 16.7% (11,174) directly to the operating room (OR) (Table 2).

Variables Associated With Mortality

As noted in Supplemental Table, http://links.lww.com/PEC/B117 and Table 3, patients who died had a significantly higher ISS (23.4 ± 19.9 vs 6.8 ± 6.9, $P < 0.001$), a lower ED GCS (mean of 6.9 ± 5.5 vs 14.4 ± 2.1, $P < 0.001$), a lower ED SBP (mean of 86.8 ± 57.9 vs 124.7 ± 18.7 mm Hg, $P < 0.001$), a lower ED RR (15.5 ± 11.3 vs 21.1 ± 5.8, $P < 0.001$), and a lower pulse rate in the ED (78.5 ± 53.8 vs 100.6 ± 23.8, $P < 0.001$).

Trauma Severity Scores and Mortality

We analyzed the trauma scores as categorical variables based on the cut-offs in Table 1. Shock index (>0.9), rSI (<1), and rSIG (<14) were significantly associated with patient mortality ($P < 0.001$). Age-adjusted SI was only statistically significant in 2 age groups: 7 to 12 and 13 to 18 years old ($P = 0.002$ and $P < 0.001$, respectively) (Table 4).

After applying a multivariate logistic regression, we calculated the adjusted odds ratio (aOR) of SI, rSI, and rSIG with respect to mortality (Table 5). The rSIG had the most significant aOR at 8.51 (95% CI, 7.14–10.16).

DISCUSSION

In summary, in this large US database, we found that the majority of children presenting to the ED with an injury had a mean age of 11 years old, had a blunt and unintentional trauma, and were admitted to the hospital. We noted a 3% mortality rate, and albeit the identification of multiple risk factors in the bivariate analysis, our focus was on trauma scores, where we noted that the rSIG had the strongest association with mortality and the SIPA had none.

Our study is significant as it is the first to compare the commonly used 4 pediatric trauma scores in one large sample of pediatric trauma patients, avoiding bias found when comparing different groups. We used the NTDB, one of the largest trauma registries, providing strength in our sample size.

Our overall sample was comparable with the pediatric trauma population described in the literature,[6,7,14] with a mean age of 11 years and most injuries described as blunt, unintentional, or due to motor vehicle collision or falls (excluding studies on casualties in Iraq and Afghanistan where explosives were the most common injuries).[6,7,14] Similar to Acker et al,[6] the majority were admitted to the hospital: 45% to the general ward, 15% to the ICU, and 16% directly to the OR.

As previously described,[15,16] our mortality rate was 3.1%. Variables associated with mortality could be categorized as patient related, such as sex, alcohol or drug use, and vital signs upon arrival; others are injury related, such as type and location; or hospital related, such as size or whether it is a teaching hospital or not.

In the bivariate analysis, the 4 trauma scores studied had a statistically significant association with mortality; however, SIPA lost its significance in the multivariate analysis and rSIG had the highest aOR. In other words, we show that mortality was associated with higher mean SI, low mean rSI, and lower mean rSIG values.

This is in contradiction with what was shown in other studies where mortality was higher in those with an elevated SIPA score reaching 13%.[5,17] Unlike the rSI, rSIG, and SI, the pediatric-adjusted SIPA score has been more extensively studied in the pediatric population and postulated to predict mortality.[6,14] In one study, Acker et al[6] demonstrated that SIPA was a better identifier of poor outcomes in children with traumatic injury than SI. However, in our larger sample (67,098 vs 543 and 2917),[6,7,14] we found that the SIPA score did not perform as well as the other 3. In fact, it did not correlate with mortality except in children between 13 and 18 years of age, pediatric patients who are already transitioning into adulthood, and adult physiology. The failure of SIPA to be of prognostic value has been highlighted in a recent study on war-injured children. Although the difference was attributed to the fact that the severe injuries seen in a warzone did not represent the regular blunt injuries seen in the civilian setting,[17] we have demonstrated similar findings, in a very large sample size across different institutions, putting into question the actual validity of the SIPA as a marker of poor outcome in pediatric trauma patients.

