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Pre-hospital shock index correlates with transfusion, resource utilization and mortality; The role of patient first vitals☆

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ABSTRACT

Introduction: The aim of our study was to evaluate if pre-hospital shock index (SI) can predict transfusion requirements, resource utilization and mortality in trauma patients.
Methods: We performed a 2-year analysis of all adult trauma patients in the TQIP database. Shock index was calculated by dividing heart-rate over systolic blood pressure. Patients were divided into two groups pre-hospital $SI \leq 1$ and prehospital $SI > 1$. Regression and ROC curve analyses were performed.
Results: 144951 patients were included in the study. Mean age was 45 ± 34 years, 61% were male, 84.7% had blunt injuries and median ISS was 13 [9–17]. Overall 9.1% of the patients had a pre-hospital $SI > 1$. Patients with pre-hospital $SI > 1$ had higher likelihood of requiring massive transfusion (25% vs. 0.012%, $p < 0.02$), interventional-radiology intervention (6.2% vs. 1%,$p < 0.001$) or operative intervention (14.7% vs. 2%,$p < 0.001$) compared to $SI \leq 1$. Similarly, patients with $SI > 1$ had higher mortality (12.3% vs. 5.2%, $p < 0.001$) and were more likely to be discharged to Rehab/SNF (34.6% vs. 21.4%, $p < 0.001$).
Conclusions: Pre-hospital SI predicts trauma-center resource utilization and can guide patient triage and trauma resource recruitment.

Introduction

Unintentional injury represents the leading cause of mortality among patients 1–45 years old, causing over 214,000 deaths and 2.8 million hospitalizations annually.[1] Within the first 24 h following injury, hemorrhage is responsible for over 40% of these deaths making bleeding one of the most preventable causes of death worldwide.[2,3] In addition to bleed source control, the mainstay in treating hemorrhage is early and aggressive resuscitation with blood products and adjuncts like cryoprecipitate and factor concentrates. To achieve this goal, patients that may require massive transfusion need to be rapidly identified in order to activate the appropriate level of trauma resources. There remains, however, a paucity of objective tools that can be used for patient triage upon arrival to the hospital and in the pre-hospital environment and has traditionally been based on vital signs like blood pressure, heart rate, Glasgow coma scale (GCS), and anatomy and mechanism of injury.[4,5]

Recent studies have shown that the shock index (SI), as defined as the heart rate/systolic blood pressure is more predictive of trauma outcomes than vitals, GCS, or injury mechanism alone.[6–9] In particular, several authors have noted that pre-hospital SI may have more utility in predicting trauma resource activation, triage level, and mortality than the first SI obtained in the hospital.[10] Initial analysis on this subject have shown conflicting results and their remains no consensus regarding the appropriate SI threshold (>0.8, >0.9, or >1) that should be used clinically.[7,11,12] The goals of this study were therefore to examine the role of the pre-hospital SI, using a large nationwide database, in predicting transfusion requirements, resource utilization, and mortality following a traumatic injury. We hypothesized that pre-hospital SI can predict trauma resource utilization, ICU and OR requirement, and the need

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for blood products transfusion.

Methods

Study design and population

We performed a 2-year retrospective analysis of the American College of Surgeons, Trauma Quality Improvement Program (ACS-TQIP) database from 2013 to 2014. We analyzed all trauma patients in ACS-TQIP over this 2-year study period. The TQIP is a robust dataset administered by the American College of Surgeons (ACS) that can be used to compare risk-adjusted outcomes in the trauma centers across the US. More than 700 trauma centers across the US report data to the TQIP. This dataset is collected by specialized data abstractors at each institution and they record more than 100 variables, including patient demographics; pre-hospital EMS vitals and pre-hospital interventions; emergency department (ED) vitals; ED disposition; injury parameters (mechanism and mode of injury); objective injury scores [injury severity score (ISS) and abbreviated injury scale (AIS)]; in-hospital interventions (blood transfusion, surgical intervention and interventional radiology (IR) procedures), and outcomes (complications, in-hospital mortality and discharge disposition).

