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Elevated pediatric age-adjusted shock-index (SIPA) in blunt solid organ injuries☆

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ABSTRACT

Background/Purpose: Shock index-pediatric age-adjusted (SIPA) is a proven tool to predict outcomes in blunt pediatric trauma. We hypothesized that an elevated SIPA in either the pre-hospital or in the emergency department (ED) would identify children with blunt liver or spleen injury (BLSI) needing a blood transfusion and those at risk for failure of non-operative management (NOM).
Methods: Pediatric patients (1–18 years) in the ACS pediatric-TQIP database (2014–2016) with a BLSI were included. Patients were stratified by the need for a blood transfusion and/or abdominal operation.
Results: A total of 3561 patients had BLSI, of which 4% received a blood transfusion, and 4% underwent an abdominal operation. Patients who received blood had higher ISS scores (27.0 vs. 5.0, $p < 0.001$) and mortality (22% vs. 0.4%, $p < 0.001$). Those who failed NOM had higher ISS scores (17.0 vs. 5.0, $p < 0.001$) and mortality (7.9% vs. 0.9%, $p < 0.001$). On multivariable regression, an elevated SIPA score in either pre-hospital or ED was significantly associated with blood transfusion (odds ratio (OR) 8.2, 95% confidence intervals (CI) 5.8–11.5, $p < 0.001$) and failure of NOM (OR 2.3, CI 1.5–3.4, $p < 0.001$).
Conclusions: Hemodynamic instability, represented by an elevated pre-hospital or ED SIPA, accurately identifies children with BLSI who may need blood products or an operative intervention.
Type of Study: Retrospective Comparative Study.
Level of Evidence: Level III.

Blunt liver or spleen injury (BLSI) remains a significant cause of morbidity and mortality in the pediatric population. Although some patients require an operative intervention to control bleeding, data supports that 90% of these injuries can be managed non-operatively, and non-operative management (NOM) is presently the standard of care [1–4]. Prior studies show that children with higher-grade injuries are more likely to receive a blood transfusion [5,6]. However, current NOM guidelines have shifted from management based on injury grade to management based on hemodynamic stability [7]. Nonetheless, there are insufficient markers and tools available to accurately predict who will require blood transfusion in this patient population [7]. Early identification of those who will require blood transfusion is critical for improving outcomes, because mortality associated with failure of NOM in pediatric patients remains significantly elevated at 24% [2].

The shock index-pediatric age-adjusted (SIPA) is a proven tool to predict outcomes in individuals with blunt trauma. It has demonstrated utility in predicting which injured children are at risk for worse outcomes [8–12]. In a recent study from our institution, elevated SIPA values in the pre-hospital setting and upon emergency department (ED) arrival were associated with early blood transfusion. These elevated values suggest that monitoring serial SIPA values may be useful in the early identification of those who will require transfusion after sustaining a BLSI [13]. Although this retrospective study was from a single institution, it showed that patients with a single elevated SIPA score in either the pre-hospital or ED setting significantly predicted blood product transfusion [odds ratio (OR) of 7.8], indicating elevated SIPA scores are excellent markers for injury severity.

To validate our institution-specific study findings, we utilized the American College of Surgeons (ACS) pediatric Trauma Quality Improvement Program (TQIP) database (2014–2016) to perform a similar study.

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We hypothesized that an elevated SIPA, in either the pre-hospital or ED, would identify children with BLSI needing a blood transfusion and at risk for failure of NOM.

1. Methods

1.1. Data source

The Pediatric TQIP dataset was utilized for this study. It collects data from 463 participating level I/II trauma centers. This study used de-identified data and was not considered human subjects research per the Colorado Multiple Institutional Review Board (COMIRB). Therefore, institutional review board oversight was not required.

