Shock Index, Lactate, and Base Deficit as Bleeding Predictors in Trauma Patients from a Complex Emergency Department: A Prospective Cohort Study

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ABSTRACT

Background: Hemorrhagic shock (HS) is the leading preventable cause of death in trauma patients. Shock index (SI), lactate, and base deficit (BD) are suggested to be rapid markers for triage tools; this study aimed to assess whether these tools can identify bleeding and predict specific outcomes in trauma patients.

Methods: A prospective cohort of trauma patients from a complex Emergency Department were analyzed between October 2019 and March 2020. Sociodemographic and clinical data, prehospital care, vital signs, arterial blood gases on admission, and 30-day follow-ups were collected. Evidence of significant bleeding was defined as physical or imaging findings of significant bleeding that led to blood transfusions, hemostatic surgery, and death due to hypovolemic shock.

Results: Out of the 111 patients aged 35 ± 16.2 years (97% male), 72% had nonpenetrating trauma, and 63% had high-energy trauma, with a mean injury severity score (ISS) of 15.8 ± 14.1, and revised trauma score (RTS) 7.3 ± 1.3. The cut-off points for bleeding were determined by the following—SI > 0.9 with an area under the curve (AUC) of 0.64 [95% confidence interval (CI) 0.541–0.743]; lactate levels >2 with an AUC of 0.77 [95% CI 0.695–0.864], and a BD <−6 with an AUC of 0.74 [95% CI 0.657–0.839]. The sensitivity was 32.4, 76.5, and 64.7%, and the specificity was 93, 62.8, and 79.1%, respectively.

Conclusion: Base deficit (BD) and lactate are good triage tools for identifying HS in trauma patients.

Keywords: Base deficit, Blood gas analysis, Emergencies, Hemorrhage, Lactic acid, Shock, Shock index, Wounds and injuries.

Panamerican Journal of Trauma, Critical Care & Emergency Surgery (2023): 10.5005/jp-journals-10030-1416

INTRODUCTION

Hemorrhagic shock (HS) is the leading cause of death in trauma patients. Several triage markers have been proposed to predetermine HS in patients. The first is the SI, which was described by Allgower and Burri in 1967 as the relationship between heart rate and systolic blood pressure.[1] The second is BD, recently adopted by the advanced trauma life support (ATLS) from its tenth edition in 2018.[2] The last marker is lactate, which has been studied in different shock scenarios.[3,4] Various trauma triage tools with adequate sensitivity allow for early identification of HS that would otherwise be overlooked due to compensatory mechanisms.

The objective of this study was to compare SI, BD, and lactate in trauma settings to predetermine patient bleeding and predict blood component transfusion, vasopressor requirement, Intensive Care Unit (ICU) admission, surgery to control bleeding, and 30-day mortality.

METHODS

A prospective cohort was carried out between October 2019 and March 2020. This included patients (14 years and older) admitted to the Hospital Universitario San José (HUSJ in Spanish) Emergency Department for Trauma that required attention from the general surgery team. Patients excluded were those who received extrainstitutional surgical management, who were admitted to cardiorespiratory arrest, and those referred to other institutions. All included patients had complete vital signs taken on admission, which were used to calculate SI and arterial blood gases with

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lactate to determine significant bleeding (defined as the presence of hemostatic surgery and the need for transfusion of blood components and/or death due to hypovolemic shock) whether due to clinical history, diagnostic imaging, or surgical procedure. This study had an institutional ethical endorsement from the HUSJ in Popayán, Cauca, Colombia, and followed national and international bioethical regulations for research. Since there is an institutional protocol to measure arterial gases in emergency trauma, the patient's informed consent was provided as an intervention, which is different from usual practice. Sociodemographic, clinical, and blood gas variables at admission, and results from 30 days of follow-up were included. The need for blood transfusions in the

first 24 hours and the need for vasopressors, hemostatic surgical procedures, admission to the ICU, and mortality were evaluated.

