Prehospital shock index predicts outcomes after prolonged transport: A multicenter rural study

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BACKGROUND: Shock index (SI) predicts outcomes after trauma. Prior single-center work demonstrated that emergency medical services (EMSs) initial SI was the most accurate predictor of hospital outcomes in a rural environment. This study aimed to evaluate the predictive ability of SI in multiple rural trauma systems with prolonged transport times to a definitive care facility.

METHODS: This retrospective review was performed at four American College of Surgeons–verified level 1 trauma centers with large rural catchment basins. Adult trauma patients who were transferred and arrived >60 minutes from scene during 2018 were included. Patients who sustained blunt chest or abdominal trauma were analyzed. Subjects with missing data or severe head trauma (Abbreviated Injury Scale score, >2) were excluded. Poisson and binomial logistic regression were used to study the effect of SI and delta shock index (ΔSI) on outcomes.

RESULTS: After applying the criteria, 789 patients were considered for analysis (502 scene patients and 287 transfers). The mean Injury Severity Score was 8 (interquartile range, 6) for scene and 8.9 (interquartile range, 5) for transfers. Initial EMSs SI was a significant predictor of the need for blood transfusion and intensive care unit care in both scene and transferred patients. An increase in ΔSI was predictive of the need for operative intervention ($p < 0.05$). There were increased odds for mortality for every 0.1 change in EMSs SI; those changes were not deemed significant among both scene and transfer patients ($p < 0.1$).

CONCLUSION: Providers must maintain a high level of clinical suspicion for patients who had an initially elevated SI. Emergency medical services SI is a significant predictor for use of blood and intensive care unit care, as well as mortality for scene patients. This highlights the importance of SI and ΔSI in rural trauma care. (*J Trauma Acute Care Surg.* 2023;94: 525–531. Copyright © 2023 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Prognostic and Epidemiological; Level IV.

KEY WORDS: Rural trauma; prehospital care; shock index.

Rural Americans comprise nearly 60 million people, which is 19% of the population. Of these, 30 million reside over an hour from high-level trauma care.[1,2] To deliver comprehensive care in these environments, states have developed trauma systems to deliver emergency medical services (EMS) care and transport; they also rely on Levels III and IV trauma centers to provide initial evaluation and stabilization before transport to a definitive care center. Because of extended travel times to many rural patients, it can take several hours for EMS to both reach and return a patient to definitive and surgical trauma care. En route, patients receive variable levels of resuscitation and intervention. Despite these systems, rural trauma patients continue to have significant disparities and higher mortality than their matched urban counterparts.[3–5] How rural patients are optimally triaged and transported remains an area for further research.

Shock index (SI) and delta shock index (ΔSI) predict outcomes in trauma patients and have been associated with mortality and the need for blood transfusion.[6–8] An elevated SI is well validated enough in prehospital care that it was added as a new criterion to the 2021 iteration of the national guidelines for field triage.[9] Research evaluating the use of prehospital SI showed that increases in ΔSI, which occur from EMS vital signs to hospital arrival, were also associated with poor outcomes.[10] Most of the data currently available on SI have been from urban centers. There is, however, a prior single-center study, which demonstrated that the initial EMS SI was the most accurate predictor of hospital outcomes in a rural environment with prolonged transport times.[11] In that study, increased EMS SI predicted the use of blood products, intensive care unit (ICU) need, length of stay (LOS), and mortality. As time from injury increased, SI on hospital arrival or at a transferring facility was less predictive. This is of critical importance because, as en route care and resuscitation continue to advance, there is the potential to mask vital sign changes that are expected with severe injury.

This study builds upon that prior work by evaluating the utility of EMS SI across multiple rural trauma systems. With total time in transport to definitive care routinely over several hours, the authors hypothesized that SI on hospital arrival was less predictive in a rural environment. Therefore, this study aimed to evaluate the predictive ability of SI and ΔSI in rural environments and investigate the impact of prolonged transport times.