1.2. Study population

Pediatric patients (ages 1–18 years old) in the ACS pediatric TQIP database (2014–2016) with any grade BLSI, and complete pre-hospital and ED vital signs were included. Patients with a BLSI were identified by using ICD-9 and ICD-10 codes. Failure of NOM was defined as a patient undergoing an abdominal surgical procedure in the operating room within the first 24 h of ED arrival. Angioembolization was not considered a failure of NOM to remain consistent with other published literature (2, 5). We excluded patients with penetrating injuries, incomplete vital signs, missing transfusion data, and children <1 year of age (See Fig. 1).

Data collected included demographics, Glasgow coma score (GCS), injury severity score (ISS), initial vital signs on scene and upon ED arrival. Blood transfusion data was dichotomized into two groups, either a yes for any amount available or no if not available, to avoid mislabeled unit confusion in analysis. Primary outcome measures included transfusion requirement within 4 h of admission, need for an abdominal operation, and mortality.

1.3. Statistical analysis

SIPA was calculated as previously reported [9]. To maintain consistency with our previous work, we placed patients into four distinct groups based on whether their pre-hospital and ED SIPA values were elevated or normal, as shown in Table 1. Patients were stratified for separate analysis by the need for blood transfusion within the first 4 h and the need for abdominal operation within the first 24 h of ED arrival. Summary statistics for demographic and outcomes data are presented as medians (first and third quartile), and frequencies (percentages) based on the distribution of the data. Continuous variables were tested for group differences using student t-test, while chi-squared testing was utilized for categorical variables to compare demographics and outcomes data. Finally, multivariable models were created to determine factors associated with blood transfusion and failure of NOM. All testing used 0.05 as a significance cutoff. All statistical processes were conducted using R version 3.6.1 software (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/).

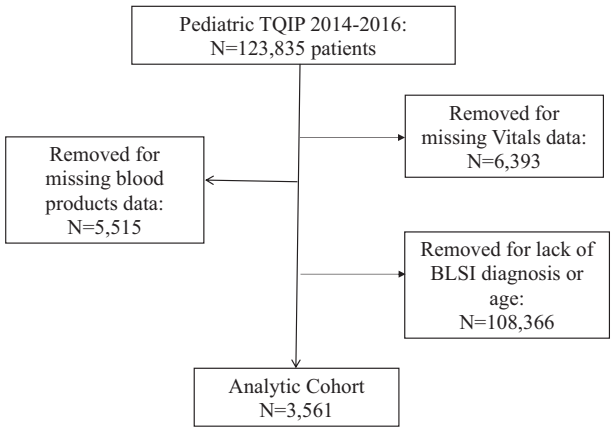

Fig. 1. Consort diagram.

Table 1
Four cohorts stratified by SIPA calculation and categorized as elevated or normal in the pre-hospital setting and upon ED arrival.

Pre-hospital SIPA	ED SIPA	Cohort
Elevated	Elevated	*Elevated-elevated*
Elevated	Normal	*Elevated-normal*
Normal	Elevated	*Normal-elevated*
Normal	Normal	*Normal-normal*

Abbreviations: SIPA, shock index-pediatric age-adjusted; ED; emergency department.

2. Results

2.1. Demographics and injury characteristics of BLSI patients

Of 123,835 children included in the pediatric TQIP dataset from 2014 to 2016, a total of 3561 patients had BLSI and were included in the analytic cohort. Of these, 4% received a blood transfusion within 4 h of arrival, and 4% underwent an abdominal operation within 24 h of arrival to the ED. Those patients who received blood and failed NOM were significantly older and had lower GCS scores (all p's < 0.001).

Patients who received blood had significantly higher ISS scores (27.0 vs. 5.0, p < 0.001) and mortality (22% vs. 0.4%, p < 0.001) (Table 2). Similarly, patients who failed NOM had significantly higher ISS scores (17.0 vs. 5.0, p < 0.001) and mortality (7.9% vs. 0.9%, p≤0.001) (Table 3). Those who failed NOM received significantly more blood product transfusions at 4 hours after admission to a pediatric trauma center (32.3% vs. 3.0%, p < 0.001). Demographic and injury data for the cohorts stratified by blood transfusion status are presented in Table 2. Demographic and injury data for the cohorts stratified by NOM status are presented in Table 3.