Statistical analysis was performed using the Statistical Package for the Social Sciences V.25 program. Descriptive statistics were applied, presenting frequencies and proportions or means ± standard deviation according to the variables. Receiver operating characteristic curves were developed to estimate the AUC and determine the cut-off points to calculate the sensitivity, specificity, and predictive values.

RESULTS

Between 15th October 2019, and 17th March 2020, 188 trauma patients were admitted to HUSJ. Of these patients, 63 were excluded because they lacked adequate initial care, arterial blood gases upon admission, and insufficient clinical histories (Flowchart 1).

This study included 111 patients with a mean age of 35 years [standard deviation (SD) ± 16.2], where 87.4% ($n = 97$) were male with a mean ISS of 15.8 (SD ± 14.1). Only seven patients reported chronic diseases, with arterial hypertension being the most frequently reported ($n = 5$), followed by diabetes mellitus ($n = 4$). Additionally, 64.9% presented nonpenetrating trauma ($n = 92$), which involved high-energy kinematics in 56.8% of the cases ($n = 63$). Out of the 83.7% of patients ($n = 93$) who received care before they were admitted to the Emergency Department, 57.7% of them ($n = 64$) received care from health centers in rural areas and care centers in urban areas of Cauca. The median time spent from the moment of the traumatic event to admission to the Emergency Department was 2 hours. Still, there were records of up to 5 days from trauma to admission, probably because they came from areas that were difficult to access. The mean ISS was 15.8, with a mean RTS of 7.3. When classifying the patients according to the BD values from ATLS for HS, 40.5% of the patients ($n = 45$) fell into a range of −2 to −6, corresponding to HS grade II, followed by 27.9% ($n = 31$) of the group from −6 to −10, HS grade III, and 19.8% of the group with values <−10, HS grade IV ($n = 22$). For hemodynamic variables and arterial blood gases according to the HS classification, there was a mean IS of 0.67 (SD ± 0.13), 0.78 (SD ± 0.27), 0.83 (SD ± 0.29), and 1.09 (SD ± 0.47), respectively. For lactate, there was a mean

of 1.39 (SD ± 0.45), 2.59 (SD ± 3.24), 2.84 (SD ± 1.14), and 6.1 (SD ± 4.2), respectively. Bicarbonate (HCO_3) presented a trend inversely proportional to HS—23.7 (SD ± 1.1), 20.1 (SD ± 2.8), 17.8 (SD ± 1.4), and 14.6 (SD ± 2.7) (Table 1).

The presence of bleeding marked different cut-off points—for SI, it was >0.9, with an AUC of 0.64 [95% CI 0.541–0.743], a sensitivity of 32.4%, and a specificity of 93.0%; for lactate, it was >2 with an AUC of 0.77 [95% CI 0.695–0.864], a sensitivity of 76.5% and specificity of 62.8%; for the BD, it was <−6 with an AUC of 0.74 [95% CI 0.657–0.839], a sensitivity of 64.7%, and a specificity of 79.1% (Fig. 1 and Table 2).
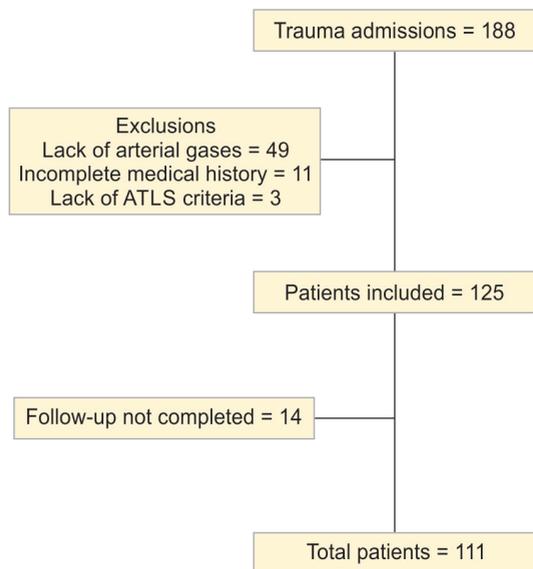
During the study, 85 patients underwent surgery, 34.2% ($n = 29$) underwent reconstructive surgeries, 65.8% ($n = 56$) underwent hemostatic surgical procedures, and 41.1% ($n = 24$) of these underwent damage control surgeries. The average number of interventions performed in patients undergoing damage control surgery was 5.6 ± 4.2, with a minimum of two and a maximum of 16. The mean SI of 0.8 ± 0.3, BD −8 ± 5, and lactate 3.6 ± 3.2 in patients who underwent hemostatic surgeries differ from patients who did not require surgery or were taken only for reconstructive surgeries. The latter group of patients had a mean SI of 0.8 ± 0.3, BD −5 ± 3, and lactate 2.8 ± 3.1, revealing statistically significant differences between the three variables ($p \leq 0.001$, $p \leq 0.001$, and $p = 0.001$) (Table 3).