PATIENTS AND METHODS

This was a retrospective registry review performed at four American College of Surgeons–verified Level 1 trauma centers as a portion of a research collaborative. Each center serves as the tertiary referral center for large rural catchment basins. The database was constructed to include all patients in 2018, which arrived as a full or partial trauma team activation and were transferred from another facility to the Level 1 center or a scene transport that arrived more than 60 minutes after injury. Inpatient transfers, patients operated on at a transferring facility, and subjects younger than 18 years old were excluded from the database. For this analysis, the database was queried for all adult subjects presenting after blunt chest or abdominal trauma (Abbreviated Injury Scale [AIS] score, ≥1). Subjects with missing SI data, severe head trauma

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This study was presented at the 81st Annual Meeting of AAST and Clinical Congress of Acute Care Surgery, September 22, 2022, in Chicago, Illinois.

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(AIS head, >2), penetrating injuries, missing transport times, and deaths in the emergency department were excluded. Institutional review board approval was obtained at each center before database creation. The study was completed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C835).

Each center prospectively maintains its trauma database by using trained registrars. Data abstracted included demographics, injury data, Injury Severity Score (ISS), AIS score by region, transport type, time in transport, hospital procedures, EMS and transferring facility data on vital signs and transfusions, and hospital data on operations and procedures.

Shock index was calculated as heart rate divided by systolic blood pressure (SI = heart rate/systolic blood pressure). This was calculated from registry vitals from the first set of scene EMS vitals (emergency medical services shock index [SI-EMS]), transferring facilities (shock index at transferring facility [SI-TX]), and on arrival for definitive care (shock index at definitive care center [SI-DC]). ΔSI and SI were determined at each phase of transport to understand the importance of the different time periods associated with outcomes. Hypotension was considered for analysis as well; this was defined as a patient having a systolic blood pressure of <90 mm Hg for EMS. Primary outcomes were mortality and the need for a hemorrhage control operation within 24 hours. Secondary outcomes focused on resource utilization and included need for ICU, ICU LOS, need for blood product transfusion, and the number of units transfused.

Statistical analysis was performed using zero inflated Poisson regression for outcomes of ICU LOS and units of blood used. This approach allows for the statistical analysis to simultaneously consider all covariates and the statistical models impact on the binary use of the resource while also estimating the impact the covariate has on the amount of the resource. A binomial logistic regression was used for outcomes of surgical intervention and mortality. Scene and transfer patients were analyzed separately to study the effect of time in transport and SI/ΔSI on resource utilization and outcomes. Because this is a multicenter study, fixed effects for each center were included in the regression model for each outcome studied to account for between center differences. The models also included an indicator variable for hypotension, SI-EMS, and relevant ΔSI for each patient group, similar to prior published work.[11] Because hypotension and SI are related, we also perform an analysis with hypotension omitted from the regression models. $p < 0.05$ was considered significant.

RESULTS

After applying inclusion and exclusion criteria, a sample of 789 patients was analyzed (Fig. 1). This included 502 scene patients (63.6%) and 287 (36.4%) transferred from another facility. Baseline demographics are reported in Table 1. After arrival for definitive care, blood products were transfused in 8.8% of scene patients and 9.4% of transfer patients. Operative intervention was required in 109 (21.7%) of scene patients and 101 (35.2%) of transfers.

We investigated SI and corresponding ΔSI as a correlate for injury severity. There was a weak positive correlation ($r = 0.12$) between ISS and SI-EMS, and no correlation between ISS and ΔSI. For scene patients transported to the trauma center SI-EMS had a mean of 0.66 (SD, 0.22), while the patients who were routed through a transferring facility had a mean SI-EMS of 0.65 (SD, 0.19). This difference was not significant ($p = 0.357$). For transferred patients, SI-TX had a mean of 0.63 (SD, 0.19). On arrival for definitive care, the mean SI-DC was 0.65 (SD, 0.20) for scene transports and 0.64 (SD, 0.18) for transfers ($p = 0.917$).

