American Journal of Emergency Medicine 38 (2020) 187–190

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

Pre-hospital modified shock index for prediction of massive transfusion and mortality in trauma patients

Il-Jae Wang, MD [a], Byung-Kwan Bae, MD [a], Sung-Wook Park, MD [a,*], Young-Mo Cho, MD [a], Dae-Sup Lee, MD [b], Mun-Ki Min, MD [b], Ji-Ho Ryu, MD [b], Gil-Hwan Kim, MD [c], Jae-Hoon Jang, MD [d]

[a] Department of Emergency Medicine, Pusan National University Hospital, Biomedical Research Institute, Pusan National University Hospital, 179, Gudeok-ro, Seo-gu, Busan 602-739, South Korea
[b] Department of Emergency Medicine, Pusan National University Yangsan Hospital, Beomeo-ri, Mulgeum-eup, Gyeongsangnam-do 626-770, South Korea
[c] Department of Trauma and Acute Care Suregery, Pusan National University Hospital, 179, Gudeok-ro, Seo-gu, Busan 602-739, South Korea
[d] Department of Orthopedic Surgery, Pusan National University Hospital, 179, Gudeok-ro, Seo-gu, Busan 602-739, South Korea

ARTICLE INFO

Article history:
Received 24 October 2018
Received in revised form 13 January 2019
Accepted 17 January 2019

Keywords:
Trauma
Hemorrhagic shock
Emergency medical services
Blood transfusion

ABSTRACT

Background: Modified shock index (MSI) is a useful predictor in trauma patients. However, the value of prehospital MSI (preMSI) in trauma patients is unknown. The aim of this study was to investigate the accuracy of preMSI in predicting massive transfusion (MT) and hospital mortality among trauma patients.
Methods: This was a retrospective, observational, single-center study. Patients presenting consecutively to the trauma center between January 2016 and December 2017, were included. The predictive ability of both prehospital shock index (preSI) and preMSI for MT and hospital mortality was assessed by calculating the areas under the receiver operating characteristic curves (AUROCs).
Results: A total of 1007 patients were included. Seventy-eight (7.7%) patients received MT, and 30 (3.0%) patients died within 24 h of admission to the trauma center. The AUROCs for predicting MT with preSI and preMSI were 0.773 (95% confidence interval [CI], 0.746–0.798) and 0.765 (95% CI, 0.738–0.791), respectively. The AUROCs for predicting 24-hour mortality with preSI and preMSI were 0.584 (95% CI, 0.553–0.615) and 0.581 (95% CI, 0.550–0.612), respectively.
Conclusions: PreSI and preMSI showed moderate accuracy in predicting MT. PreMSI did not have higher predictive power than preSI. Additionally, in predicting hospital mortality, preMSI was not superior to preSI.

1. Introduction

Trauma is the most common cause of death in people less than years and is a major financial problem worldwide [1,2]. Bleeding accounts for nearly 50% of deaths within 24 h of the trauma, and is the largest preventable cause of death [3,4]. If a patient with severe bleeding does not receive treatment quickly, irreversible damage may follow [5]. Therefore, it is very important to accurately classify bleeding patients at the pre-hospital stage and transfer them to the appropriate hospital [6].

Shock index (SI) is a useful parameter that can be used at the pre-hospital stage for trauma patients. It is calculated as the ratio of heart rate (HR) to systolic blood pressure (SBP), and is superior to both SBP and HR alone in predicting blood loss [7,8]. SI provides potentially good inter-observer reliability for use patients with multiple injuries [9]. Since SI can be easily calculated only by knowing the SBP and HR values, it can be used easily at the pre-hospital stage. Several studies have reported the value of pre-hospital SI in trauma patients [10-13].

However, because SI does not reflect diastolic blood pressure (DBP), Liu et al. [14] introduced the modified shock index (MSI), which is calculated by replacing SBP with mean arterial pressure (MAP) in the equation for SI. They reported that since MSI is influenced by DBP, it reflects stroke volume and systemic vascular resistance more accurately than SI. Ajai et al. [15] compared the predictive values of SI and MSI for in-hospital mortality in 9860 adult trauma patients, and reported that MSI was a better predictor for mortality. MSI can be easily measured at the pre-hospital stage. However, no studies have examined the value of MSI in the pre-hospital stage of trauma patients.

