Emergency medical services shock index is the most accurate predictor of patient outcomes after blunt torso trauma

James M. Bardes, MD, FACS, Bradley S. Price, PhD, Donald A. Adjeroh, PhD, Gianfranco Doretto, PhD, *and* **Alison Wilson, MD, FACS**, *Morgantown, West Virginia*

CONTINUING MEDICAL EDUCATION CREDIT INFORMATION

Accreditation

This activity has been planned and implemented in accordance with the Essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of the American College of Surgeons and American Association for the Surgery of Trauma. The American College of Surgeons is accredited by the ACCME to provide continuing medical education for physicians.

AMA PRA Category 1 Credits™

The American College of Surgeons designates this journal-based activity for a maximum of 1.00 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.
Of the *AMA PRA Category 1 Credit*™ listed above, a maximum of 1.00 credit meets the requirements for self-assessment.

American College of Surgeons
Inspiring Quality: Highest Standards, Better Outcomes
100+*years*

ACCME ACCREDITED WITH COMMENDATION

AMERICAN COLLEGE OF SURGEONS
DIVISION OF EDUCATION

Objectives

After reading the featured articles published in the *Journal of Trauma and Acute Care Surgery*, participants should be able to demonstrate increased understanding of the material specific to the article. Objectives for each article are featured at the beginning of each article and online. Test questions are at the end of the article, with a critique and specific location in the article referencing the question topic.

Disclosure Information

In accordance with the ACCME Accreditation Criteria, the American College of Surgeons must ensure that anyone in a position to control the content of the educational activity (planners and speakers/authors/discussants/moderators) has disclosed all financial relationships with any commercial interest (termed by the ACCME as "ineligible companies", defined below) held in the last 24 months (see below for definitions). Please note that first authors were required to collect and submit disclosure information on behalf all other authors/contributors, if applicable.

Ineligible Company: The ACCME defines an "ineligible company" as any entity producing, marketing, re-selling, or distributing health care goods or services used on or consumed by patients. Providers of clinical services directly to patients are NOT included in this definition.

Financial Relationships: Relationships in which the individual benefits by receiving a salary, royalty, intellectual property rights, consulting fee, honoraria, ownership interest (e.g., stocks, stock options or other ownership interest, excluding diversified mutual funds), or other financial benefit. Financial benefits are usually associated with roles such as employment, management position, independent contractor (including contracted research), consulting, speaking and teaching, membership on advisory committees or review panels, board membership, and other activities from which remuneration is received, or expected. ACCME considers relationships of the person involved in the CME activity to include financial relationships of a spouse or partner.

Conflict of Interest: Circumstances create a conflict of interest when an individual has an opportunity to affect CME content about products or services of a commercial interest with which he/she has a financial relationship.

The ACCME also requires that ACS manage any reported conflict and eliminate the potential for bias during the session. Any conflicts noted below have been managed to our satisfaction. The disclosure information is intended to identify any commercial relationships and allow learners to form their own judgments. However, if you perceive a bias during the educational activity, please report it on the evaluation.

Authors/Contributors

James M. Bardes, Bradley S. Price, Donald A. Adjeroh, Gianfranco Doretto, Alison Wilson have nothing to disclose.

Editorial Board Members

First Name	Last Name	Disclosure?	Name of Commercial Interest	What was Received?	What was the Role?
Michael	Nance	Yes	Endo Pharmaceuticals	Consulting fee	Consultant
Heena	Santry	Yes	NBBJ	Salary	Employee
Jose	Diaz	Yes	Acumed/Acute Innovations	Consulting fee	Consultant
Lena	Napolitnao	Yes	Merck Global Negative Advisory Board/Abbvie Critical Care Working Group	Consulting fee	Advisor/ Consultant

Claiming Credit

To claim credit, please visit the AAST website at http://www.aast.org/ and click on the "e-Learning/MOC" tab. You must read the article, successfully complete the post-test and evaluation. Your CME certificate will be available immediately upon receiving a passing score of 75% or higher on the post-test. Post-tests receiving a score of below 75% will require a retake of the test to receive credit.

