Utility of the Shock Index in Predicting Mortality in Traumatically Injured Patients

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Background: Currently, specific triage criteria, such as blood pressure, respiratory status, Glasgow Coma Scale, and mechanism of injury are used to categorize trauma patients and prioritize emergency department (ED) and trauma team responses. It has been demonstrated in previous literature that an abnormal shock index (SI = heart rate [HR]/systolic blood pressure, >0.9) portends a worse outcome in critically ill patients. Our study looked to evaluate the SI calculated in the field, on arrival to the ED, and the change between field and ED values as a simple and early marker to predict mortality in traumatically injured patients.

Methods: A retrospective chart review of the trauma registry of an urban level I trauma center. Analysis of 2,445 patients admitted over 5 years with records in the trauma registry of which 1,166 also had data for the field SI. An increase in SI from the field to the ED was defined as any increase in SI regardless of the level of the magnitude of change.

Results: Twenty-two percent of patients reviewed had an ED SI >0.9, with a mortality rate of 15.9% compared with 6.3% in patients with a normal ED SI. An increase in SI between the field and ED signaled a mortality rate of 9.3% versus 5.7% for patients with decreasing or unchanged SI. Patients with an increase in SI of ≥0.3 had a mortality rate of 27.6% versus 5.8% for patients with change in SI of <0.3.

Conclusion: Trauma patients with SI >0.9 have higher mortality rates. An increase in SI from the field to the ED may predict higher mortality. The SI may be a valuable addition to other ED triage criteria currently used to activate trauma team responses.

Key Words: Shock index, Trauma, Mortality predictors, Trauma triage.

Methods

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Mortality

More deaths result from trauma between the ages of 1 year and 44 years than from any other illness. According to the National Center for Health Statistics, trauma causes 46% of all deaths from ages 5 years to 14 years and 73% of all deaths from ages 15 years to 24 years.1 More than 100,000 Americans of all ages die from trauma annually. After a major trauma, early and accurate assessment of a patient's shock state is necessary to provide appropriate interventions to decrease morbidity and mortality. Currently, specific triage criteria such as blood pressure, respiratory status, Glasgow Coma Score, and mechanism of injury are used to categorize trauma patients and prioritize emergency department (ED) and trauma team responses. Early resuscitation includes control of bleeding and restoration of circulating blood volume for oxygenation of tissues.2 Therapy is generally guided by the rate of bleeding and changes in hemodynamic parameters such as heart rate (HR), systolic blood pressure (SBP), and central venous pressure. Significant improvements in HR and SBP may occur during resuscitation such that the indices approach “normal” limits, but the patient has persistent occult hypoperfusion.3 Inadequate resuscitation with persistent shock can result in higher mortality rates.

The normal ratio of HR to SBP is generally <0.7. This ratio is elevated in the setting of acute hypovolemia and circulatory failure and is referred to as the shock index (SI).4,5 The SI has been demonstrated to be a useful guide for diagnosing early acute hypovolemia in the presence of normal HR and blood pressure.6 It has also been used as a marker for severity of injury and poor outcome in trauma patients.6,7 As an early indicator of ongoing hemorrhage during gastrointestinal bleeding,8 and as an early signal of rupture and intra-abdominal hemorrhage during ectopic pregnancy.9 Measurement of the SI may be more useful in predicting early shock than either the HR or the SBP alone and has been shown to correlate with other indices of end-organ perfusion such as central venous oxygen saturation and arterial lactate concentration.2

The goal of our study was to evaluate the SI and determine its utility as an early predictor of mortality risk in traumatically injured patients. We calculated the SI and compared measurements from the field and on arrival to the ED. We then compared the change between the field and ED values to determine whether a change in the SI can predict mortality. Our hypothesis is that a worsening SI predicts a higher mortality than an improving or unchanged SI. We also attempted to identify the numerical change in value of the SI between the field and the ED that was most predictive of higher mortality.

