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Pediatric specific shock index accurately identifies severely injured children☆

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ABSTRACT

Introduction: Shock index (SI) (heart rate/systolic blood pressure) >0.9 predicts mortality in adult trauma patients. We hypothesized that age adjusted SI could more accurately predict outcomes in children.
Methods: Retrospective review of children age 4–16 years admitted to two trauma centers between 1/07 and 6/13 following blunt trauma with an injury severity score (ISS) >15 was performed. We evaluated the ability of SI >0.9 at emergency department presentation and elevated shock index, pediatric age adjusted (SIPA) to predict outcomes. SIPA was defined by maximum normal HR and minimum normal SBP by age. Cutoffs included SI >1.22 (age 4–6), >1.0 (7–12), and >0.9 (13–16).
Results: Among 543 children, 50% of children had an SI > 0.9 but this fell to 28% using age adjusted SI (SIPA). SIPA demonstrated improved discrimination of severe injury relative to SI: ISS > 30: 37% vs 26%; blood transfusion within the first 24 hours: 27% vs 20%; Grade III liver/spleen laceration requiring blood transfusion: 41% vs 26%; and in-hospital mortality: 11% vs 7%.
Conclusion: A pediatric specific shock index (SIPA) more accurately identifies children who are most severely injured, have intraabdominal injury requiring transfusion, and are at highest risk of death when compared to shock index unadjusted for age.

Accurate triage of the trauma patient is critical to the function of a trauma center [1]. Triage schemes must balance under triage resulting in missed injuries with over triage which can lead to the overcrowding of trauma centers with only mildly injured patients [1,2]. In the adult population, most trauma centers utilize the revised trauma score (RTS), which relies on physiologic derangement to identify severely injured patients [1,3], as a triage tool. Components measured in the RTS include respiratory rate (RR), systolic blood pressure (SBP), and Glasgow Coma Scale (GCS) score. Unfortunately, in children, these factors are difficult to measure accurately [1,4]. Further confounding the problem of a scoring system is the fact that normal vital signs vary with patient age among children [5–7], making the use of a scoring system based on vital sign cutoff values, such as the case of the RTS, difficult to apply in children.

Given the shortcomings associated with applying adult derived scores to pediatric populations, previous groups have aimed to determine what factors can be used to accurately predict injury severity and outcomes among injured children. These data have demonstrated that mechanism alone is a poor predictor of injury severity [8] but that clinical and physiologic parameters are better indicators of injury in children [9]. Recent work in the adult literature has focused on newer markers of physiologic status, such as shock index (SI) (heart rate/systolic blood pressure), to attempt to improve the predictive value of traditional vital signs in identifying severely injured patients [10]. An elevated SI (>0.9), prior to hospital arrival, has been shown to predict mortality and need for massive transfusion in adult trauma patients [10–12]. Prior work evaluating the utility of elevated SI in predicting outcome among pediatric trauma patients has not been performed. Considering that normal vital signs vary significantly with age, we hypothesized that a pediatric age adjusted SI would better predict outcomes among blunt injured children, than an elevated SI based on adult derived cutoff values.

1. Methods

Following approval of the Colorado Multiple Institution Review Board, we performed a retrospective review of the medical records of all children age 4–16 years admitted to two trauma centers, Children's Hospital Colorado and Denver Health Medical Center, between 1/07 and 6/13 following blunt trauma with an injury severity score (ISS) >15. Children were identified from the prospectively collected trauma databases at each institution. Data were obtained from the trauma

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Table 1
Normal pediatric vital sign ranges based on patient age.

Age	Heart rate	Systolic blood pressure	Diastolic blood pressure	Respiratory rate	Maximum normal SIPA
4–6 years	65-110	90–110	60–75	20–25	1.222222222
6–12 years	60–100	100–120	60–75	14–22	1
>12 years	55–90	100–135	65–85	12–20	0.9

SIPA—shock index, pediatric age adjusted; equal to maximum normal heart rate/minimum normal SBP.

database; missing data were obtained from retrospective review of the electronic medical record. Outcomes evaluated were divided into early and late outcomes and markers of severe injury. Early outcomes included AIS head, ISS, and need for blood transfusion in the first 24 hours. Late outcomes included ICU and hospital length of stay (LOS), days of mechanical ventilation, discharge to a rehabilitation facility, severe anemia (defined by hemoglobin 8.0 g/dL) [13], thrombocytopenia (defined by platelet count <100,000/L) [14], ventilator associated pneumonia, urinary tract infection, surgical site infection, and bacteremia. Markers of severe injury included ISS > 24, the presence of a grade 3 or higher liver or spleen laceration requiring blood transfusion, and in-hospital mortality.