TABLE 2. Disposition of Patients at ED and Hospital Discharge

	Frequency (N = 67,098)	%
Disposition from the ED		
Deceased/expired	1297	1.9%
Floor bed (general admission, nonspecialty unit bed)	30,120	44.9%
Home with or without services and other (jail, institutional care facility, mental health)	9721	14.5%
ICU	10,217	15.2%
Observation unit	2482	3.7%
OR	11,174	16.7%
Telemetry/step-down unit (less acuity than ICU)	2087	3.1%
Disposition from the hospital		
Not applicable	11,018	16.4%
Deceased/expired	796	1.2%
Discharged to home or self-care (routine discharge)	51,276	76.4%
Transferred to other destination	3664	5.5%
Left against medical advice or discontinued care	344	0.5%

TABLE 3. Association Between Continuous Variables and Mortality

	Alive	Dead	*P*
Time from dispatch of EMS unit to hospital arrival (min)	272.37 ± 569.6	161.05 ± 397.48	<0.001
ISS	6.85 ± 6.96	23.43 ± 19.95	<0.001
Total hospital length of stay (d)	3.21 ± 5.75	2.20 ± 6.17	<0.001
ICU length of stay (d)	4.51 ± 6.58	4.63 ± 8.6	0.634
Time on the ventilator (d)	5.71 ± 7.99	3.61 ± 7.98	<0.001
ED GCS	14.44 ± 2.1	6.95 ± 5.49	<0.001
ED SBP (mm Hg)	124.72 ± 18.78	86.85 ± 57.90	<0.001
ED RR (breaths/min)	21.06 ± 5.80	15.53 ± 11.31	<0.001
ED pulse	100.65 ± 23.87	78.47 ± 53.83	<0.001
ED SI (pulse /SBP) or (SI)	0.82 ± 0.38	1.05 ± 4.15	0.038
ED SI (pulse /SBP) by age groups			
1–3 y	1.18 ± 0.36	1.15 ± 0.76	0.693
14–6 y	0.97 ± 0.49	0.95 ± 0.32	0.672
17–12 y	0.83 ± 0.26	0.85 ± 0.36	0.246
13–18 y	0.73 ± 0.34	1.18 ± 5.95	0.048
ED rSI (SBP/pulse) or (rSI)	1.33 ± 0.89	1.22 ± 0.97	<0.001
ED rSIG (SBP/pulse × GCS)	19.30 ± 13.08	11.02 ± 14.19	<0.001
ED age-adjusted rSI (rSI/age)	2.35 ± 2.72	1.55 ± 2.33	<0.001

Recent studies have evaluated a dynamic and delta SIPA rather than a static value, for example, comparing SIPA at ED presentation and 24 hours after hospital admission. They showed a correlation with mortality and poor outcomes when SIPA values changed and better outcomes when they remained stable.[18–20]

TABLE 4. Association Between Trauma Score Cut-offs and Mortality

	Alive	Dead	*P*
ED SI (pulse/SBP)			
<0.9	42,679 (98.1%)	805 (1.9%)	<0.001
>0.9	17,925 (96.7%)	610 (3.3%)	
ED SI (pulse/SBP) by age groups			
1–3 y			
<1.2	3824 (97.6%)	93 (2.4%)	0.834
>1.2	2342 (97.5%)	59 (2.5%)	
4–6 y			
<1.2	6573 (97.5%)	165 (2.5%)	0.331
>1.2	666 (96.9%)	21 (3.1%)	
7–12 y			
<1	12,372 (97.5%)	319 (2.5%)	0.002
>1	1898 (96.2%)	74 (3.8%)	
13–18 y			
<0.9	28,542 (98.7%)	384 (1.3%)	<0.001
>0.9	4387 (93.6%)	300 (6.4%)	
ED rSI (SBP/pulse)			
<1	11,645 (95.7%)	524 (4.3%)	<0.001
>1	48,971 (98.2%)	878 (1.8%)	
rSIG (SBP/pulse × GCS)			
<14	9942 (92.2%)	837 (7.8%)	<0.001
>14	48,085 (98.9%)	554 (1.1%)	