IRB and consent

As the TQIP only contains de-identified data, this study was exempted from the Institutional Review Board (IRB) approval. All the data in TQIP is de-identified and this is a retrospective study and did not require patient consents.

Inclusion & exclusion criteria

We included all adult trauma patients (age $\geq$ 18 years) in ACS-TQIP over the 2-year study period. We excluded all patients with who were transferred from other hospitals or dead on arrival.

Definitions

Shock Index (SI): Shock index was defined as the ratio of heart rate (HR)/systolic blood pressure (SI=HR/SBP).

Massive Transfusion (MT): Massive transfusion was defined as transfusion of ten or more units of packed red blood cells (pRBC) in the first 24 h post injury.

Data points

We collected the following data points from the TQIP dataset: patients demographic characteristics; including age, gender, and race, pre-hospital and ED vital parameters; including systolic blood pressure (SBP), heart rate (HR) and Glasgow Coma Scale (GCS), Injury parameters including; mechanism of injury, ISS and body region specific AIS, Complications; including, Acute Respiratory Distress Syndrome (ARDS), Acute Kidney Injury (AKI), Deep Venous Thrombosis (DVT), Pulmonary Embolism (PE), Pneumonia and Cerebrovascular Accident (CVA); the need for Intervention; including interventional radiology (angiography with or without angioembolization) or surgical (laparotomy or thoracotomy), ventilator days intensive care unit (ICU) and Hospital length of stay, disposition; home, rehab/SNF and mortality.

Patient stratification

Shock was identified as a shock index >1.

Patients were stratified into two groups; SI $\leq$ 1 and SI > 1.

Outcomes

Our primary outcome measure was the need for blood products transfusion (pRBC, Platelets and FFP) and the need for intervention (interventional radiology and surgical). Secondary outcome measures were ED disposition, overall complications, hospital and ICU length of stays, ventilator days, discharge disposition and mortality. We also performed a sub-analysis of transfusion requirements in patients with penetrating injuries.

Missing data analysis

We analyzed the data for all the pre-hospital variables, vitals and injury parameters for missingness. The data was missing at random and was treated as missing completely at random (MCAR). Multiple imputations were performed using a missing value analysis technique to account for the missing values. This technique is used to reduce bias and increase the number of available cases. To impute the datasets, the original data set was analyzed for random missing data points using Little's missing completely at random (MCAR) test. We used the Markov Chain Monte Carlo method for multiple imputations. This method refers to a collection of methods for simulating random draws from nonstandard distributions.

Data reporting and statistical analysis

We reported data as a mean ± standard deviation (SD) for continuous variables, as frequency and proportions for categorical variables, and as median [with interquartile range] for ordinal variables. We performed chi-square test to explore the differences in categorical variables between the two groups. In addition, we used the independent student's t-test for continuous parametric data and the Mann-Whitney *U* test for continuous non-parametric data. We considered $p < 0.05$ as statistically significant for our study.

We performed regression analysis to control for the confounders while evaluating our adjusted analysis for our sub-analysis. The model fit was assessed by the Hosmer-Lemeshow test. In the logistic regression model, the Hosmer-Lemeshow test exceeded 0.05 and the tolerance was greater than 0.1 for all independent variables with a variance inflation factor of less than 10.0.

We also performed the Receiver Operator Characteristic (ROC) curve analysis to evaluate the cutoff of pre-hospital SI for different outcomes and to compare the predictive power of pre-hospital SI against prehospital SBP and HR in predicting outcomes.

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, Version 24; SPSS, Inc., Armonk, NY).

Results

A total of 144951 patients met our inclusion and exclusion criteria and were included in our study. Mean age was 45 ± 34 years, 61% were male,76% were White and 7.6% were Hispanics. Median ISS was 13 [9–17] and 84.7% had blunt injuries. Overall 9.1% of the patients had a SI > 1.

Multiple ROC curve analysis for pre-hospital SI were performed separately to choose the optimal cutoff for predicting each individual outcome (blood transfusion, operative/interventional radiology intervention, ICU admission and mortality). The cutoff varied for each individual outcome and ranged from 0.92 to 1.08 for the highest specificity and sensitivity. For the sake of simplicity and based on the highest specificity and sensitivity for most of the outcomes evaluated (on ROC curve analysis) a cutoff of pre-hospital SI > 1 was selected. Patients were then divided into two groups

Table 1
Demographics.