The purpose of this study was to determine the ability of prehospital MSI (preMSI) to predict massive transfusion (MT) and in-hospital mortality in trauma patients. In addition, we compared the predictive power

Abbreviations: ABC, Assessment of Blood Consumption; AUROC, areas under the receiver operating characteristic curves; DBP, diastolic blood pressure; ED, emergency department; HR, heart rate; ICU, intensive care unit; ISS, injury severity score; KTDB, Korean Trauma Data Base; MAP, mean arterial pressure; MSI, modified shock index; MT, massive transfusion; PACT, Prediction of Acute Coagulopathy of Trauma; PRBC, packed red blood cell; ROC, receiver operating characteristic; SBP, systolic blood pressure; SI, shock index; TASH, Trauma Associated Severe Hemorrhage.

* Corresponding author at: Pusan National University Hospital Department of Emergency Medicine, Biomedical Research Institute, Pusan National University Hospital, 179, Gudeok-ro, Seo-gu, Busan 602-739, South Korea.
E-mail address: psu52156@naver.com (S.-W. Park).

https://doi.org/10.1016/j.ajem.2019.01.056
0735-6757/

of prehospital SI (preSI) and preMSI for MT and 24-hour mortality among the trauma patients. The authors hypothesized that preMSI would be a useful predictor of MT and 24-hour mortality. We also predicted that preMSI had a better predictability score than preSI.

2. Methods

2.1. Study design and setting

This was a retrospective, observational, single-center study conducted at a trauma center of a 1400-bed, tertiary care, university-affiliated hospital in Pusan, Korea. The study was approved by the institutional review board of the hospital. The trauma center serves as a Level I regional trauma center for patients primarily from Busan City and Kyung-Nam Province; the total population of both areas is approximately 6.8 million people. In 2017, >1000 trauma patients with injury severity score (ISS) >15 presented to the unit.

2.2. Participants

Between January 2016 and December 2017, all consecutive adult patients (18 years of age or older) with blunt or penetrating injuries were screened as candidates for inclusion in the study. Blood pressure was measured using a sphygmomanometer at the pre-hospital phase. During this period, there was no use of either blood transfusion or vasopressors in the pre-hospital phase. Patients transferred from other hospitals, as well as pre-hospital cardiac arrest patients who had no values for HR or SBP and DBP were excluded. Patients with missing values for SBP, DBP, and HR at the pre-hospital stage, and those without blunt or penetrating injury mechanism were also excluded.

2.3. Data collection and variables

The data were extracted from the Korean Trauma Data Base (KTDB) and the electrical medical records for each patient in our hospital. KTDB was established by the Ministry of Health and Welfare of Korea in 2013, to collect data on trauma patients from selected regional trauma centers [16]. Data collected included age, sex, vital signs (SBP, DBP, HR) at pre-hospital injury place, packed red blood cell (PRBC) transfused within the first 4 and 24 h of admission from emergency department (ED), and 24-hour mortality. We calculated preSI and preMSI using the following formulas:

preSI = heart rate/systolic blood pressure in the prehospital stage

preMSI = heart rate/mean arterial pressure in the prehospital stage

At the pre-hospital phase, the blood pressure was measured once or twice. In a situation where there were two blood pressure measurements, we used the lower of the two to calculate preSI and preMSI.

2.4. Outcome measure

The primary outcome was MT, which was defined as 10 or more units of packed red cells transfused within 24 h of admission to the ED [17]. The secondary outcome was 24-hour mortality. In addition, we calculated the transfusion requirement within the first 4, and 24 h of admission to the ED.

2.5. Statistical analysis

Continuous variables with normal and abnormal distribution were reported as mean ± standard deviation (SD) or median with interquartile range (IQR), while categorical variables were reported as frequency (percentage). To determine the optimal cut-off values of preSI and preMSI, (i.e. maximizing the sum of sensitivity and specificity), receiver operating characteristic (ROC) curve was drawn. The predictive ability of each index for MT was assessed by calculating the areas under the ROC curves. High accuracy was defined as an area under the receiver operating characteristic curve (AUROC) of >0.9, while moderate accuracy was defined as an AUROC of 0.7–0.9, and low accuracy was defined as the AUROC of <0.7 [18]. A p-value of <0.05 was considered statistically significant. SPSS version 18.0 software (IBM, Corporation, Armonk, NY, USA) was used for statistical analysis.