2.2. Comparison of SIPA values in those who received blood

Out of all of the patients with an elevated SIPA (pre-hospital and/or ED), 10% (109/1112) received a blood transfusion compared to 1.9% (47/2449) of patients with a normal SIPA (both pre-hospital and ED) (p < 0.001). Correspondingly, 70 % (109/156) of patients who received a blood transfusion had at least one elevated SIPA value in either setting (pre-hospital or ED).

Table 2
Demographic and clinical characteristics of children with BLSI stratified by blood transfusion status.

	Blood transfused (n = 156)	No blood transfused (n = 3405)	p-Values
Age, years	16.0 (10.0, 18.0)	14.0 (9.0, 17.0)	< 0.001
Female	48 (30.8%)	1145 (33.6%)	NA
Mortality	35 (22.4%)	12 (0.4%)	< 0.001
GCS	7.0 (3.0, 15.0)	15.0 (15.0, 15.0)	< 0.001
ISS	27.0 (17.0, 34.0)	5.0 (4.0, 10.0)	< 0.001
Failure of NOM	53 (34.4%)	111 (3.3%)	< 0.001
Blood transfused within 4 hours	156 (100%)	0 (0%)	< 0.001

Continuous variables presented as median (first and third quartiles); categorical variables presented as n (%).
Abbreviations: BLSI, blunt liver or spleen injury, NOM, non-operative management; GCS, Glasgow coma score; ISS, injury severity score.

Table 3
Demographic and clinical characteristics of children with BLSI stratified by NOM status.

	Failure of NOM (n = 164)	Successful NOM (n = 3397)	p-Values
Age, years	16.0 (13.0, 17.3)	14.0 (9.0, 17.0)	< 0.001
Female	44 (26.8%)	1147 (33.7%)	NA
Mortality	13 (7.9%)	32 (0.9%)	< 0.001
GCS	15.0 (7.0, 15.0)	15.0 (15.0, 15.0)	< 0.001
ISS	17.0 (9.0, 27.0)	5.0 (4.0, 10.0)	< 0.001
Failure of NOM	164 (100%)	0 (0%)	< 0.001
Blood transfused Within 4 hours	53 (32.3%)	101 (3.0%)	< 0.001

Continuous variables presented as median (first and third quartiles); categorical variables presented as n (%).
Abbreviations: BLSI, blunt liver or spleen injury, NOM, non-operative management; GCS, Glasgow coma score; ISS, injury severity score.

Overall, over 40 % of patients (65/156; 42%) who received blood had an *elevated-elevated* SIPA. In comparison, 18/156 (12%) had *elevated-normal* SIPA values, 26/156 (17%) had *normal-elevated* SIPA values, and 47/156 (30%) had *normal-normal* SIPA values (See Table 4). On unadjusted regression analysis, an elevated SIPA score in either setting (pre-hospital or ED) was significantly associated with blood transfusion (OR 8.2, 95% confidence intervals (CI) 5.8–11.5, $p < 0.001$). On a multivariate regression analysis after adjusting for GCS and ISS, an elevated SIPA score in either setting (pre-hospital or ED) remained a significant predictor of blood transfusion (OR 5.3, CI 3.5–8.2, $p < 0.001$) (Table 5).