	Pre-hospital SI ≤ 1 (n = 131761)	Pre-hospital SI > 1 (n = 13190)	*p-value*
Age, y, mean ± SD	46 ± 34	44 ± 27	0.78
Male, %	60.5%	65.5%	0.34
Race, %			
White	76%	74.5%	0.42
African American	8.7%	12.4%	
Hispanics, %	7.8%	6.7%	0.75
Pre-hospital Vitals			
SBP, mean ± SD	115 ± 24	83 ± 22	<0.001
HR, mean ± SD	88 ± 18	118 ± 13	<0.001
GCS, median [IQR]	15 [15-15]	15 [13–15]	0.63
ED Vitals			
SBP, mean ± SD	123 ± 22	91 ± 15	<0.001
HR, mean ± SD	91 ± 17	97 ± 16	<0.001
GCS, median [IQR]	15 [15-15]	15 [14–15]	0.83
Mechanism of injury, %			
Blunt Injury	86%	72%	0.01
Penetrating Injury	14%	28%	0.01
Injury Parameters, median [IQR]			
ISS	13 [9–17]	18 [13–29]	<0.001
Head-AIS	1 [1-1]	1 [1–2]	0.79
Thorax-AIS	0 [0–1]	2 [1–2]	0.04
Abdomen-AIS	1 [1–2]	2 [1–2]	0.51
Extremity-AIS	1 [1-1]	1 [1–2]	0.79

SD=Standard deviation, SBP=Systolic Blood Pressure, HR=Heart Rate, GCS = Glasgow Coma Scale, IQR=Interquartile Range, ISS=Injury Severity Score, AIS = Abbreviated injury scale.

based on the SI cutoff of 1.

The demographics of these two groups are demonstrated in Table 1. Patient in both groups had no difference in age ($p = 0.78$), gender ($p = 0.34$), race ($p = 0.42$) or ethnicity ($p = 0.75$). Patients who had a pre-hospital SI > 1 were more likely to have lower prehospital as well as ED SBP ($p < 0.001$) and higher HR ($p < 0.001$) but no difference in the GCS ($p = 0.63$). Patients with SI > 1 were more likely to have penetrating injuries ($p = 0.01$), higher ISS ($p < 0.001$) and severe injuries to chest ($p = 0.04$), however, there was no difference in the severity of other body injuries compared to patients with SI ≤ 1.

The primary outcomes of our two-groups are demonstrated in Table 2. Patients with pre-hospital SI > 1 had higher blood products (pRBC, FFP, Platelet) requirement in the initial 4-h as well as the first 24-h of resuscitation compared to patients with pre-hospital SI ≤ 1. Patients with SI > 1 had higher likelihood of massive transfusion (25% vs. 0.012%, $p < 0.02$) compared to SI ≤ 1. Similarly, patients with SI > 1 had higher likelihood of requiring interventional radiology intervention (angiography with or without embolization) as well as higher rates of operative intervention (laparotomy and thoracotomy).

The ED disposition of the two groups is demonstrated in Table 3. Patients with a prehospital SI > 1 were more likely to be transferred to the OR (34.1% vs. 13.8%, $p < 0.001$) or ICU (41.1% vs. 32.9%, $p < 0.001$) instead of floor (14.9% vs. 38.6%, $p < 0.001$) compared to patients with pre-hospital SI ≤ 1.

The overall outcomes of the two groups are presented in Table 4. Patients with SI > 1 had higher rates of overall complications, AKI, ARDS, DVT and pneumonia however, similar rates of PE and CVA compared to patients with SI ≤ 1. In addition, patients with pre-hospital SI > 1 had higher ICU (4 days vs. 1 day, $p < 0.001$), hospital length of stay (7 days vs. 5 days, $p = 0.01$) and ventilator days (1 day vs. 0 day, $p < 0.001$) compared to SI ≤ 1. Similarly, patients with SI > 1 had higher mortality (12.3% vs. 5.2%, $p < 0.001$) and were more likely to be discharged to Rehab/SNF (34.6% vs. 21.4%, $p < 0.001$).