A total of 22.5% of the transfused patients ($n = 25$) had a mean of 6.2 units, median of 4, SD 5.5, and range of 1–27 units of blood components. In the blood transfused patients, there was a SI average of 1.16 ± 0.46 BD −10 ± 5.23 and lactate 4.97 ± 4.26.

A total of 38 patients were admitted to the ICU, including 22 transfused patients, of whom had a mean BD of −9.9 ± 5.8, lactate of 5.1 ± 4.7, and SI of 1.03 ± 0.44. There were 27 patients who required vasoactive agents, with the following mean values——10.7 ± 5.9 for BD, 5.8 ± 2.3 for lactate, and 1.13 ± 0.47 for SI.

There was an association between transfusion, the use of vasoactive agents, admission to the ICU, and the need for hemostatic surgery with a BD, lactate, and SI ($p < 0.001$). A mortality of 7.2% (n = 8) was reported. There was also an association between BD and SI ($p \leq 0.001$ and $p \leq 0.001$, respectively) but not with lactation ($p = 0.002$). These results were confirmed with the nonparametric Mann–Whitney U test. The multivariate logistic regression analysis identified the excess base as the variable that best predicts the outcomes studied in the trauma patient.

DISCUSSION

Hemorrhagic shock (HS) has become one of the leading causes of death in trauma patients, mainly affecting people around 35 years of age. Traumatic injuries account for 1,920.7 years of potential life lost per 1,00,000 people.[5] For this reason, there is a need to establish better triage methods for trauma patients. This study had a predominantly male population with an average age of 35 years, similar to another study from Southwestern Colombia.[6] However, unlike the study in Southwestern Colombia, where the main cause of trauma was from penetrating wounds,[6] the main cause of trauma in this study was due to vehicular collisions. Only four patients met the definition of massive transfusion (MT),[7] despite not undergoing institutional protocol. Some studies have found that SI values >0.9 significantly increase the possibility of receiving MT protocol in trauma.[8] In this study, an average of 1.16 patients required blood components. Similarly, lactate has demonstrated its predictive value in terms of MT when values >2.5 mmol/L are
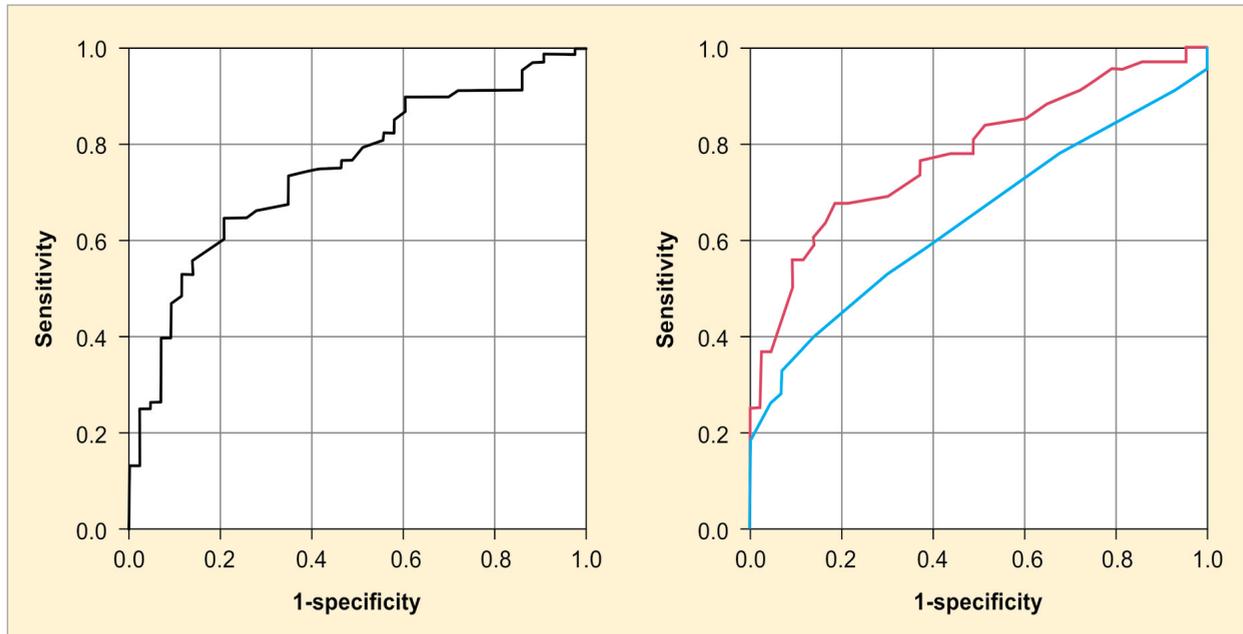
Flowchart 1: Data collection flowchart