The mean ΔSI from SI-EMS to SI-DC for patients who were transported directly from the scene was −0.010 (SD, 0.18), while those coming through a transfer facility had a mean ΔSI from SI-EMS to SI-DC of 0.0024 (SD, 0.20) ($p = 0.38$). For patients who were transferred, the ΔSI between SI-EMS and the SI-TX had a mean of −0.017 (SD, 0.17).

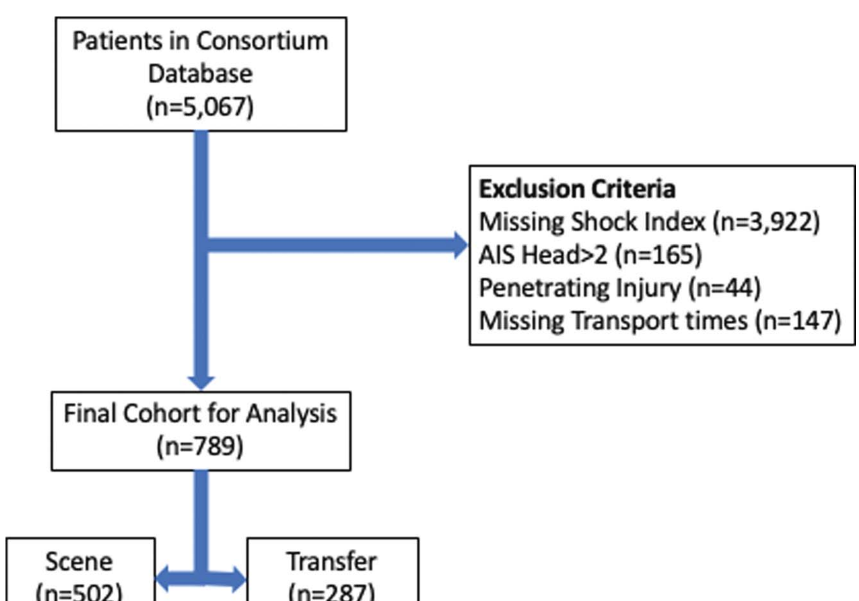

Figure 1. Flow diagram of patients included in final analysis.

TABLE 1. Baseline Characteristics of Patient Cohort

	Scene	Transfer
Age, y		
Mean ± SD	51.8 ± 21.4	57 ± 20.6
Median	51	57
IQR	34	34
Sex	F: 39.4%	F: 53.2%
	M: 60.6%	M: 46.8%
Time in transport, min		
Mean ± SD	96.3 ± 90.9	326 ± 140.5
Median	71	308.5
IQR	30	167.75
Mechanism of injury		
Auto vs. ped	1.99%	1.05%
Fall	36.45%	49.30%
MCC	7.17%	3.50%
MVC	42.03%	36.71%
Other	12.35%	9.44%
Hypotension at scene		
	2.39%	2.80%
ISS		
Mean ± SD	7.7 ± 6.3	8.9 ± 6
Median	5	9
IQR	6	5
AIS thorax		
Mean ± SD	0.66 ± 1.1	0.64 ± 1.2
Median	0	0
IQR	1	1
AIS abdomen		
Mean ± SD	0.30 ± 0.8	0.3 ± 0.8
Median	0	0
IQR	0	0
ICU LOS, d		
Mean ± SD	0.8 ± 2.3	1.1 ± 2.7
Median	0	0
IQR	0	1
Days on ventilator		
Mean ± SD	0.2 ± 1.0	0.5 ± 2.4
Median	0	0
IQR	0	0
Hospital LOS, d		
Mean ± SD	5.1 ± 7.8	5.1 ± 5.4
Median	3	3
IQR	4	4

Auto vs. ped, automobile versus pedestrian; IQR, interquartile range; MCC, motorcycle collision; MVC, motor vehicle collision.