3. Results

3.1. General characteristics of the study population

A total of 2562 patients presented to the trauma center ED during the study period. The following patients were excluded: patients aged <18 years ($n = 160$), those transferred from other hospitals ($n = 1180$), those who experienced pre-hospital cardiac arrest ($n = 108$), those with missing or no values for SBP, DBP, and HR at the pre-hospital stage ($n = 98$), and patients with burn injuries ($n = 9$); finally 1007 patients were included in the study. There were 792 male patients (78.6%) and 215 female patients (21.4%), with a median age (IQR) of 53.0 (37.0–63.0) years. At presentation to the ED, 931 (92.5%) patients had blunt injuries, and 76 (7.5%) had penetrating injuries. The median values of preSI and preMSI were 0.73 (0.60–0.92) and 0.94 (0.79–1.21), respectively. A total of 313 (31.1%) patients received emergent surgery or embolization. PRBC transfusion was administered to 304 (30.2%) within 4 h, and 377 (37.4%) within 24 h of admission. In total, 78 (7.7%) patients received MT. From the ED, 67.4% of patients were admitted to the intensive care unit (ICU), 22.8% were admitted to the general ward, 9.0% were transferred to the other facilities and 7 patients died in the ED. 24-hour mortality of the study patients was 3.0% ($n = 30$). The preSI and preMSI in the MT group were significantly higher than those in the non-MT group ($p < 0.001$, and $p < 0.001$, respectively). Table 1 summarizes the general characteristics of the study population.

3.2. ROC curves and AUROCs to predict transfusion and 24-hours mortality

Table 2 shows the optimal cut-off values of preSI and preMSI to predict transfusion within 4 h and 24 h and MT. The preSI and preMSI cut-off values of for prediction of MT were 0.91 (sensitivity, 0.65; specificity, 0.77), and 1.28 (sensitivity, 0.60; specificity, 0.82), respectively. The AUROCs for predicting MT with preSI and preMSI were 0.773 (95% CI, 0.746–0.798) and 0.765 (95% CI, 0.738–0.791), respectively. There were no differences between the AUROCs of both indices (Fig. 1). Table 2 also shows the optimal cut-off values of preSI and preMSI to predict 24-hour mortality, which were 1.28 (sensitivity, 0.27; specificity, 0.93) and 1.70 (sensitivity, 0.26; specificity, 0.93), respectively. The AUROCs for predicting 24-hour mortality with preSI and preMSI were 0.584 (95% CI, 0.553–0.615) and 0.581 (95% CI, 0.550–0.612), respectively. There were no differences between the AUROCs of both indices (Fig. 2).

4. Discussion

In this study, we investigated the accuracy of preSI and preMSI in predicting MT in trauma patients. The accuracy of preSI and preMSI in predicting MT was better than that for predicting the 4 h and 24 h transfusion requirements. In predicting MT, both indices showed moderate accuracy. In contrast with the hypothesis, preMSI did not have higher predictive power than preSI. Regarding the mortality rate, preSI and preMSI showed low accuracy, and there was no significant difference between them.

Immediate awareness of patients at risk of hemorrhagic shock in the pre-hospital phase is essential to optimize patients' clinical outcome [6]. If a patient experiencing a massive bleeding event is transferred to a hospital without sufficient trauma care resources, the patient will likely