Credits can only be claimed online

Cost

For AAST members and Journal of Trauma and Acute Care Surgery subscribers there is no charge to participate in this activity. For those who are not a member or subscriber, the cost for each credit is $25.

Questions

If you have any questions, please contact AAST at 800-789-4006. Paper test and evaluations will not be accepted.

INTRODUCTION: Shock index (SI) and delta shock index (ΔSI) predict mortality and blood transfusion in trauma patients. This study aimed to evaluate the predictive ability of SI and ΔSI in a rural environment with prolonged transport times and transfers from critical access hospitals or level IV trauma centers.

METHODS: We completed a retrospective database review at an American College of Surgeons verified level 1 trauma center for 2 years. Adult subjects analyzed sustained torso trauma. Subjects with missing data or severe head trauma were excluded. For analysis, poisson regression and binomial logistic regression were used to study the effect of time in transport and SI/ΔSI on resource utilization and outcomes. $p < 0.05$ was considered significant.

RESULTS: Complete data were available on 549 scene patients and 127 transfers. Mean Injury Severity Score was 11 (interquartile range, 9.0) for scene and 13 (interquartile range, 6.5) for transfers. Initial emergency medical services SI was the most significant predictor for blood transfusion and intensive care unit care in both scene and transferred patients ($p < 0.0001$) compared with trauma center arrival SI or transferring center SI. A negative ΔSI was significantly associated with the need for transfusion and the number of units transfused. Longer transport time also had a significant relationship with increasing intensive care unit length of stay. Cohorts were analyzed separately.

CONCLUSION: Providers must maintain a high level of clinical suspicion for patients who had an initially elevated SI. Emergency medical services SI was the greatest predictor of injury and need for resources. Enroute SI and ΔSI were less predictive as time from injury increased. This highlights the improvements in en route care but does not eliminate the need for high-level trauma intervention. (*J Trauma Acute Care Surg.* 2022;92: 499–503. Copyright © 2021 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Therapeutic/care management, level IV.

KEY WORDS: Blunt torso trauma; rural trauma; shock index.

Millions of Americans reside over an hour from definitive trauma care.[1,2] In a rural trauma environment, patients are frequently taken through a multiple step process before arriving at definitive surgical care. As trauma systems mature, there are additional critical access and smaller trauma centers available for initial evaluation and stabilization. Patients undergo evaluation and resuscitation at every stage of this process but at the cost of increased time to definitive care. Despite these systems, rural trauma victims have higher mortality than matched urban counterparts.[3–6] Optimal care and transfer pathways in rural America still require further study and development.

Shock index (SI) and delta shock index (ΔSI) predict mortality and blood transfusion in trauma patients.[7–9] This has been shown both during emergency medical service (EMS) transport and on hospital admission. In particular, an increase in SI that occurs from prehospital to hospital arrival is associated with worse outcomes.[10] However, it should be noted that these data come from an urban environment. Data on prehospital vital signs data in a rural environment are lacking in detail, quantity, and clarity. Compounding this lack of data is evidence that longer times in transport decrease the correlation between EMS vital signs and arriving emergency department vital signs.[11,12] This has made prior work on SI hard to generalize in a rural setting.

Submitted: September 13, 2021, Revised: October 31, 2021, Accepted: November 15, 2021, Published online: November 29, 2021.

From the Division of Trauma, Surgical Critical Care and Acute Care Surgery, Department of Surgery (J.M.B., A.W.), Department of Management Information Systems (B.S.P.), John Chambers College of Business and Economics, and Lane Department of Computer Science and Electrical Engineering (D.A.A., G.D.), Benjamin M. Statler College of Engineering and Mineral Resources, West Virginia University, Morgantown, West Virginia.