The effects of SI and ΔSI were then evaluated on the need for blood product transfusion, number of units of packed red blood cells (PRBCs) (Table 2), ICU LOS (Table 3, Fig. 2), need for surgical intervention (need for operating room [OR]), and mortality (Table 4). In scene patients, SI-EMS was a significant predictor ($p < 0.05$) for PRBCs transfusion when identifying the need and number of units transfused. A 0.1 change in SI-EMS produced a 25.87% increase in the odds ratio on the use of blood. Similarly, ΔSI for scene patients was also significant ($p < 0.001$), with a 0.1 change in ΔSI resulting in a 36.93% increase in the odds ratio of the use of blood. In scene patients, a patient who had hypotension on scene had 41.90% higher odds ratio ($p < 0.001$) than one who did not present with hypotension. For transfer patients, we find that ΔSI in both legs of the transport is predictive of the use of blood with a 0.1 increase in ΔSI: SI-EMS to SI-TX increasing the odds ratio of blood use by 67.31% ($p < 0.0001$) and a 0.1 increase in ΔSI: SI-TX to SI-DC increasing the odds ratio of blood use by 38.28% ($p < 0.01$). For scene patients, we saw a 7.633% ($p < 0.01$) and 12.08% ($p < 0.001$) increase in the number of units of PRBCs transfused with a 0.1 increase in SI and ΔSI, respectively. In the case of transfer patients, results show that a 0.1 increase in SI resulted in a 45.79% ($p < 0.001$) increase in the number of units transfused, while a 0.1 increase in the ΔSI between EMS and transfer facility resulted in 14.27% increase in the number of units used ($p < 0.01$).

When assessing the utilization of ICU resources, we found that ΔSI is also a significant predictor for both scene and transfer patients. In the case of scene patients, we found that a 0.1 change in ΔSI from scene to definitive care led to a 33.45% change in the odds ratio of needing an ICU stay ($p < 0.001$), while, in the case of transfer patients, the change in SI from transfer to definitive care resulted in a 28.01% ($p < 0.01$) increase in the odds ratio of an ICU stay with a 0.1 increase in SI-EMS to definitive care. Note that the only other significant predictor in identifying the need for an ICU stay was the indicator of hypotension for scene patients, which showed an increase of 30.61% in the odds ratio in the need for an ICU stay for patients who presented to EMS with hypotension. When considering the number of days spent in the ICU for scene patients, scene SI and transport time were presented as significant predictors. A 0.1 increase in SI-EMS resulted in a 6.76% ($p < 0.01$) increase in the number of days spent in the ICU, while an increase in transport time led to a 0.003% ($p < 0.05$) decrease in the number of days in the ICU. For transfer patients, a 0.1 increase in SI-EMS led to a 14.56% ($p < 0.01$) increase, and a 0.1 increase in ΔSI between EMS and definitive care led to an 8.74% ($p < 0.001$) increase in number of ICU days, respectively. Furthermore, an increase in transport time for scene patients by 1 minute led to a 0.16% ($p < 0.001$) increase in the expected number of ICU days.

The need for operative intervention was then evaluated. We found that ΔSI from EMS to definitive care and hypotension were the significant predictors of the need for OR in scene patients. A 0.1 increase in the ΔSI from EMS to definitive care resulted in a 14.60% ($p < 0.05$) increase, and if a patient had hypotension, it resulted in a 18.68% ($p < 0.05$) increase in log odds of the need for surgery for scene. For transfer patients, the only significant predictor was the change in SI from transfer facility to definitive care where we find that a 0.1 change in SI leads to a 21.01% in the odds ratio of needing surgery.

In the case of mortality, there were increased odds for mortality for every 0.1 change in EMS SI; those changes were not deemed significant among both scene and transfer patients ($p < 0.1$). For transfer patients, we also found that, for each minute transport time increased, the odds ratio of mortality increased by 0.093% ($p < 0.01$).