We used three different approaches to determine the ability of elevated SI to predict early and late outcomes among blunt injured children. We first used an SI cutoff of >0.9, which has been demonstrated to predict outcomes in adult trauma patients [15], to determine its ability to predict outcomes among all children, with no adjustments made for age. We then performed receiver operating characteristic (ROC) analysis for each outcome to determine the best cutoff value for the population as a whole, again with no adjustment for age. Finally, we determined the maximum normal shock index for each age group, defined here as shock index, age adjusted (SIPA), by dividing the maximum normal heart rate by the minimum normal systolic blood pressure. Normal vital signs used for these calculations were based on published normal ranges compiled from two pediatric textbooks and the United States Department of Health and Human Services Pediatric Basic and Advanced Life Support guidelines [5–7] and are shown in Table 1. Elevated SIPA on presentation was defined as SI greater than the maximum age adjusted SI. Cutoffs included SI > 1.22 (age 4–6), >1.0 (7–12), and >0.9 (13–16). We then evaluated the ability of elevated SIPA to predict each of the given outcomes.

1.1. Statistical analysis

Patient demographics and clinical characteristics were summarized using descriptive statistics. Comparisons between age groups were performed with chi-squared analysis. Multiple logistic regression was performed to model the relationship between binary outcomes and shock index after adjusting for other covariates. ROC analysis was used to identify the best cut-off for each outcome. Generalized linear models were performed for continuous outcomes.

2. Results

We identified 543 children who met inclusion criteria; no children were excluded from analysis. Demographic characteristics are documented in Table 2. Also contained in Table 2 is the rate of all outcomes evaluated, with comparisons made between age groups. Of all factors measured, only weight, SI on presentation, and hospital LOS varied with age. SI decreased with increasing age from an average of 1.06 among those aged 4–6 to 0.83 among children 13–16 ($p < 0.0001$). Hospital length of stay was slightly longer in the older children (median 4 days among all ages; IQR 2-7 age 4–12, 2-11 days age 13–16).

Elevated SI > 0.9 was present in 266 of 543 children (49.0%) and was associated with a variety of adverse outcomes among blunt injured children (Table 3). SI > 0.9 was associated with higher ISS, need for blood transfusion in the first 24 hours, longer ICU and hospital LOS, longer need for mechanical ventilation, severe injury (ISS >24), grade 3 or higher liver or spleen laceration requiring blood transfusion, and in-hospital mortality. SI > 0.9 was not associated with discharge to a rehabilitation facility. Analysis was then repeated using elevated SIPA as a cutoff value. Elevated SIPA was present in only 27.6% of children ($n = 150$) on admission and was also associated with all of the adverse outcomes identified by SI > 0.9 including higher ISS, need for blood transfusion in the first 24 hours,

Table 2
Demographic characteristics and outcomes of injured children by age group.

	Age 4–6, $n = 128$	Age 7–12, $n = 237$	Age 13–16, $n = 194$	p Value
Male, n (%)	81 (63.3%)	150 (63.3%	131 (67.5%)	0.61
Weight (kg), mean (SEM)	20.3 (0.4)	39.16 (0.9)	60.8 (1.2)	<0.0001
ISS, mean (SEM)	23.3 (0.9)	23.4 (0.6)	24.3 (0.7)	0.58
Highest AIS head, median (IQR)	4 (4–5)	4 (4–5)	4 (4–5)	0.61
SI, mean (SEM)	1.06 (0.03)	0.92 (0.02)	0.83 (0.02)	<0.0001
GCS, median (IQR)	15 (7–15)	15 (6–15)	15 (6–15)	0.85
Blood transfusion in first 24 hours, n (%)	23 (18.0%)	27 (11.4%)	27 (13.9%)	0.22
ICU LOS (days), median (IQR)	2 (1–5)	2 (1–5)	2 (1–6)	0.26
Hospital LOS (days), median (IQR)	4 (2–7)	4 (2–7)	4 (2–11)	<0.01
Days of mechanical ventilation, median (IQR)	2.5 (1-6.75)	2 (1–9)	2 (1–8)	0.35
Discharge to rehabilitation, n (%)[a]	19 (15.6%)	46 (20.4%)	41 (22.0%)	0.37
Severe anemia, n (%)[b]	23 (21.7%)	38 (18.4%)	45 (24.9%)	0.3
Thrombocytopenia, n (%)[b]	11 (10.7%)	18 (9.0%)	18 (10.1%)	0.89
Ventilator associated pneumonia, n (%)	10 (7.8%)	15 (6.3%)	15 (7.7%)	0.81
Urinary tract infection, n (%)	3 (2.3%)	5 (2.1%)	9 (4.6%)	0.27
Surgical site infection, n (%)	3 (2.3%)	1 (0.4%)	6 (3.1%)	0.1
Bacteremia, n (%)	1 (0.8%)	1 (0.4%)	1 (0.5%)	0.9
ISS > 24, n (%)	43 (33.6%)	90 (38.0%)	81 (41.8%)	0.33
Grade III liver/spleen laceration requiring transfusion, n (%)[c]	3 (20%)	6 (15%)	5 (16.7%)	0.91
In-hospital mortality, n (%)	6 (4.7%)	11 (4.6%)	8 (4.1%)	0.96