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                    ┌─────────────────────────────┐
                    │   Trauma admissions = 188   │
                    └─────────────────────────────┘
                                   │
    ┌──────────────────────────────┐
    │ Exclusions                   │
    │ Lack of arterial gases = 49  │
    │ Incomplete medical history = 11
    │ Lack of ATLS criteria = 3    │
    └──────────────────────────────┘
                                   │
                    ┌─────────────────────────────┐
                    │   Patients included = 125   │
                    └─────────────────────────────┘
                                   │
    ┌──────────────────────────────┐
    │ Follow-up not completed = 14 │
    └──────────────────────────────┘
                                   │
                    ┌─────────────────────────────┐
                    │    Total patients = 111     │
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Fig. 1: ROC curve of DB, lactate and shock index depending on the evidence of bleeding. Graphic left DB, graphic right SI (blue line) and lactate (red line)

Table 1: Hemodynamic variables according to the ATLS classification of hemorrhagic shock using the BD

Category BD ATLS	2/-2.00	-2.01/-6.00	-6.01/-10.0	< -10
n (%)	13 (11.7%)	45 (40.5%)	31 (27.9%)	22 (19.8%)
	Media (DE)	Media (DE)	Media (DE)	Media (DE)
SBP*	125.7 (14.8)	115.8 (18.4)	116.3 (25.1)	101.7 (31.1)
DBP**	77.4 (10.3)	68.8 (11.8)	71.6 (13.9)	61.3 (20.2)
HR***	83.7 (14.5)	86.5 (13.9)	90.9 (16.2)	100.7 (23.1)
SI	0.67 (0.13)	0.78 (0.27)	0.83 (0.29)	1.09 (0.47)
RR****	18.8 (2.6)	18.7 (4.2)	19.7 (4.3)	21.2 (7.7)
Sat O_2%	94.7 (3.1)	94.9 (3.7)	92.7 (4.2)	90.5 (7.5)
Temperature	36.1 (0.2)	36.0 (0.2)	36.1 (0.2)	36.1 (0.4)
pH	7.43 (0.03)	7.39 (0.14)	7.24 (0.66)	7.21 (0.15)
HCO^3	23.7 (1.1)	20.1 (2.8)	17.8 (1.4)	14.6 (2.7)
PCO^2	36.1 (3.9)	33.6 (5.7)	32.3 (7.1)	35.2 (8.3)
PO^2	77.0 (19.6)	99.0 (62.1)	96.3 (39.2)	130.8 (85.1)
Lactate	1.39 (0.45)	2.59 (3.24)	2.84 (1.14)	6.1 (4.2)