Methods

This study was conducted at an American College of Surgeons-verified level one trauma center. The patient population served is both urban and rural. The investigational review board approved the study protocol. Data involved in this research project were obtained from the Collector Trauma Registry. The registry contains more than 10,000
patient records collected over 10 years. We used ten consecutive years of data for this study (1996–2005). A retrospective review identified the patient population. The data used contained no identifying factors that could be traced to the patients. A total of 2,445 patients were reviewed. Prehospital and ED SI values were calculated, as well as the interim change in SI (increasing vs. decreasing or no change). The vital signs used to calculate the SI values were the initial vital signs in both the field and the ED.

Inclusion Criteria
Patients with a mechanism of injury and an accompanying International Classification of Diseases—9th Revision code 800–959 were included in the study. The patients met the trauma system activation criteria and were brought into the ED as a type 2 (moderate trauma, mechanism) or type 1 (severe trauma with or without hemodynamic stability) trauma patient. The patients in the study were direct arrivals to the ED from the field (by ambulance, helicopter, or private vehicle) and either died in the ED or were admitted to the hospital.

Exclusion Criteria
Patients transferred to the hospital from an outside institution were excluded from the study. Patients with incomplete records and those admitted through the ED but not requiring trauma system activation were excluded.

Statistical Methods
SI was calculated for each patient: HR/SBP. Standard ratio is 0.5 to 0.7 for normal individuals. SI ratio greater than 0.9 was used in our study as the cutoff to suggest increased mortality risk based on published studies.6,7 The primary comparison groups were labeled field SI (>0.9 vs. ≤0.9), ED SI (>0.9 vs. ≤0.9), and change in SI (increasing vs. decreasing or no change). To assess the balance between these groups, statistical tests were performed to compare the distributions of age, sex, and type of trauma across levels of the predictor variables. For age, the Kruskal-Wallis test was used. The sex and type of trauma distributions were compared across groups using Pearson’s χ² test.

For mortality, Pearson’s χ² test was used to compare proportion of survivors between field and ED SI levels and across changes from field SI to ED SI. The mortality comparison between those with increasing (vs. decreasing or no change) SI among the subgroup whose field SI was >0.9 used Fisher’s exact test. Kaplan-Meier survival curves were also generated using the mortality and length of stay (LOS) variables, and the hazard of death was compared across SI levels and change in SI using the log-rank test. To further examine the change in SI, a cutpoint analysis was performed to determine the change in score that was most predictive of mortality. For this analysis, Cox regressions models were generated, again using the mortality and LOS variables. The sole predictor in these models was a variable that indicated whether a subject had a change in SI at least as high as the current cutpoint being tested in the model. The log-likelihood value for each of these models was retained, and the model with the highest log-likelihood value was deemed to have the optimal cutpoint for determining mortality risk. This cutpoint was then tested as a predictor of mortality using the Pearson’s χ² and log-rank tests previously described.

Additional analyses were performed that compared field and ED SI levels across the outcome variable Injury Severity Score (ISS). The Kruskal-Wallis test was used to compare this outcome across SI levels and change in SI. Subgroup analyses of this outcome and mortality were also performed to compare the SI levels using only the subgroup of individuals with a normal SBP ≥90 mm Hg. We also compared the predictive performance of the SI to that of SBP and HR alone.

RESULTS
In the trauma registry, 1,166 of the 2,445 patients had field data available for analysis (Table 1). A total of 8.9% of the patients with field SI >0.9 died versus 5.8% of patients with field SI ≤0.9 (p = 0.05). The log-rank test comparing these groups failed to detect a difference (p = 0.31), likely because the Kaplan-Meier survival curves crossed (data not shown). The median ISS for patients with field SI >0.9 was 10.0 versus 9.0 for patient with SI ≤0.9 (p < 0.0001).

On arrival to the ED, 528 (21.6%) of 2,445 patients reviewed had an elevated SI (Table 2). Patients with an ED SI >0.9 had a 15.9% mortality rate versus 6.3% in patients with a normal ED SI ≤0.9 (p < 0.0001). The median ISSs were 17.0 versus 9.0, respectively (p < 0.0001). Among patients with a normal ED SBP (≥90), those with an elevated ED SI had a 12.8% mortality rate versus 6.1% in patients with a normal SI (p < 0.0001). The median ISSs were 17.0 versus 9.0.