SEM—standard error of the mean, ISS—injury severity score, AIS—abbreviated injury score, IQR—interquartile range, GCS—Glasgow Coma Score, LOS—length of stay.
[a] Discharge to rehab based on patients surviving to hospital discharge.
[b] Calculated based on available data.
[c] Calculated based on number of patients with Grade III liver/spleen laceration.

Table 3
Ability of elevated shock index and shock index, pediatric age adjusted (SIPA) to predict outcomes in blunt injured children.

	SI < 0.9 (n = 277)	SI > 0.9 (n = 266)	p	Normal SIPA (N = 393)	Elevated SIPA (N = 150)	P
AIS head, mean (SEM)	4.04 (0.06)	4.07 (0.07)	0.73	4.04 (0.05)	4.07 (0.1)	0.85
ISS, mean (SEM)	20.4 (0.34)	25.6 (0.72)	<0.0001	21.9 (0.36)	28.9 (1.12)	<0.0001
ICU LOS, median (IQR)	1 (0–2)	2 (0–4)	<0.0001	1 (0–3)	2 (1–6)	<0.0001
Hospital LOS, median (IQR)	3 (2–6)	4 (2–9.25)	0.001	4 (2–6)	6 (3–12.25)	0.0035
Ventilator days, median (IQR)	0 (0–1)	0 (0–2)	<0.0001	0 (0–1)	1 (0–4)	<0.0001
Blood transfusion in first 24 hours, n (%)	22 (7.9%)	53 (19.9%)	<0.0001	34 (8.7%)	41 (27.3%)	<0.0001
Discharge to rehab, n (%)	49 (17.7%)	55 (20.7%)	0.23	62 (16.0%)	42 (31.6%)	<0.001
ISS > 24	93 (33.6%)	117 (44.0%)	0.01	129 (32.8%)	81 (54.0%)	<0.0001
Grade 3 or higher liver or spleen laceration requiring transfusion	3 of 39 (7.7%)	12 of 46 (26.1%)	0.04	4 of 58 (6.9%)	11 of 27 (40.7%)	<0.001
In-hospital mortality, n (%)	4 (1.4%)	20 (7.5%)	<0.001	7 (1.8%)	17 (11.3%)	<0.0001

Normal SIPA based on age adjusted vitals; elevated SIPA defined as SI >1.22 (age 406), >1.0 (age 7–12), and >0.9 (age 13–16). SIPA—shock index, pediatric age adjusted, SI—shock index, ISS—injury severity score, LOS—length of stay, IQR—interquartile range.

longer ICU and hospital LOS, longer need for mechanical ventilation, severe injury (ISS > 24), grade 3 or higher liver or spleen laceration requiring blood transfusion, and in-hospital mortality, as well as discharge to a rehabilitation facility (Table 3). The ability of SI > 0.9 and elevated SIPA to detect outcomes is presented in Fig. 1.

ROC analysis revealed that the optimal SI cutoff to predict each outcome among the entire cohort of children was highly variable (Table 4). Optimal cutoff ranged from 1.05 to 5.23 depending on outcome evaluated.