This study was presented at the 80th Annual Meeting of the American Association for the Surgery of Trauma, September 30, 2021, in Atlanta, Georgia.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for reprints: James M. Bardes, MD, FACS, Division of Trauma, Surgical Critical Care and Acute Care Surgery, Department of Surgery, West Virginia University, PO Box 9238 HSC-S, Morgantown, WV 26508; email: james.bardes@hsc.wvu.edu.

DOI: 10.1097/TA.0000000000003483

The authors hypothesized that SI on hospital arrival was less predictive in a rural environment. With total time in transport routinely over multiple hours, patients would essentially pass the test of time or be resuscitated throughout their transport to definitive trauma care. In either case, this would render hospital arrival SI less valuable as a predictor of mortality and resource need. This study aimed to evaluate the predictive ability of SI and ΔSI in a rural environment with prolonged transport times and transfers from critical access hospitals or level IV trauma centers.

PATIENTS AND METHODS

This was a retrospective review of the trauma registry at an American College of Surgeons–verified level 1 trauma center from January 1, 2017, to December 31, 2018. This center serves as the tertiary referral center for a large rural catchment basin, and half of patients are transferred through a level III or level IV trauma center or critical access hospital. The study included all adult subjects presenting as a trauma activation, after blunt chest or abdominal trauma (Abbreviated Injury Scale score, >1). Subjects with transport times less than 30 minutes, severe head trauma (Abbreviated Injury Scale Head score, >3), and penetrating injuries; those who received blood products before arrival for definitive care; inpatient transfers; and direct from outside hospital operating room transfers were excluded. The study was conducted with approval from the West Virginia University Institutional Review Board and completed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Supplemental Digital Content, http://links.lww.com/TA/C267).

The trauma registry is prospectively maintained by trained registrars. Registry data collected included demographics, injury and transport data, vital signs (EMS, transferring facility, arrival), and hospital outcomes. Shock index was calculated as heart rate divided by systolic blood pressure (SBP), and this was calculated from registry vitals from the first set of EMS vitals (SI-EMS), transferring facilities (SI-TX), and on arrival for definitive care (SI-DC). Delta shock index was calculated as a time dependent function, for example, ΔSI = (SI-EMS) – (SI-DC), as a result of negative values for ΔSI indicates worsening SI. Delta SI and SI

TABLE 1. Evaluation of ICU LOS, Use of Blood Products, and Number of Units PRBC Based on Scene Versus Transfer Status When Considering Only SI-EMS

	Transfer Patients			Scene Patients			All Patients
	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Mortality (Binomial Logistic)
Intercept	0.372 (0.219)*	−5.778 (1.543)‡	−1.349 (0.726)	1.028 (0.110)‡	−6.083 (0.747)‡	1.447 (0.358)	−5.844 (1.021)‡
Time	0.001 (0.0002)‡	0.001 (0.002)	0.000 (0.001)	−0.001 (0.001)	0.001 (0.001)	−0.006 (0.003)	0.001 (0.002)
SI-EMS	1.058 (0.220)‡	4.875 (1.599)†	2.167 (0.661)†	0.623 (0.129)‡	5.147 (0.815)‡	0.218 (0.637)	2.80 (1.228)**
ΔSI (EMS-DC)				0.23 (0.145)	3.134 (0.782)‡	0.637 (0.286)**	0.358 (1.451)
ΔSI (EMS-TX)	−0.388 (0.343)	2.254 (2.034)	1.219 (0.916)				
ΔSI (TX-DC)	0.4445 (0.231)*	1.954 (1.216)	1.277 (0.441)†				

Regression coefficients corresponding to analysis.
*$p < 0.10$.
**$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.

were determined at each phase of transport to understand the importance of the different periods associated with outcomes in transport. Hypotension was defined as SBP of <90 mm Hg. Registry data were reviewed to collect data on hemorrhage control procedures through either open or endovascular techniques.

Statistical analysis was performed using Poisson regression and binomial logistic regression to study the effect of time in transport and SI/ΔSI on resource utilization and outcomes. $p < 0.05$ was considered significant.