Sub-analysis of transfusion requirements in patients with penetrating injuries is demonstrated in Fig. 1. After adjusting for age, gender, race, and mode of trauma patients with SI > 1 had higher adjusted requirements of pRBC, FFP and platelet transfusion

Table 2
Blood products and interventions.

	Pre-hospital SI ≤ 1 (n = 131761)	Pre-hospital SI > 1 (n = 13190)	*p-value*
Blood Products in 4 h			
pRBC, median [IQR]	0 [0-0]	1 [0–3]	<0.001
Plasma, median [IQR]	0 [0-0]	1 [0–4]	<0.001
Platelets, median [IQR]	0 [0-0]	1 [0–3]	<0.001
Blood Products in 24 h			
pRBC, median [IQR]	0 [0-0]	4 [2–10]	<0.001
Plasma, median [IQR]	0 [0-0]	1 [1–5]	<0.001
Platelets, median [IQR]	0 [0-0]	1 [0–5]	<0.001
Massive transfusion, %	0.12%	25%	<0.002
Intervention, %			
Interventional radiology (IR)[a]	1%	6.2%	<0.001
Surgical intervention, %			
Laparotomy	1.7%	12.3%	<0.001
Thoracotomy	0.3%	2.4%	<0.001

SI=Shock Index, pRBC = Packed Red Blood Cells, IQR=Interquartile Range.
[a] IR = Angiography with or without embolization.

Table 3
ED outcomes.

	Pre-hospital SI ≤ 1 (n = 131761)	Pre-hospital SI > 1 (n = 13190)	*p-value*
Disposition, %			
ICU	32.9%	41.1%	<0.001
Died	0.8%	3%	<0.001
Floor	38.6%	14.9%	<0.001
Discharged	13.9%	6.9%	<0.001
Operating Room	13.8%	34.1%	<0.001

SI=Shock Index, ICU=Intensive Care Unit.

Table 4
Outcomes.

	Pre-hospital SI ≤ 1 (n = 131761)	Pre-hospital SI > 1 (n = 13190)	*p-value*
Overall Complications			
ARDS	0.6%	2.9%	<0.001
AKI	0.9%	2.7%	<0.001
DVT	0.7%	2.2%	<0.001
PE	1.2%	1.8	0.42
Pneumonia	0.6%	1.5%	<0.001
CVA	1.2%	1.4%	0.61
ICU LOS, median [IQR]	1 [0–2]	4 [0–5]	<0.001
Ventilator Days, median [IQR]	0 [0–2]	1 [0–2]	<0.001
Hospital LOS, median [IQR]	5 [3–8]	7 [3–16]	0.01
Disposition, %			
Mortality	5.2%	12.3%	<0.001
Rehab/SNF	21.4%	34.6%	<0.001

ARDS = Acute Respiratory Distress Syndrome, AKI = Acute Kidney Injury, DVT = Deep Venous Thrombosis, PE=Pulmonary Embolism, CVA=Cerebrovascular Accident, ICU=Intensive Care Unit, LOS = Length of Stay, IQR=Interquartile Range, Rehab/SNF=Rehabilitation/Skilled Nursing Facility.

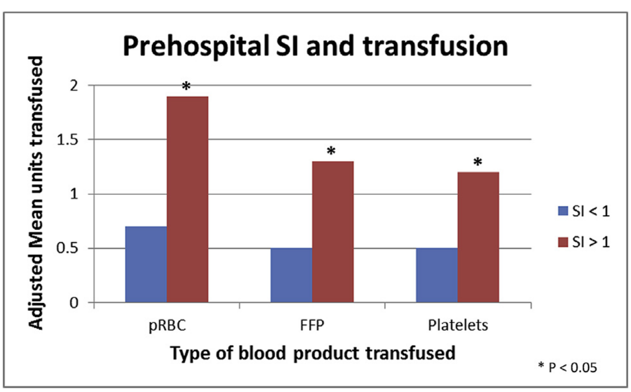

Fig. 1. Adjusted sub-analysis of patients with penetrating injuries.

in this subgroup as well.