Ability of SI > 0.9 and elevated SIPA to identify severely injured children was compared. Among all children, 50% had an SI > 0.9 but this fell to 28% using age adjusted SI (SIPA). SIPA demonstrated improved discrimination of severe injury relative to SI: 54% of patients with elevated SIPA had ISS > 24 compared to 34% of those with SI > 0.9. Similarly, 27% of patients with elevated SIPA required blood transfusion within the first 24 hours compared to 20% of those with SI > 0.9. 27% of those with a grade III liver/spleen laceration and an elevated SIPA required a transfusion compared to 20% among those with elevated SI. In-hospital mortality was 11% among those with elevated SIPA but only 7% among those with elevated SI.

Table 5 demonstrates the percentage of children with each SI cutoff value, based on patient age. Approximately one fourth to one third of patients have an elevated SIPA (22.0% of those age 4–6, 25.1% of those age 7–12, and 32.0% of those age 13–16). Table 5 demonstrates that using a single SI cutoff identifies a variable percentage of patients, depending on patient age. For example, 70.9% of children age 4–6 have an SI > 0.9 while only 32.0% of those age 13–16 have an SI > 0.9.

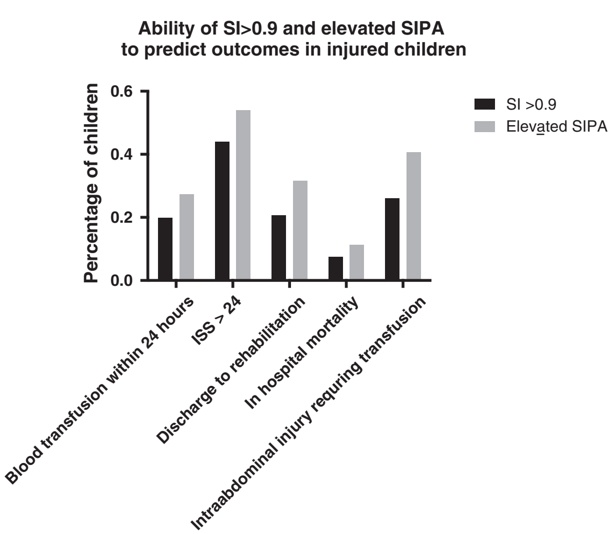

Fig. 1. Percentage of children with either an SI > 0.9 (shown in black) or an elevated SIPA (shock index, pediatric age adjusted) (shown in gray), with each of five outcomes measured. These data demonstrate that for each outcome, the pediatric age adjusted score, SIPA, detects a higher percentage of patients with a given complication, suggesting that the SIPA has better discriminate ability to identify severely injured children than does the SI cutoff of >0.9 that has been used in adults. SI—shock index.

3. Discussion

We have demonstrated that as in adult patients, the shock index is able to accurately identify severely injured children. However, by adding an adjustment for patient age, the discriminate ability of this tool is increased substantially. The shock index, pediatric age adjusted (SIPA) is able to accurately identify those children who are most severely injured following blunt trauma. Elevated SIPA is associated with higher injury severity, need for blood transfusion in the first 24 hours, longer ICU and hospital LOS, higher number of ventilator days, and discharge to a rehabilitation facility. Additionally, elevated SIPA can be used as an accurate identifier of severe injury as it is associated with ISS > 24, a grade 3 or higher liver or spleen laceration requiring blood transfusion as well as in-hospital mortality. At a time when accurate trauma center triage, with a careful balance of under and over triage, is critical, SIPA provided better discriminate ability to identify severely injured children than did an SI of >0.9. Elevated SIPA identifies approximately 25% of the most severely injured children, regardless of age, while an SI > 0.9 identifies anywhere from 32% to 71% of injured children, depending on age.

When comparing SI > 0.9 and elevated SIPA, both factors appear to accurately identify the most severely injured children, making the pediatric age adjustment seem unnecessary. However, closer evaluation of the two demonstrates that the age adjusted SIPA seems to better differentiate severely injured children from those with mild injury. As demonstrated in Fig. 1, the percentage of patients with an elevated SIPA and each adverse outcome is higher than the percentage of patients with an SI > 0.9 and each outcome. The converse is also true, the percentage of patients with each of the evaluated adverse outcomes and a normal SIPA is lower than the percentage with a

Table 4
ROC based SI cutoffs which best predict outcomes in blunt injured children.

	ROC based SI cutoff
Blood transfusion in first 24 hours	1.22
Need for ICU admission	1.23
Need for mechanical ventilation	1.06
Severe anemia	1.23
Thrombocytopenia	1.26
Ventilator associated pneumonia	1.05
Urinary tract infection	5.23
Blood stream infection	2.82
Surgical site infection	2.69
Discharge to rehab	1.1

Data based on entire cohort without age specific adjustment. ROC—receiver operating characteristic, SI—shock index.