Although SI can predict mortality in pediatric patients,[21] only recently did a study compare rSIG and SIPA,[22] showing that age-adjusted rSIG outperformed SIPA. However, it was a small sample size in a military setting with mostly penetrating trauma, making the data hard to generalize. Yet, its results are in alignment with our large, multicenter study, showing an elevated rSIG to be the best predictor of mortality in pediatric trauma where among all 4 scores, rSIG had the highest aOR. In other words, an injured pediatric patient with an rSIG score greater than 14 was 8 times more likely to die.

rSIG is easy to calculate, and its variables are easily obtained upon presentation of pediatric trauma patients to the ED. We have shown that it is independently the best score to predict mortality. We therefore recommend its application in clinical care and more specifically to help with the early disposition of patients with a high score to more specialized pediatric trauma centers.

Limitations

Potential limitations of this study are attributed to its retrospective nature and to the use of a large database, in which some data points can be missing or vary from an institution to another in calculation. For example, the GCS is missing in 5% of cases and at times potentially, inaccurately calculated.[23] However, the sample size is large enough to dilute the bias of these small percentages. In addition, such databases do not provide granular information about the patients. However, given that mortality is in generally a rare outcome in kids, such databases are needed for these studies.

We excluded subjects who were dead on scene or before arrival to the ED; this may have underestimated the true mortality rate. Furthermore, the reason and time of death are not indicated in the data collection. However, this is beyond the purpose of this study and does not preclude the use of the trauma scores in the ED as an indicator of increased mortality allowing early identification of high-risk patients.

We excluded close to 48% of the patients from this database because of unknown outcomes (eg, transfer to other facility). This

TABLE 5. Unadjusted odds ratio and aOR of the Trauma Scores

Trauma Score (Reference Category)	Unadjusted Odds Ratio (95% CI)	P	aOR (95% CI)	P
SI (Pulse/SBP) (<0.9)	1.80 (1.62–2.01)	<0.001	1.28[a] (1.08–1.50)	0.003
rSI (SBP/pulse) (>1)	2.51 (2.25–2.80)	<0.001	1.92[b] (1.61–2.30)	<0.001
rSIG (SBP/pulse × GCS) (>14)	7.31 (6.55–8.15)	<0.001	8.51[c] (7.14–10.16)	<0.001
SIPA for patients aged 1–3 y (<1.2)	1.04 (0.75–1.44)	0.834	0.83[d] (0.52–1.33)	0.447
SIPA for patients aged 4–6 y (<1.2)	1.26 (0.79–1.99)	0.33	1.57[e] (0.79–3.14)	0.197
SIPA for patients aged 7–12 y (<1)	1.51 (1.17–1.96)	0.002	1.45[f] (0.93–2.26)	0.102
SIPA for patients aged 13–18 y (<0.9)	5.08 (4.36–5.93)	<0.001	1.94[g] (1.55–2.44)	<0.001

All trauma scores were adjusted for age, sex, race, ethnicity, hospital teaching status, American College of Surgeons pediatric verification level, number of licensed beds in facility, geographic region for the hospital, comorbidity, indication of the type (nature) of trauma produced by an injury, injury intentionality as defined by the Center for Disease Control injury intentionality matrix, *ICD-9-CM* mechanism of injury E-Code, location where injury occurred, whether patient used alcohol, whether patient used drugs, the patient's primary method of payment, mode of transportation, and the ISS reflecting the patient's injuries directly submitted by the facility regardless of the method of calculation.

[a] In addition, adjusted for ED SI and GCS.

[b] In addition, adjusted for ED rSI and GCS.

[c] In addition, adjusted for rSIG.

[d] In addition, adjusted for ED SI and GCS.

[e] In addition, adjusted for ED SI and GCS.

[f] In addition, adjusted for ED SI and GCS.

[g] In addition, adjusted for ED SI and GCS.

may explain our lower mortality rate compared with previously published data.

CONCLUSION

In conclusion, our data suggest that use of the SIPA score to predict mortality in children should be reevaluated given its poor performance. rSIG appears to be a more promising variable that can be easily calculated and used at all ages. Future studies looking at the change in rSIG over time as a predictor of outcomes as well as understanding how these findings can impact clinical decisions and hence outcomes are needed.

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