The area under the Receiver Operative Characteristic (ROC) curve for predicting adverse outcomes is demonstrated in Fig. 2. Pre-hospital SI (AUROC = 0.81) was a better indicator of predicting hospital resource utilization compared to the pre-hospital SBP (AUROC = 0.55) and pre-hospital HR (AUROC = 0.66).

Discussion

Trauma triage and resource allocation remains an ongoing area of research. The results of this nationwide study suggest that pre-hospital shock index can predict hospital resource utilization. Patients with pre-hospital SI > 1 were more likely to go to the operating room or ICU compared to patients with hospital SI < 1. Similarly, patients with pre-hospital SI > l had higher blood product requirement (pRBC, FFP and platelets) within the first 4 h and during the 24-h resuscitation period. In addition, patients with prehospital SI > 1 stayed longer in the ICU and hospital and had higher adjusted mortality. Patients with a prehospital SI > 1 also had higher rates of complications during their stay including ARDS, AKI, DVT, and pneumonia. ROC analysis showed that the pre-hospital SI had more predictive value for hospital resource utilization than heart rate or SBP alone. Finally, we also showed that the pre-hospital SI was associated with increased rates of discharge to a rehab or nursing facility.

To date, we believe that this is the largest study looking at the predictive value of the pre-hospital SI in trauma. Prior to this, McNab et al. performed the largest study of prehospital SI ≥ 0.9 on trauma resource use and mortality. 19.7% of their 16,269 patients had a SI ≥ 0.9. Those with prehospital SI ≥ 0.9 had a relative risk for death of 1.5 in the field and 1.7 in the trauma center. This group also showed a correlation between prehospital SI and hospital and ICU length of stay, ventilator days, blood product use, and ED disposition.[11] In our population, only 9.1% had a prehospital SI > 1, which may reflect a difference between the thresholds utilized in these studies. Likewise, we observed a 7.1% increase in mortality with a prehospital shock index >1 compared to a prehospital SI ≤ 1. We believe that a cutoff of 1 is most appropriate since this value is easier to use by emergency personnel as it is the value when the HR is greater than the SBP, thus requiring no additional calculation. Moreover, independent ROC analyses of each primary endpoint yielded ideal SI cutoffs between 0.9 and 1.08 thus we argue that a threshold of 1 should be used clinically.

Cannon et al. compared pre-hospital and in hospital increases in SI with outcomes and found that an increase in >0.3 was associated with a 22% increase in mortality suggesting that the change in SI over time may also have clinical value.[10] This group found a median ISS of 10 and a mortality of 8.9% mortality in those with a pre-hospital SI > 0.9. Our analysis showed a prehospital SI > 1 had a median ISS of 18 and a mortality of 12.3%. When comparing the high SI groups in both studies, this difference may be explained by a higher rate of penetrating injury (38.5% versus 28%) in the Cannon study. Interestingly, both Cannon et al. and El-Menyar et al. found