RESULTS

After applying inclusion and exclusion criteria, a sample of 676 patients were analyzed. This included 549 scene patients (81.2%), and 127 (18.8%) transferred from another facility. Of the transferred patients, 61 (48.0%) were female, compared with 190 females (34.7%) who were direct from scene. Mean Injury Severity Score (ISS) was 11 (interquartile range [IQR], 9.0) for scene and 13 (IQR, 6.5) for transfers. The time to arrival to the trauma center from the scene differ between the two groups as expected and shows that the mean time for patients transported direct from scene was 75.63 minutes (median, 58 minutes; IQR, 27 minutes) and those routed through a transferring facility had a mean time of 366.5 minutes (median, 341 minutes; IQR, 166.5 minutes). After arrival for definitive care, blood products were transfused in 9.1% of scene patients and 15.0% of transfer patients. Hemorrhage control procedures were required in 38 (6%) of scene patients and 16 (12%) of transfers.

We investigated SI and corresponding ΔSI as a measure of injury severity. There was a weak positive correlation ($r = 0.34$) between ISS and SI, and no correlation between ISS and ΔSI The SI-EMS for scene patients transported to the trauma center had a mean of 0.684 (SD, 0.213), while the patients who were routed through a transferring facility had a mean SI-EMS of 0.701 (SD, 0.240). This difference was not significant ($p = 0.450$). For transferred patients, SI-TX had a mean of 0.686 (SD, 0.2). On arrival for definitive care, the mean SI-DC was 0.676 (SD, 0.191) for scene transports and 0.708 (SD, 0.0.248) for transfers ($p = 0.178$).

The mean ΔSI from SI-EMS to SI-DC for patients who were transported directly from the scene is −0.007 (SD, 0.189), while those being transported through a transfer facility have a mean ΔSI from scene to trauma center of 0.006 (SD, 0.250)

TABLE 2. Evaluation of ICU LOS, Use of Blood Products, and Number of Units PRBC Based on Scene Versus Transfer Status When Considering Only EMS Hypotension

	Transfer Patients			Scene Patients			All Patients
	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Mortality (Binomial Logistic)
Intercept	1.009 (0.124)*	−2.250 (0.641)‡	0.985 (0.248)‡	1.499 (0.052)‡	−2.437 (0.266)‡	1.601 (0.178)	−3.970 (1.021)‡
Time	0.001 (0.000)‡	0.001 (0.002)	0.000 (0.001)	−0.000 (0.000)	0.001 (0.001)	−0.003 (0.002)	0.001 (0.002)
EMS hypotension	1.207 (0.229)‡	2.873 (1.117)‡	1.424 (0.364)‡	0.149 (0.138)‡	4.270 (0.815)‡	−0.231 (0.637)	1.433 (0.977)
ΔSI (EMS-DC)				0.032 (0.128)	1.331 (0.671)**	−0.581 (0.286)†	−0.547 (1.064)
ΔSI (EMS-TX)	−0.363 (0.330)	0.901 (1.561)	1.276 (0.523)**				
ΔSI (TX-DC)	0.4445 (0.231)*	1.48 (1.097)	1.050 (0.321)†				

Emergency medical services hypotension defined as SBP of <90 mm Hg. Regression coefficients corresponding to analysis.
*$p < 0.10$.
**$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.

TABLE 3. Evaluation of ICU LOS, Use of Blood Products, and Number of Units PRBC Based on Scene Versus Transfer Status When Considering Both SI-EMS and EMS Hypotension