2.3. Comparison of SIPA values in those who failed NOM

Overall, 49% (81/164) of patients had an elevated SIPA (pre-hospital or ED) failed NOM (Table 6). Overall, over 18 % of patients (30/164; 18%) who failed NOM had an *elevated-elevated* SIPA. In comparison, 27/164 (17%) had *elevated-normal* SIPA values, 24/164 (15%) had *normal-elevated* SIPA values, and 83/164 (50%) had *normal-normal* SIPA values. One third (34%) of those who received a blood transfusion also failed NOM. On unadjusted regression analysis, an elevated SIPA score in either setting (pre-hospital or ED) was significantly associated failure of NOM (OR 2.3, CI 1.5–3.4, $p < 0.001$). However, this association was no longer significant after adjusting for GCS and ISS (OR 1.2, CI 0.7–1.9, $p = 0.478$).

The positive predictive value (PPV) of SIPA for prognosticating failure of NOM was calculated. The PPV for an elevated SIPA prior to ED arrival was 96.1%. The PPV for an elevated SIPA in the ED was 96.2%. Therefore, in either setting, an elevated SIPA has a very high likelihood of predicting a patient will fail NOM.

3. Discussion

Among pediatric patients with BLSI, an elevated pre-hospital or ED SIPA, accurately identifies children who may need blood product transfusion or operative intervention. Specifically, patients in whom SIPA is elevated in the pre-hospital setting and remains elevated upon arrival to the ED have the highest rate of receiving a blood product transfusion. These findings add to the growing body of literature regarding the usefulness of monitoring serial SIPA values in the management of severely injured pediatric patients [10,11,13]. Given the high associated mortality with failure of NOM in pediatric patients, monitoring serial SIPA scores provides a useful adjunctive clinical tool to alert providers of patients at high risk for worse outcomes, potentially allowing them to intervene sooner.

The data presented in this study indicate an association between persistently elevated or rising SIPA scores and children who are most likely to receive a blood product transfusion after BLSI. Previous data have identified that the need for blood product transfusion is likely to occur early in a child's hospital course, within 2 h after injury [3]. Furthermore, studies have shown that pediatric patients who fail NOM do so early (within 6 h) [2,7,8]. These studies showed that time from initial injury to the pediatric trauma center averaged over 3 hours. This leaves 3 hours in which an injured child typically fails NOM. Having better pre-hospital non-invasive predictive information will aid the teams' ability to mobilize the operating rooms and blood banks, potentially even before the patient arrives, avoiding an unnecessary three-hour delay. Our results indicated an elevated SIPA in a pre-hospital or ED setting has a high PPV, which reinforces the observation that SIPA can be used as a tool to accurately and expeditiously identify these at-risk patients. The sooner we as clinicians can identify that a BLSI patient will require blood or surgical intervention, the faster we can achieve timely hemostasis and subsequently improve the chances of survival for these patients.

Past studies, including from our institution, have shown that children with BLSI who receive blood product transfusion and fail NOM are at a higher risk of mortality. In the pilot study of this project, we found 22% of children with BLSI who received a blood product transfusion ultimately died [13]. Furthermore, a 2016 prospective study by the ATOMAC group found that of 1008 pediatric patients included in the study, 7% failed NOM of their BSLI. Of those patients who failed NOM there was a 24% mortality rate. Every mortality in their series was due to hemorrhage with a median time to the operating room of 2.9 h [2]. In this series using TQIP data, the mortality associated with failure of NOM was 7.9%.

To provide a comprehensive picture of pediatric patients requiring surgical intervention we included all cases of children undergoing an

Table 5
Multivariate regression analysis of predictors of elevated SIPA vs. not for blood transfusion and failure of NOM.

	Blood transfusion at 4 hours			Failure of NOM		
Predictors	*Odds ratios*	*CI*	*p*	*Odds ratios*	*CI*	*p*
GCS	0.88	0.84–0.91	**<0.001**	0.97	0.93–1.02	0.241
ISS	1.09	1.07–1.11	**<0.001**	1.07	1.05–1.08	**<0.001**
Elevated SIPA	**5.33**	3.48–8.17	**<0.001**	1.19	0.74–1.93	0.478

Abbreviations: CI, confidence intervals; GCS, Glasgow Coma Score; ISS, injury severity score; NOM, non-operative management.