*SBP, Systolic Blood Pressure; **DBP, Diastolic Blood Pressure; *** HR, Heart Rate; ****RR, Respiratory Rate

Table 2: Sensitivity, specificity, positive and negative predictive values of the variables studied

	Area	SD	CI 95%	PPV	NPV	Sensitivity	Specificity
BD < −6	0.748	0.047	0.657–0.839	83.0	58.6	64.7	79.1
Lactate >2	0.779	0.043	0.695–0.864	76.5	62.8	76.5	62.8
SI >0.9	0.642	0.052	0.541–0.743	88.0	46.5	32.4	93.0

SD; standard deviation, CI; confidence interval, PPV; positive predictive value, NPV; negative predictive value

present.[9] In this study, an average of 4.97 mmol/L was required for blood transfusions; however, this sample is much smaller than in other works. These two tools have been used in MT protocol activation scales, such as the focused assessment with sonography in trauma score, which has a sensitivity of 90%.[10] For the BD, values <−10 are associated up to 51% with the requirement of MT,[11] and its results have even been included in the Trauma Associated Severe Hemorrhage (TASH) score, which presents a sensitivity of 84.4% with its highest cut-off point to 8.5 for MT.[12] This coincides with the mean value of our patients.

Differences were found in SI, BD, and lactate between patients undergoing hemostatic surgical procedures and those without. In patients with penetrating wounds, values above 4 mmol/L increase the probability of requiring hemostatic surgery up

Table 3: Mean DB, lactate and SI with the need for admission to the ICU, vasoactive or inotropic agents, transfusion of blood products and admission to hemostatic surgery

			Mean (SD)		
		n	BD	Lactate	SI
ICU	Yes	38	−9.9 (5.8)	5.1 (4.7)	1.03 (0.44)
	NO	73	−5.1 (2.9)	2.2 (1.0)	0.74 (0.20)
	p Value		<0.001	<0.001	<0.001
Transfused	Yes	25	−10 (5.2)	4.9 (4.2)	1.16 (0.45)
	NO	86	−5.8 (4.1)	2.7 (2.6)	0.75 (0.21)
	p Value		<0.001	0.002	<0.001
Vasoactive/Inotropic	Yes	27	−10.7 (5.9)	5.8 (5.3)	1.13 (0.47)
	NO	84	−5.5 (3.4)	2.3 (1.2)	0.75 (0.21)
	p Value		<0.001	<0.001	<0.001
Hemostatic surgery	Yes	56	−8.1 (5.4)	3.6 (3.2)	0.8 (03)
	NO	55	−5.3 (3.3)	2.8 (3.1)	0.8 (0.3)
	p Value		<0.001	0.001	<0.001
Mortality	Yes	8	−9.1 (3.8)	7.0 (6.6)	1.21 (0.50)
	NO	103	−6.6 (4.7)	2.9 (2.6)	0.81 (0.30)
	p Value		<0.001	0.002	<0.001

to 4.17 times.[14] Lactate values greater than 3.1 umol/L with a sensitivity of 64% and specificity of 83% have been considered predictors of hemostatic surgery.[13] In this study, the average lactate value was 3.6.

A multicenter prospective study found a directly proportional relationship with BD levels.[15] Other studies have associated mortality with SI values ranging from 0.9 to >1.1;[16,17] however, it has been described that sensitivity is lost in individuals over 55 years, making it a poor predictor in older adults.[18] Sensitivity can also be influenced by drugs that can alter vital signs, such as β blockers.[19] Similarly, it has been described that lactate with values greater than 2.5 mmol/L are better predictors than traditional vital signs.[20] In our study, we found an association between SI and BD with mortality but not with lactate. Although numerical cut-off points could not be established given the sample size and the low mortality reported, our results differ from another study where lactate has been documented to be superior to BD in predicting mortality.[21]

This work shows the usefulness of three tools in detecting significant bleeding in trauma patients. Among them, the SI was the one with the lowest predictive capacity. These results are consistent with other studies[22,23] with cut-off points of 0.9, but many authors have proposed changing this value to 0.8 to improve the sensitivity of the tool.[16,22–24] Some authors have even dismissed SI as a triage tool due to its low sensitivity to distinguish minor trauma from major trauma,[25,26] preferring lactate[9,14] and BD[15,27] as trauma triage instruments due to their high sensitivity.