	Transfer Patients			Scene Patients			All Patients
	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Days in ICU (Log Scale)	Use of Any Blood Product (Binomial Logistic)	No. Units of PRBC (Log Scale)	Mortality (Binomial Logistic)
Intercept	0.143 (0.236)	−5.324 (1.66)†	−1.570 (0.730)**	1.431 (0.052)‡	−5.344 (0.266)‡	1.325 (0.363)	−5.716 (1.114)‡
Time	0.001 (0.000)‡	0.001 (0.002)	−0.000 (0.001)	−0.000 (0.000)	0.001 (0.004)	−0.006 (0.003)*	−0.002 (0.002)
SI-EMS	1.284 (0.275)‡	4.117 (1.863)**	2.760 (0.828)‡	0.088 (0.182)	3.903 (0.896)‡	0.422 (0.355)	2.610 (1.406)*
EMS hypotension	−0.727 (0.372)*	1.711 (2.59)	−1.185 (0.828)‡	0.129 (0.154)	3.237 (0.887)‡	−0.354 (0.254)	0.331 (1.079)
ΔSI (EMS-DC)				−0.060 (0.166)	3.545 (0.818)‡	0.606 (0.291)**	0.391 (1.446)
ΔSI (EMS-TX)	−0.816 (0.439)*	2.846 (2.128)	0.487 (1.154)				
ΔSI (TX-DC)	0.244 (0.278)	1.987 (1.248)	1.088 (0.487)**				

Emergency medical services hypotension defined as SBP of <90 mm Hg. Regression coefficients corresponding to analysis.
*p < 0.10.
**p < 0.05.
†p < 0.01.
‡p < 0.001.

(p = 0.5518). For patients who were transferred, the ΔSI between SI-EMS and the SI-TX demonstrated a mean of −0.015 (SD, 0.169).

The effects of SI and ΔSI were then evaluated on need for blood product transfusion, number of units of packed red blood cells (PRBCs), intensive care unit length of stay (ICU LOS), and mortality. For comparison, the effect of SI was evaluated both with and without accounting for the presence of hypotension in the respective models. Results show that SI-EMS (Table 1) and EMS hypotension (Table 2) are significant predictors of resource use when investigated separately, with the exception being that hypotension was not shown to be significant in mortality. Hence, we study the impact of SI-EMS when hypotension is included in the models (Table 3). SI-EMS was the most significant predictor for PRBC transfusion and ICU care in both scene and transferred patients when adjusting for the impact of SBP <90 mm Hg. A 0.1 change in SI produces a 50.9% increase in odds ratio of receiving any blood and a 31% increase in the expected number of units of PRBC. Similarly, a 0.1 change in SI-EMS predicts a 13.7% increase in the expected days spent in ICU (p < 0.0001 in transferred patients) compared with SI-TX or SI-DC. A negative ΔSI was significantly associated with the need for transfusion and the number of PRBC transfused. Longer transport time also had a significant relationship with increasing ICU LOS (p < 0.01) for transfer patients. Mortality was found to be associated with SI-EMS in all patients at the p < 0.1 level (0.1 increase in SI predicts a 29.87% increase in the odds ratio of death, p < 0.1), while time, hypotension, and ΔSI were not significant at any standard level.

Figure 1 presents a comparison of the models for the probability of using any blood products and for the number of units of PRBC used on arrival for definitive care. These were performed for each patient type under the assumption that hypotension was present, and all other variables are set to the mean for that patient type. The results show the impact of SI-EMS in resource usage and the importance of this calculation specifically in transfer patients to do their increased number of PRBC required.

DISCUSSION

Rural trauma patients face barriers in time, distance, and access to receiving surgical care. State trauma systems have developed to allow for initial triage, transport, and stabilization en route to a definitive care center. The differences in transport time effect the applicability of some urban studies to rural locations. Because of this