Table 4
Comparison of Elevated and Normal SIPA values in the pre-hospital and the ED in those who required blood transfusion compared those who did not.

Pre-hospital SIPA	ED SIPA	Blood transfused* (n = 156)	No blood transfused (n = 3405)
Elevated	Elevated	65 (41.7%)	274 (8.0%)
Elevated	Normal	18 (11.5%)	439 (12.9%)
Normal	Elevated	26 (16.7%)	290 (8.5%)
Normal	Normal	47 (30.1%)	2402 (70.5%)

* There is a significant difference between the groups with an elevated pre-hospital or ED SIPA compared to those with a normal SIPA. They were more likely to receive a blood transfusion ($p < 0.001$).

Table 6
Comparison of elevated and normal SIPA values in the pre-hospital and the ED in those who failed NOM compared those who did not.

Pre-hospital SIPA	ED SIPA	Failure of NOM* (n = 164)	Successful NOM (n = 3397)
Elevated	Elevated	30 (18.3%)	308 (9.1%)
Elevated	Normal	27 (16.5%)	429 (12.6%)
Normal	Elevated	24 (14.6%)	290 (8.5%)
Normal	Normal	83 (50.6%)	2365 (69.7%)

* There is a significant difference between the groups with an Elevated Pre-hospital or ED SIPA compared to those with a normal SIPA. They were more likely to fail non-operative management ($p < 0.001$).

abdominal operation. Patients in our cohort who were candidates for abdominal operations due to pancreatic or small bowel injuries were included in the failure of NOM cohort, but did not die from hemorrhage related to liver or spleen injuries. We calculated this subset's SIPA scores and found that the average SIPA for those who underwent laparotomy but did not receive blood at 4 h were 1.17 and 1.11 in the pre-hospital and ED setting, respectively. SIPA scores for those who did not receive blood at 24 h in these settings were 1.10 and 1.17, respectively. These differences could help explain differences from our study and the ATOMAC study. The earlier in a child's course that their risk of failure of NOM is recognized, the higher the likelihood of achieving timely hemostasis and subsequent survival for these children. We believe monitoring serial SIPA values provides a useful adjunctive tool that the clinical team can use to help assist in their decision to transfuse or operate, and should be used as an important adjunct to clinical judgment and institutional protocols.

There are limitations to this study. Our analysis was restricted to centers that participate in ACS Pediatric TQIP and thus, our conclusions may not be generalizable to all trauma centers. Furthermore, hundreds of TQIP trained registrars collected these data, and it is possible that human errors in data capturing, coding of injury, and reporting could have occurred. The TQIP 2014–2016 data set does not have information regarding Abbreviated Injury Scale data by body region, which limits the granularity of our data and does not allow us to account for extra-abdominal injuries in our analysis. We excluded patients with missing data, which could add bias to our results. Furthermore, we defined failure of NOM based on the established definition in the literature of requiring an abdominal operation, therefore not every patient in our cohort who underwent an abdominal operation did so from hemorrhage from their liver or spleen injuries. We felt, however, that it was important to include all cases of patients needing an abdominal operation to provide a broader picture of the management of all patients with blunt abdominal injuries.

In conclusion, monitoring serial SIPA scores allows clinicians another tool to monitor children with BLSI more closely and potentially intervene sooner. Our data add to a growing body of work, demonstrating that children with elevated SIPA require closer monitoring, while also validating our previous work on the value of an elevated pre-hospital or ED SIPA in identifying children at high risk of blood transfusion and failure of NOM. Based on the current data, we believe that monitoring both the pre-hospital and ED SIPA should be one factor considered by clinicians when determining where a child with BLSI should be monitored, what the details of that monitoring protocol will include, as well as what the threshold for blood transfusion and operative intervention will be. In addition to vital signs, SIPA is a dynamic factor that can continue to be monitored throughout a child's clinical course to help guide decisions regarding when a child requires an intervention.

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