Table 5
Percentage of blunt injured children with each SI cutoff based on age.

Shock index	Age 4–6 (n = 127), n (%)	Age 7–12 (n = 235), n (%)	Age 13–16 (n = 194), n (%)
>1.22	28 (22.0%)	27 (11.5%)	17 (8.9%)
>1.0	72 (56.7%)	59 (25.1%)	33 (17.0%)
>0.9	90 (70.9%)	112 (47.7%)	62 (32.0%)

SI—shock index.

normal SI and adverse outcome, indicating that elevated SIPA misses fewer children with severe injury while also minimizing over triage. Using the adult based criteria, elevated SI was present in nearly 50% of children on presentation to the emergency department. When the overall mortality in the population is around 10%, a triage tool which indicates that half of patients are at risk for severe injury is not nearly as useful to a provider as one which identifies only one fourth of patients as being at increased risk. The age adjustment included in the SIPA helps to substantially decrease the over triage of children that occurs when the adult based cutoff of 0.9 is used. ROC analysis failed to identify a single SI cutoff that could be reliably used in all children to predict adverse outcomes. The age adjustment inherent to the SIPA increases the utility of this triage tool.

In adult patients, hypovolemic shock secondary to traumatic blood loss can lead to predictable changes in vital signs including tachycardia and hypotension. Unlike in adults, hypotension is a late finding of hypovolemic shock in children [16]. Early signs in children include tachycardia, poor peripheral perfusion, and weak peripheral pulses [17], findings that are difficult to quantify in a busy trauma bay. Because vital signs are poor predictors of morbidity and mortality in both adult and pediatric trauma patients [18,19], other more invasive tests are now being used in the prehospital setting to predict injury severity. Shah et al. [18] have shown that elevated serum lactate level during prehospital helicopter transportation is associated with severe traumatic injuries, even among children with normal vital signs during the prehospital period. As these authors point out, the benefit of identifying severely injured patients using accurate early predictors of trauma outcomes would be a decrease in the rate of over triage [18]. Here we demonstrate that by combining heart rate and systolic blood pressure and incorporating patient age, the utility of the child's vital signs on initial presentation to indicate injury severity is increased substantially. Our data offer an additional tool that can be easily obtained at initial presentation and accurately predict severe injury. An elevated SIPA can be used by a provider to either indicate need for transfer to a higher level of care or to heighten awareness of the child's elevated risk of severe injury.

There are a variety of limitations to the current work that should be considered. As with all data collected in a retrospective manner, our data are inherently limited. Additionally, we have proposed age specific cutoffs to the SI and demonstrated their utility in a single population. These cutoffs and their predictive value require further validation in a second cohort. The population from which these data are derived included only blunt injured children aged 4–16. The applicability of these findings to young infants and toddlers as well as patients who suffer from penetrating injury is unknown and will require follow up evaluation. Furthermore, we have chosen to look only at one value of SI, at the time of presentation to the emergency department. Previous groups have demonstrated that an SI that increases between the field and ED may also predict poor outcomes [12]. This finding among injured children will be the focus of future work.

Despite these limitations, these data provide further validation to the utility of an elevated SI on presentation to the emergency department in identifying severely injured patients. Similar to the Pediatric Trauma Score (PTS), first described in 1987 and known to predict injury severity in children [20], the SIPA presented here demonstrates the significant benefit of age based adjustments when using scoring systems to evaluate injured children. We have demonstrated how a relatively simple adjustment for patient age can increase the utility of this tool in the pediatric population. The data presented here demonstrate that SIPA can be used at the time of initial presentation following trauma to help identify severely injured children. However, we hypothesize that SIPA can also be used to follow patients over time and offer further information regarding a patient's ongoing hemodynamic status. Further research will evaluate the utility of continuous SIPA monitoring in the setting of severe illness or injury. Although SI is not as readily available as traditional vital signs, SI can be easily calculated and made available to the trauma team during primary survey of the injured child. Additionally, normal SIPA can be added to the age based vital sign charts which are frequently found in pediatric emergency departments. SIPA is a readily available tool, which can be easily incorporated into the initial triage of injured children to either alert the clinician to the risk of severe injury or indicate need for transfer to a higher level of care.

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