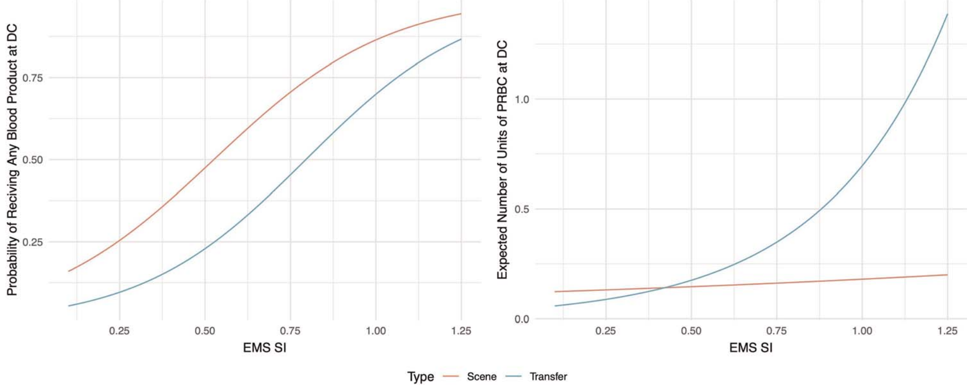

Figure 1. Effect plots for binomial logistic and Poisson regression models, demonstrating need for any blood product and expected number of PRBCs on arrival for DC. Models performed under the assumption hypotension were present, and all other variables are set to the mean for that patient type. DC, definitive care.

observation, the authors aimed to evaluate the predictive ability of SI at multiple stages in a patients care. This study demonstrated that initial SI-EMS was the most predictive of patient outcomes and resource utilization. Our findings build upon the work by Seamon et al.[13] demonstrating that a single episode of hypotension was predictive of severe injury, despite subsequent improvements in blood pressure. As a result, trauma surgeons must maintain a high level of clinical suspicion for patients who had an initially elevated SI, despite improvement during transport and resuscitation. This is particularly important for the surgeon at an accepting facility, and providers should not have a false sense of security because of the time that has passed since the injury occurred if the initial SI was elevated.

Evaluating the mean SI and ΔSI at each phase of patient contact had some interesting findings. Transfer patients had a higher mean SI-EMS than scene patients. While not statistically significant, this may imply that rural patients requiring transfer are sicker and beyond the capability of the initial facility. Similarly, the initial facility may identify a severe but not life-threatening injury and still be able to successfully transfer the patient, leading to the increase in ICU LOS seen with increased time from injury. On average, there was also a negative ΔSI during transport, indicating worsening SI as time from injury increased. For the patient with noncompressible hemorrhage, this is to be expected. However, the patients who went through a transferring facility had a smaller change in SI. This is likely explained by increased resuscitation or interventions during transport; however, those data were not reliable for analysis.

As expected, hypotension independently predicted increased ICU days and the need for blood products. However, SI-EMS demonstrated a larger effect size for these predictions. This study then identified the added value using SI-EMS in conjunction with the presence of hypotension. Perhaps because of long transport time, this combination demonstrated an even greater ability to predict days in ICU and use of blood products based on SI-EMS. This suggests further study to be conducted on the use of SI in trauma team activation criteria after blunt torso trauma.

This study has all the usual limitations of a retrospective study. The lack of serial vital signs and timing of interventions must be mentioned. The registry routinely collects a single set of vital signs from each phase of patient transport, and resuscitation interventions performed by EMS and transferring facilities are poorly captured. Unfortunately, there was a high percentage of missing data on prehospital fluids, which precluded analysis on its effects of SI over time. This practice is common place in trauma registries and demonstrated in large national databases as well.[14] This could worsen the survivor bias seen in this environment. For subjects who received ongoing and progressive resuscitation en route to definitive care, this lack of granular data could blunt the impact of ΔSI, SI-TX, and SI-DC, but the demonstrated use of SI-EMS should be preserved. Finally, the impact on SI-EMS on the need for hemorrhage control procedures is an area for further study; this cohort was limited by the small percentage of patients requiring operative intervention.

SI-EMS was the greatest predictor of need for resources and mortality. Shock index and ΔSI were less predictive as time from injury increased and patients stopped at transferring facilities. This highlights the improvements in en route care but does not eliminate the need for high-level trauma intervention. Based on these results, elevated SI-EMS could also be considered a triage component for use in rural environments. Trauma surgeons in similar clinical settings should maintain a high index of suspicion for patients with an elevated SI-EMS, despite improvements in vital signs during transport.