To evaluate the impact of SI, separate from the effect of hypotension, results with hypotension omitted from each of these

TABLE 2. Evaluation of Use of Blood Products and Number of Units PRBCs Based on Scene or Transfer Status and the Effect of SI Via Regression Coefficients

	Scene		Transfer	
Response Variable	Use of Blood (Binomial Logistic)	No. Units of PRBCs (Poisson)	Use of Blood (Binomial Logistic)	No. Units of PRBCs (Poisson)
SI-EMS	2.301**	0.7385†	−2.724	3.771‡
95% CI	0.4407–4.162	0.2417–1.235	−6.791 to 1.344	1.739–5.802
ΔSI: SI-EMS to SI-DC	3.547‡	1.141‡	—	—
95% CI	1.766–5.327	0.5835–1.698	—	—
ΔSI: SI-EMS to SI-TX	—	—	5.147†	1.421*
95% CI	—	—	1.809–8.486	−0.0031 to 2.880
ΔSI: SI-TX to SI-DC	—	—	3.241**	0.5125
95% CI	—	—	0.7332–5.748	−0.4780 to 1.505
Hypotension	3.500‡	0.394	21.67	−2.846†
95% CI	1.695–5.304	−0.1010 to 0.8890	−1211 to 1224	−4.762 to −0.9299
Transport time	0.0001	−0.0004	0.0009	−0.0002
95% CI	−0.0037 to 0.0039	−0.0026 to 0.0018	−0.0030 to 0.0048	−0.0031 to 0.0027

*$p < 0.10$.
**$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.
ΔSI, change in shock index.

models can be found in Supplemental Digital Content (Supplementary Data 2, Tables 5–7, http://links.lww.com/TA/C836). These analyses show minor changes in the results, with the most notable being that, when hypotension is omitted from the model, SI-EMS is found to be significantly related to scene patient mortality ($p < 0.001$), and the need for ICU in both scene ($p < 0.001$) and transfer patients ($p < 0.05$).

DISCUSSION

Vital signs remain critical to the triage and treatment of trauma patients. They are an intricate portion of trauma team activation criteria and are used in the field to guide treatment and transport decisions.[9] Multiple studies that evaluated the predictive impact of prehospital hypotension on patient outcomes have been conducted. Authors have repeatedly found that prehospital hypotension is associated with the need for operative intervention and increases in mortality after trauma.[12,13] Seamon et al.[14] demonstrated that even a single report of prehospital hypotension was associated with the presence of severe injuries that required operative intervention. That study urged trauma teams not to consider a single reading of hypotension as erroneous and for trauma surgeons to maintain a high index of suspicion until the

TABLE 3. Evaluation of Use of ICU and Number of ICU Days Based on Scene or Transfer Status and the Effect of SI Via Regression Coefficients

	Scene		Transfer	
Response Variable	Need for ICU Stay (Binomial Logistic)	No. Days in ICU (Poisson)	Need for ICU Stay (Binomial Logistic)	No. Days in ICU (Poisson)
SI-EMS	1.022	0.6540†	1.425	1.360†
95% CI	−2.869 to 2.330	0.2480–1.060	−0.5403 to 3.390	0.5440–2.177
ΔSI: SI-EMS to SI-DC	2.883‡	0.2778	—	—
95% CI	1.430–4.335	−0.1363 to 0.6910	—	—
ΔSI: SI-EMS to SI-TX	—	—	1.114	0.4692
95% CI	—	—	−0.9475 to 3.175	−0.1889 to 1.127
ΔSI: SI-TX to SI-DC	—	—	2.469†	0.8376†
95% CI	—	—	0.6136–4.325	0.2954–1.380
Hypotension	2.671†	0.2817	1.490	−0.4995
95% CI	1.044–4.298	−0.1442 to 0.7075	−0.8435 to 3.824	−1.255 to 0.2559
Transport time	0.0004	−0.0027**	−0.0012	0.0016‡
95% CI	−0.0039 to 0.0030	−0.0052 to 0.0002	−0.0034 to 0.0012	0.0009–0.0024

*$p < 0.10$.
**$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.
ΔSI, change in shock index.