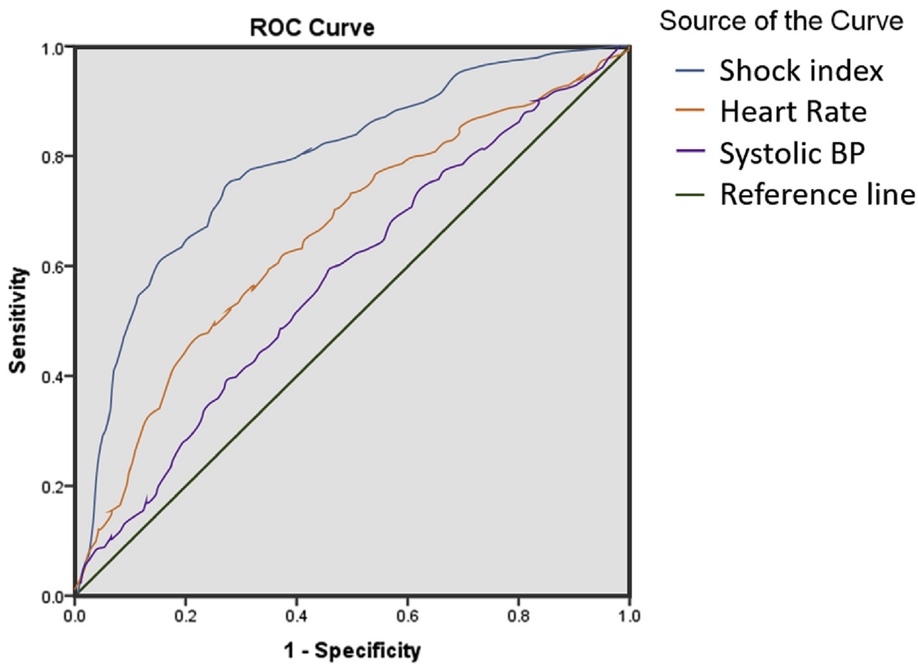

Fig. 2. Area under the Receiver Operative Characteristic (ROC) curve for predicting need for increased resource utilization (OR, ICU or blood transfusion).

that a higher percentage of those with an in-hospital and pre-hospital SI > 0.9 or in hospital SI > 0.8, respectively, were women.[7,10] Using a larger and national dataset we failed to show any differences in pre-hospital SI based on sex and thus the differences in gender observed by others may have been a result of limited sample size.

The results of our study are in line with several other studies that evaluated the impact of SI on specific outcomes in trauma patients.[13–21]

Timely and accurate triage of trauma patients is pivotal in achieving optimal outcomes in patients after trauma. Triage and decision-making regarding infield interventions and transfer of trauma patients begin in the prehospital environment with the arrival of first responders or emergency medical personnel. Relaying accurate and objective information to the trauma centers by first responders is a key in the preparation for arrival of a trauma patient by a trauma center. The ideal trauma triage criteria are continuously evolving and has remain an area of debate for decades. The emphasis is on simplifying and information into objective measures that can be standardized across all trauma centers and systems. Triage criteria has always been under constant research at regional and national levels due to the need for continued improvement. Our study adds to the growing body of literature that the use of prehospital SI by the first responders/EMS will serve as a valuable tool for the prehospital triage of trauma patients when determining the need for transport to a trauma center, preparation of resources, or activation of the trauma team. SI > 1 is a very simple tool that can be easily calculated in the field by EMS teams and the information can be relayed to nearby trauma center.

Limitations and future research

Rau et al. showed that hospital-acquired SI, but not age-adjusted SI, was predictive of mortality and transfusion requirement. This group went on to show that the presence of underlying co-morbidities, such as hypertension, diabetes mellitus, or coronary artery disease, compromise the predictive value of the SI.[9] Frailty, most commonly measured by the modified frailty index, is a state of reduced physiologic reserve. In this study we did not consider the effect that underlying conditions have on trauma outcomes.[22,23] Future study is therefore needed to evaluate the role of a frailty-adjusted shock index. Another limitation of this study was that we did not exclude traumatic brain injury (TBI) which may confound the data due to the classic Cushing reflex where SBP increases and HR decreases. Future studies are therefore needed to evaluate a *low* SI as a predictor of outcomes following a TBI. Although the ACS-TQIP is a robust dataset with reliable data, however, this dataset does not capture all the trauma comers. For instance, some patients with minimal/trivial trauma may not be captured in the database. This may skew our ROC curve analysis and the possibility that including these patients may change the cutoff of SI does exist. Beyond having utility in hospital resource mobilization and mortality prediction, the pre-hospital shock index may have value in the pre-hospital management of trauma patients. A reduction in SI has been utilized in Afghanistan to evaluate the response to flight-medic directed blood transfusions.[24] Thus there is potential in civilian medicine to use pre-hospital SI in the pre-hospital care of trauma patients. Our data shows that the pre-hospital SI predicts trauma outcomes thus further study is needed to determine whether an aggressive reduction in pre-hospital SI can alter trauma outcomes.

Conclusion

In the study presented herein, we provide evidence that a pre-hospital shock index is predictive of in hospital resource use, mortality, discharge location, ED disposition, and complications. This has implications for patient triage, trauma resource recruitment, EMS training, and trauma system design.

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Conflicts of interest

There are no identifiable conflicts of interests to report.

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