### Table 1. Field (Prehospital), n = 1,166*

<table>
<thead>
<tr>
<th>SI &gt;0.9, (n = 392)</th>
<th>SI ≤0.9, (n = 774)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 392)</td>
<td>(n = 774)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Injury Severity Score (median)</td>
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<td></td>
</tr>
<tr>
<td>Penetrating</td>
<td>38.5%</td>
<td>22.8%</td>
</tr>
<tr>
<td>Age in years (median)</td>
<td>33.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Female</td>
<td>32.4%</td>
<td>22.5%</td>
</tr>
</tbody>
</table>

* Statistical test p values based on Pearson’s χ² test for categorical variables and the Kruskal-Wallis test for continuous variables.

### Table 2. Emergency Department Arrival, n = 2,445*

<table>
<thead>
<tr>
<th>SI &gt;0.9, (n = 528)</th>
<th>SI ≤0.9, (n = 1,917)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 528)</td>
<td>(n = 1,917)</td>
<td></td>
</tr>
<tr>
<td>Injury Severity Score (median)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penetrating</td>
<td>30.1%</td>
<td>24.8%</td>
</tr>
<tr>
<td>Age in years (median)</td>
<td>32.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Female</td>
<td>31.4%</td>
<td>24.9%</td>
</tr>
</tbody>
</table>

* Statistical test p values based on Pearson’s χ² test for categorical variables and the Kruskal-Wallis test for continuous variables.
observed more penetrating (30.1%) trauma among those with ED SI >0.9 compared with the proportion with penetrating trauma among the ED SI ≤0.9 subgroup (24.8%) (p = 0.01, Table 2).

Subjects with a field SI >0.9 were older (median age, 33 years) than those with a field SI ≤0.9 (median age, 28 years; p < 0.0001; Table 1). Among those with SI measures in the ED, patients with SI >0.9 were older than those with SI ≤0.9 (median age, 32 years vs. 28 years, respectively; p < 0.0001; Table 2). More patients with a recorded field SI >0.9 were women compared with those with field SI ≤0.9 (32.4% vs. 22.5%, respectively; p < 0.001; Table 1). Among those with SI recorded in the ED, a higher portion were women among the high SI patients rather than those with normal ratios (31.4% vs. 24.9%, respectively; p < 0.01; Table 2).

**DISCUSSION**

Despite significant improvements in trauma systems resulting in remarkable decreases in preventable deaths, trauma continues to be the leading cause of death until the age of 44 years in the United States. Trauma systems rely on imperfect tools to triage patients to centers capable of caring for the critically injured. Tools such as blood pressure, respiratory status, Glasgow Coma Scale, combinations of the above (i.e., Trauma Score and Revised Trauma Score), and mechanism of injury are used to prioritize ED and trauma team responses and resources. In this age of increasing ED and trauma diversion, particularly in urban settings, allocation of these resources are more crucial than in the past.

Trauma patient factors that demonstrate utility in predicting outcomes of critically injured patients on hospital arrival include lactate, base deficit, mixed venous oxygen saturation, and cutaneous tissue oxygen saturation. These methods tend to be more invasive and/or expensive; however, decreased mortality is observed when lactate and base deficit return to normal within 24 hours of injury.

Previous studies have indicated that blood pressure and HR individually have not been accurate as predictive tools for outcomes for critically injured patients. It is well known that HR is the first vital sign to change in the face of hemorrhagic shock. The HR will increase in the face of class II shock (15–30% blood loss). An elevated SI has been shown to be predictive of poor outcomes and increasing need for resources. This was first described by Allgower and Burri when they demonstrated that an SI >1.0 was associated with a 40% mortality. Oestern et al. also described in a small study of trauma patients that an SI >1.0 was associated with a higher mortality.