AUTHORSHIP

J.B. and B.P. contributed in the study design, data collection, data analysis, data interpretation, writing, and critical revisions. D.A. and G.D. contributed in the study design and critical revisions. A.W. contributed in the study design, data interpretation, and critical revisions.

ACKNOWLEDGMENT

Research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health under award number 5U54GM104942. This work is supported in part by funds from the National Science Foundation NSF: number 1920920. Funding provided protected research time for the investigators.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Branas CC, MacKenzie EJ, Williams JC, Schwab CW, Teter HM, Flanigan MC, Blatt AJ, ReVelle CS. Access to trauma centers in the United States. *JAMA*. 2005;293(21):2626–2633.
2. Carr BG, Bowman AJ, Wolff CS, Mullen MT, Holena DN, Branas CC, Wiebe DJ. Disparities in access to trauma Care in the United States: a population-based analysis. *Injury*. 2017;48(2):332–338.
3. Jarman MP, Castillo RC, Carlini AR, Kodadek LM, Haider AH. Rural risk: geographic disparities in trauma mortality. *Surgery*. 2016;160(6):1551–1559.
4. Grossman DC, Kim A, Macdonald SC, Klein P, Copass MK, Maier RV. Urban-rural differences in prehospital care of major trauma. *J Trauma*. 1997;42(4):723–729.
5. Gonzalez RP, Cummings G, Mulekar M, Rodning CB. Increased mortality in rural vehicular trauma: identifying contributing factors through data linkage. *J Trauma*. 2006;61(2):404–409.
6. Esposito TJ, Maier RV, Rivara FP, Pilcher S, Griffith J, Lazear S, Hogan S. The impact of variation in trauma care times: urban versus rural. *Prehosp Disaster Med*. 1995;10(3):161–166; discussion 166-7.
7. Cannon CM, Braxton CC, Kling-Smith M, Mahnken JD, Carlton E, Moncure M. Utility of the shock index in predicting mortality in traumatically injured patients. *J Trauma*. 2009;67(6):1426–1430.
8. Joseph B, Haider A, Ibraheem K, Kulvatunyou N, Tang A, Azim A, O'Keeffe T, Gries L, Vercruysse G, Rhee P. Revitalizing vital signs: the role of delta shock index. *Shock*. 2016;46(3 Suppl 1):50–54.
9. Schroll R, Swift D, Tatum D, Couch S, Heaney JB, Llado-Farrulla M, Zucker S, Gill F, Brown G, Buffin N, et al. Accuracy of shock index versus ABC score to predict need for massive transfusion in trauma patients. *Injury*. 2018;49(1):15–19.
10. Schellenberg M, Strumwasser A, Grabo D, Clark D, Matsushima K, Inaba K, Demetriades D. Delta shock index in the emergency department predicts mortality and need for blood transfusion in trauma patients. *Am Surg*. 2017;83(10):1059–1062.
11. Trust MD, Schellenberg M, Biswas S, Inaba K, Cheng V, Warriner Z, Love BE, Demetriades D. Prehospital vital signs accurately predict initial emergency department vital signs. *Prehosp Disaster Med*. 2020;35(3):254–259.
12. Schellenberg M, Biswas S, Bardes JM, Trust MD, Grabo D, Wilson A, Inaba K. Longer prehospital time decreases reliability of vital signs in the field: a dual center study. *Am Surg*. 2021;87(6):943–948.
13. Seamon MJ, Feather C, Smith BP, Kulp H, Gaughan JP, Goldberg AJ. Just one drop: the significance of a single hypotensive blood pressure reading during trauma resuscitations. *J Trauma*. 2010;68(6):1289–1294.
14. Zehtabchi S, Nishijima DK, McKay MP, Mann NC. Trauma registries: history, logistics, limitations, and contributions to emergency medicine research. *Acad Emerg Med*. 2011;18(6):637–643.