There are some confounding factors in our study that could alter the results, such as the lack of blood alcohol measurement, which could alter the pulse pressure, affecting the SI and metabolism, which could increase lactate values.[28]

Conclusion

Arterial blood gases with their base and lactate deficit variables are good predictive values for active bleeding and occult shock in patients. High sensitivity and specificity values make them good triage tools in trauma.

A SI is a clinical tool that shows altered values in its cut-off points. However, it cannot be used to rule out the presence of active bleeding or hidden HS in trauma patients. Studies with a larger sample size are required to determine cut-off points in terms of mortality, transfusion requirements, hemostatic surgical interventions, or admission to the ICU.

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References

1. Allgöwer M, Burri C. Shock index. Dtsch Med Wochenschr 1967;92(43):1947–1950. DOI: 10.1055/s-0028-1106070
2. American College of Surgeons. ATLS Soporte vital avanzado en. Trauma, Manual del curso para estudiantes. 10.a ed. 2018;391.
3. Solano Arboleda N, Rojas Diaz AB. Uso de los gases arteriales en trauma. Rev Colomb Cir 2021;36(1):20–24. DOI: 10.30944/20117582.759
4. St. John A, McCoy A, Moyes A, et al. Prehospital lactate predicts need for resuscitative care in non-hypotensive trauma patients. West J Emerg Med 2018;19(2):224–231. DOI: 10.5811/westjem.2017.10.34674
5. Sanjuán Marín JF, Medina R, Botache Capera WF, et al. Tendencia de los años perdidos de vida potencial por trauma en Colombia: análisis de un periodo de nueve años. Rev Colomb Cir 2019;34(4):346–353. DOI: 10.30944/20117582.513
6. Ordóñez CA, Pino LF, Tejada JW, et al. Experiencia en dos hospitales de tercer nivel de atención del suroccidente de Colombia en la aplicación del Registro Internacional de Trauma de la Sociedad Panamericana de Trauma. Rev Col Bras Cir 2012;39(4):255–262. DOI: 10.1590/S0100-69912012000400003
7. Llau JV, Acosta FJ, Escolar G, et al. Documento multidisciplinar de consenso sobre el manejo de la hemorragia masiva (documento HEMOMAS). Rev Esp Anestesiol Reanim 2016;63(1):e1–e22. DOI: 10.1016/j.redar.2015.11.002
8. Vandromme MJ, Griffin RL, Kerby JD, et al. Identifying risk for massive transfusion in the relatively normotensive patient:

utility of the prehospital shock index. J Trauma InjInfectCrit Care 2011;70(2):384–390. DOI: 10.1097/TA.0b013e3182095a0a

9. Vandromme MJ, Griffin RL, Weinberg JA, et al. lactate is a better predictor than systolic blood pressure for determining blood requirement and mortality: could prehospital measures improve trauma triage? J Am Coll Surg 2010;210(5):861–867. DOI: 10.1016/j.jamcollsurg.2010.01.012

10. El-Menyar A, Abdelrahman H, Al-Thani H, et al. The FASILA score: a novel bio-clinical score to predict massive blood transfusion in patients with abdominal trauma. World J Surg 2020;44(4):1126–1136. DOI: 10.1007/s00268-019-05289-0

11. Mutschler M, Nienaber U, Brockamp T, et al. Renaissance of base deficit for the initial assessment of trauma patients: a base deficit-based classification for hypovolemic shock developed on data from 16,305 patients derived from the TraumaRegister DGU®. Crit Care 2013;17(2):R42. DOI: 10.1186/cc12555

12. Yücel N, Lefering R, Maegele M, et al. Trauma associated severe hemorrhage (TASH)—score: probability of mass transfusion as surrogate for life threatening hemorrhage after multiple trauma. J Trauma AcuteCareSurg 2006;60(6):1228–1237. DOI: 10.1097/01.ta.0000220386.84012.bf