Rady et al. have demonstrated in animal models that SI is inversely related to left ventricular stroke work and correlates well with shock secondary to hemorrhage and sepsis. This group has also published data demonstrating that an SI >0.9 identified critically ill ED patients with decreased central venous oxygen saturation and lactic acidosis, who had deceptively normal vital signs. The same group also demonstrated worse outcomes in trauma patients with an SI >0.9, but the predictive ability of the SI for these outcomes were no more superior to HR and SBP. Nakasone et al. were able to
demonstrate in 2007 that increased SI was associated with a significantly higher chance of an arteriogram demonstrating extravasation of contrast, signifying ongoing hemorrhage.

To date, we are not aware of any studies that evaluate both field and ED SI values and how the change between values signals patient outcome. Liao et al.20 published an article in which SI $\leq 1.1$ and decreasing to 0.8 or less after angioembolization was a significant predictor of successful cessation of bleeding following oronasal trauma. This is the only study taking change and follow-up values of SI into consideration showing that changes in that value may predict outcomes.

Previous to this study, Cannon and Bilkowski19 presented data comprising trauma patients from Henry Ford hospital, which again established that of 5,530 total patients reviewed, 647 patients (11.7%) with an SI $> 0.9$ resulted in worse outcomes. Factors shown to be significantly worse with an elevated SI were ISS, number of blood units transfused, need for intensive care unit admission, mortality, and hospital LOS. This outcome difference was noted even when looking at patients without obvious need for triage to a high level of trauma activation, thus excluding patients with SBP $< 90$ mm Hg and Glasgow Coma Scale $\leq 8$. Despite removal of these patients, ISS, need for intensive care unit, and increases in hospital LOS, mortality and transfusion persisted in the high SI group ($p = 0.08$). Data in the prehospital setting and changes in SI from field to ED were not reviewed.

In assessing the influence of age on the SI, we used unconditional logistic regression to generate results for a model that included SI ($> 0.9$ vs. $\leq 0.9$), age as a continuous variable, and the age-by-SI interaction. We found that age had little influence on the association between SI and mortality ($p = 0.50$ for the age-by-SI interaction term). We also conducted a similar analysis using the natural log of age instead of age within the logistic regression model, and this analysis produced a similar result ($p = 0.33$ for that interaction term). Thus, we concluded that age did not affect the relationship between SI and mortality.

In reviewing the patient groups with SI values $> 0.9$, prediction of mortality appeared to be a function of the ED SI value. Field SI values $> 0.9$ did demonstrate utility but were less predictive than ED values. Field values may be less helpful due to occasional inaccuracy in vital sign measurements and due to lack of documentation. Over half of the observations in this cohort were missing the field SI. One other factor that may make field SI values less useful than ED values may be that the increase in HR seen in class II shock may be easily corrected with simple resuscitative measures using intravenous fluid. The patients who reach the ED with continued deranged or worse values were generally more apt to have poor outcomes. The hospital vital signs measurements were all typically present and were thought to be more accurate. Among patients who had SBP $\geq 90$ mm Hg, those with an SI $> 0.9$ were still about twice as likely to die. Any increase in the SI values from the field to the ED resulted in a doubling of patient mortality, compared with patients having an unchanged or decreasing SI. We observed that a change in SI from field to ED by a cutpoint of 0.3 signaled nearly a five-fold increase in mortality. Monitoring the change in SI may prove to be useful in emergency medical services and ED triage, routing of patients and apportionment of trauma resources. Also, a future study should consider resuscitating patients using SI as a goal to potentially validate the SI as an endpoint for resuscitation, similar to the use of lactate or base deficit.

CONCLUSION
Trauma patients with a SI $\geq 0.9$ had significantly higher mortality rates either when measured in the ED or when they demonstrated an increasing trend when also measured in the field. This observation remained true in patients who were considered to be hemodynamically stable, which poses more difficulty to accurately determine the need for greater resources or risk of worse outcomes. This study was performed retrospectively and is prone to bias incurred by missing data. A prospective study is needed to further examine the predictive value of SI and changes in SI after arrival to the ED. A prospective study may be used to further evaluate whether these patients will benefit from a more rapid and extensive trauma team response. The SI may be a valuable addition to other emergency medical services/ED triage criteria currently used to activate trauma team responses.

REFERENCES