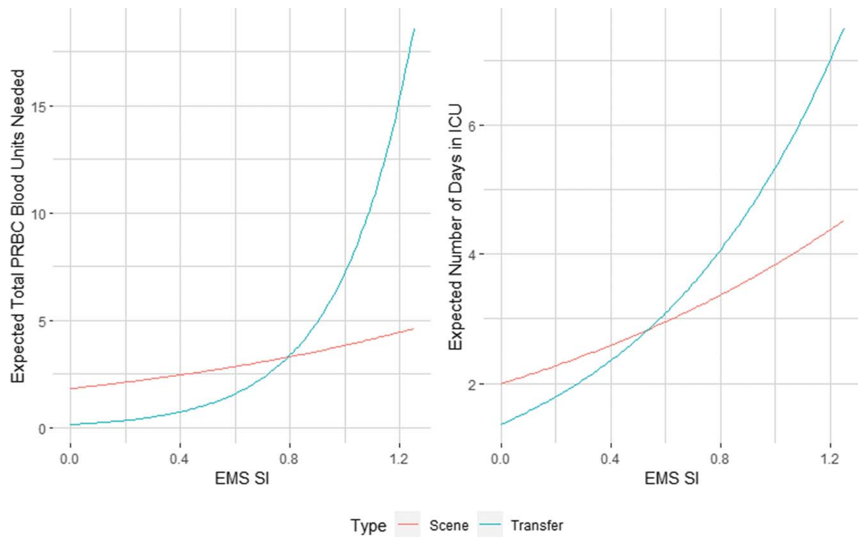

Figure 2. Effect plot demonstrating the expected total number of PRBCs transfused, and expected number of days in the ICU based on EMSs SI.

patients were fully evaluated. Prehospital hypotension was further evaluated by Lipsky et al.,[15] who demonstrated that it predicted the need for operation, even if systolic blood pressure was normal on arrival to the trauma center.

With the increased interest in using SI, a more dynamic measure encompassing multiple vital signs, authors have previously investigated its use in a rural trauma environment where transport time is routinely hours long.[10] In that single-center study, they demonstrated that EMS-SI was predictive of the need for transfusion, ICU care, and mortality. It has also been demonstrated that elevated SI and increasing ΔSI were superior to the presence of EMS hypotension alone. This further supports the need for trauma team activation and a high level of clinical suspicion for providers if SI was abnormal or elevating, regardless of time in transport. The current work was designed to test these observations across multiple rural trauma systems.

This study further supports the use of SI and ΔSI in rural trauma care. By evaluating these values at each phase in a patient's transport, we demonstrate the ability to predict resource need and outcomes. Initial SI-EMS was again associated with blood transfusion in both scene and transfer patients, as well as length of ICU stay. After adjusting for EMS hypotension, the ΔSI variables provided significant insight into resource utilization for both scene and transfer patients. This study was also similar to prior work demonstrating a negative, or worsening, SI during transport for scene patients. By selectively evaluating patients most at risk for noncompressible hemorrhage, this should be expected. Transfer patients demonstrated an improvement

TABLE 4. Evaluation of Mortality and the Need for Operative Intervention Based on Scene or Transfer Status and the Effect of SI Via Regression Coefficients