13. Fukuma H, Nakada T, Shimada T, et al. Prehospital lactate improves prediction of the need for immediate interventions for hemorrhage after trauma. Sci Rep 2019;9(1):13755. DOI: 10.1038/s41598-019-50253-6

14. Caputo N, Fraser R, Paliga A, et al. Triage vital signs do not correlate with serum lactate or base deficit, and are less predictive of operative intervention in penetrating trauma patients: a prospective cohort study. Emerg Med J 2013;30(7):546–550. DOI: 10.1136/emermed-2012-201343

15. Rixen D, Raum M, Bouillon B, et al. Base deficit development and its prognostic significance in posttrauma critical illness: an analysis by the trauma registry of the Deutsche Gesellschaft für unfallchirurgie. SHOCK 2001;15(2):83–89. DOI: 10.1097/00024382-200115020-00001

16. King RW, Plewa MC, Buderer NMF, et al. Shock index as a marker for significant injury in trauma patients. Acad Emerg Med 1996;3(11):1041–1045. DOI: 10.1111/j.1553-2712.1996.tb03351.x

17. Charry JD, Bermeo JM, Montoya KF, et al. Índice de shock como factor predictor de mortalidad en el paciente con trauma penetrante de tórax. Col J Surg 2015;30(1). DOI: 10.30944/20117582.307

18. Shibahashi K, Sugiyama K, Okura Y, et al. Can the shock index be a reliable predictor of early mortality after trauma in older patients? A retrospective cohort study. Acute Med Surg 2019;6(4):385–391. DOI: 10.1002/ams2.427

19. Koch E, Lovett S, Nghiem T, et al. Shock index in the emergency department: utility and limitations. Open Access Emerg Med 2019;11:179–199. DOI: 10.2147/OAEM.S178358

20. Salottolo KM, Mains CW, Offner PJ, et al. A retrospective analysis of geriatric trauma patients: venous lactate is a better predictor of mortality than traditional vital signs. Scand J Trauma Resusc Emerg Med 2013;21(1):7. DOI: 10.1186/1757-7241-21-7

21. Gale SC, Kocik JF, Creath R, et al. A comparison of initial lactate and initial base deficit as predictors of mortality after severe blunt trauma. J Surg Res 2016;205(2):446–455. DOI: 10.1016/j.jss.2016.06.103

22. DeMuro JP, Simmons S, Jax J, Gianelli SM. Application of the shock index to the prediction of need for hemostasis intervention. Am J Emerg Med 2013;31(8):1260–1263. DOI: 10.1016/j.ajem.2013.05.027

23. Campos-Serra A, Montmany-Vioque S, Rebasa-Cladera P, et al. Aplicación del Shock Index como predictor de hemorragia en el paciente politraumático. Cir Esp 2018;96(8):494–500. DOI: 10.1016/j.ciresp.2018.04.004

24. El-Menyar A, Goyal P, Tilley E, et al. The clinical utility of shock index to predict the need for blood transfusion and outcomes in trauma. J Surg Res 2018;227:52–59. DOI: 10.1016/j.jss.2018.02.013

25. Paladino L, Subramanian RA, Nabors S, Sinert R. The utility of shock index in differentiating major from minor injury. Eur J Emerg Med 2011;18(2):94–98. DOI: 10.1097/MEJ.0b013e32833f212b

26. Totten AM, Cheney TP, O'Neil ME, et al. Physiologic predictors of severe injury: systematic review. Agency for Healthcare Research and Quality (AHRQ); 2018 abr. Disponible en:https://effectivehealthcare.ahrq.gov/topics/predictors-trauma-care/research-2018

27. Dunham MP, Sartorius B, Laing GL, et al. A comparison of base deficit and vital signs in the early assessment of patients with penetrating trauma in a high burden setting. Injury 2017;48(9):1972–1977. DOI: 10.1016/j.injury.2017.06.011

28. Mihic SJ, Harris RA. Hypnotics and sedatives. Goodman Gilmans Pharmacol Basis Ther 12th Ed N Y USA McGraw-Hill. 2011;457–480.