	Scene		Transfer	
Response Variable	Need for OR (Binomial Logistic)	Mortality (Binomial Logistic)	Need for OR (Binomial Logistic)	Mortality (Binomial Logistic)
SI-EMS	−0.3519	2.956*	0.4148	9.307
95% CI	−1.683 to 0.9318	−0.2399 to 6.475	−1.314 to 2.150	−2.555 to 24.27
ΔSI: SI-EMS to SI-DC	1.363**	2.234	—	—
95% CI	0.0351–2.694	−1.501 to 5.278	—	—
ΔSI: SI-EMS to SI-TX	—	—	1.391	7.917
95% CI	—	—	−0.4791 to 3.322	−4.243 to 21.52
ΔSI: SI-TX to SI-DC	—	—	1.907**	11.01**
95% CI	—	—	0.2709–3.654	1.807–22.06
Hypotension	1.713**	1.377	0.275	−17.73
95% CI	0.2353–3.213	−2.229 to 4.352	−1.428 to 1.858	−1740 to 1740
Transport time	0.0013	0.0034	0.0002	0.0096**
95% CI	−0.0010 to 0.0034	−0.0047 to 0.0082	−0.0017 to 0.0022	0.0029–0.0194

*$p < 0.10$.
**$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.
ΔSI, change in shock index.

in SI by arrival at the level 1 trauma center, underscoring the resuscitation and interventions that occur before arrival for definitive care. However, over one third of these patients would require operative intervention, and 9% would require blood transfusion after arrival at the Level I trauma center. This is an important observation; until a patient is fully evaluated, improving vital signs and SI-DC are not indicative of patient condition or severity of injury.

The most important findings are the association between SI and the need for operative intervention. In scene patients, ΔSI and hypotension are the two biggest indicators of the need for an operation. Among transfer patients, ΔSI from transferring facility to definitive care was significantly associated with the need for an operation. In these cases, the patients' vital sign changes exceeded the ability of EMS to resuscitate or intervene during transportation, or for the transferring facility to provide the needed care. When EMS report an elevated SI, this presents an opportunity for the receiving trauma surgeon to alert OR staff and mobilize necessary resources. For transferred patients, ΔSI from transferring facility to definitive care and increased time were shown to be associated with mortality. This finding is significant, given that transferred patients went nearly five and half hours from injury to definitive care. Furthermore, the results of our study do show the robustness of the conclusions, as the effects of SI and ΔSI for both scene and transfer patients remain important when hypotension is accounted for or omitted from the analysis.

This study has all the usual limitations of a retrospective study. The lack of serial vital signs and reliable data from transferring facilities and EMS with regard to interventions and fluid resuscitation must also be considered. As is common in many rural trauma studies, there is the potential for survivor bias. Data were not available for patients who expired before arrival for definitive care; this may explain why EMS-SI was not as useful in transfer patients but ΔSI was. Further study using more comprehensive EMS databases and ones linked to trauma center databases are warranted to fully describe the effect of SI and ΔSI in trauma care. Improved granularity in these data sets would allow further exploration of the effects of ΔSI and outcomes associated with different intervals of change.

Shock index and ΔSI are significant predictors for resource need, operations, and mortality after blunt torso trauma in a rural environment. These data build upon prior work and demonstrate the use of SI use across multiple rural trauma systems. Shock index was also predictive of resource utilization despite a low average ISS. Based on these results, SI and ΔSI show potential as rural triage tools as well, warranting further research. Future research will be supported by the addition of SI as portion of the national field triage guidelines to further evaluate its use during prolonged transport. With time, SI can be the common language between EMS, rural transferring facilities, and the receiving tertiary care center. Trauma surgeons in similar settings must maintain a high index of clinical suspicion if initial EMS SI was elevated or SI has been elevating during transport.

AUTHORSHIP

J.M.B., B.S.P., and A.W. contributed in the study design. J.M.B., Z.D.W., A.C.B., A.L., M.C.S., S.B.A., M.B.L.D., and A.W. contributed in the data collection. J.M.B., B.S.P., H.B., and A.Q. contributed in the data analysis. J.M.B., B.S.P., and H.B. contributed in the data interpretation. J.M.B., B.S.P., and H.B. contributed in the writing. All authors contributed in the critical revisions.

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DISCLOSURE

The authors declare no conflicts of interest.

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