Table 1
Characteristics and pre-hospital vital signs of included patients

Variable	Total ($n = 1007$)	MT ($n = 78$)	Non-MT ($n = 929$)	*p*-Value
Age (y), median (range)	53.0 (37.0–63.0)	55.5 (40.0–64.3)	53.0 (37.0–63.0)	0.389
Male, n (%)	792 (78.6)	63 (80.8)	729 (78.5)	0.774
Injury mechanism, n (%)				0.042
Driver and passenger collision	206 (20.5)	19 (24.4)	187 (20.1)	
Motorcycle collision	200 (19.9)	10 (12.8)	190 (20.5)	
Pedestrian collision	23 (2.3)	0 (0.0)	23 (2.5)	
Blunt trauma by object	184 (18.3)	20 (18.3)	164 (17.7)	
Ground level fall	12 (1.2)	3 (3.8)	9 (1.0)	
Fall from height	307 (30.5)	19 (24.4)	288 (31.0)	
Penetrating	75 (7.4)	7 (9.0)	68 (7.3)	
Prehospital vital signs, median (range)				
Systolic blood pressure	120 (100–140)	90 (70–110)	120 (100–140)	<0.001
Diastolic blood pressure	80 (60–90)	60 (40–70)	80 (60–90)	<0.001
Mean arterial pressure	90 (73.3–103.3)	66.6 (50.0–83.3)	93.3 (73.3–106.6)	<0.001
Heart rate	88 (77–103)	93.5 (80–112)	85 (75–98)	<0.001
Shock index	0.73 (0.60–0.92)	1.07 (0.8–1.5)	0.71 (0.59–0.90)	<0.001
Modified shock index	0.94 (0.79–1.21)	1.37 (1.02–1.95)	0.95 (0.78–1.18)	<0.001
Prehospital consciousness, n (%)				<0.001
Alert	791 (78.6)	50 (64.1)	741 (79.8)	
Verbal	55 (5.5)	5 (6.4)	50 (5.4)	
Pain	81 (8.0)	8 (10.3)	73 (7.9)	
Unresponse	80 (7.9)	15 (19.2)	65 (7.0)	
Injury severity score	17.0 (9.0–26.0)	29.0 (24.8–38.0)	16.0 (9.0–24.0)	<0.001
Emergency department outcomes, n (%)				
Surgery or embolization	313 (31.1)	71 (91.0)	242 (26.1)	<0.001
Disposition				<0.001
Intensive care unit admission	679 (67.4)	77 (98.7)	602 (64.8)	
General ward admission	230 (22.8)	1 (1.3)	229 (24.7)	
Transfer to other facilities	91 (9.0)	0 (0.0)	91 (9.8)	
Death	7 (0.7)	0 (0.0)	7 (0.7)	
Transfusion within 4 h	304 (30.2)	77 (98.7)	227 (24.4)	<0.001
Transfusion within 24 h	377 (37.4)	78 (100.0)	299 (32.2)	<0.001
24-hour mortality, n (%)	30 (3.0)	19 (24.4)	11(1.2)	<0.001

MT, massive transfusion.

miss the most important point, the so-called 'golden hour' [19]. However, it is challenging to accurately triage severely injured patients in the pre-hospital phase. There were several studies on this topic; in 2011, Guyette et al. conducted a study of trauma patients who were transferred to a level 1 trauma center and found that pre-hospital lactate was independently associated with mortality [20]. In 2016, Peltan et al. introduced the final Prediction of Acute Coagulopathy of Trauma (PACT) score by incorporating age, pre-hospital cardiopulmonary resuscitation, pre-hospital Glasgow Coma Scale, SI, injury mechanism, intubation parameter; and reported an AUROC for acute traumatic coagulation prediction of 0.8 [21]. However, there are many settings where blood tests cannot be conducted at the pre-hospital stage. It is also practically difficult to accurately measure the score in the urgent pre-hospital phase. However, SI and MSI are simple and quick to calculate, so they are well-suited for use in the pre-hospital stage.

Previous studies have evaluated the utility of preSI in trauma patients [6,10,12,13,22]. These studies found that preSI was a useful predictor for MT, hospital resource use, mortality, and major hemorrhage. Pocheter et al. evaluated the predictive power of preSI for MT in 2557 patients with major trauma, and reported AUROC of 0.802 (95% CI,

Table 2
Predictive power of the preSI and preMSI for transfusion and hospital mortality

	cut off	Sensitivity	Specificity	LR (+)	LR (−)	AUROCs (95% CI)
4 h transfusion						
SI	0.91	0.48	0.83	2.9	0.6	0.688 (0.659–0.717)
MSI	0.99	0.69	0.62	1.8	0.5	0.681 (0.651–0.710)
24 h transfusion						
SI	0.91	0.42	0.84	2.6	0.7	0.658 (0.628–0.688)
MSI	0.98	0.64	0.62	1.7	0.6	0.652 (0.622–0.682)
MT						
SI	0.91	0.65	0.77	2.9	0.5	0.773 (0.746–0.798)
MSI	1.28	0.60	0.82	3.3	0.5	0.765 (0.738–0.791)
24 h mortality						
SI	1.28	0.27	0.93	4.0	0.8	0.584 (0.553–0.615)
MSI	1.70	0.26	0.93	3.8	0.8	0.581 (0.550–0.612)

preSI, prehospital shock index; preMSI, prehospital modified shock index; LR, likelihood ratio; AUROCs, area under the receiver operating characteristic curve; CI, confidence interval; SI, shock index; MSI, modified shock index; MT, massive transfusion.

0.74–0.87) [13]. This is slightly higher than the result of our study (0.773 [95% CI, 0.746–0.798]). This difference is presumed to be due to differences in injury severity among the patients between the studies. In the study by the Pocheter and colleagues, patients had an ISS of 14 (IQR, 8–25) and MT of 2.2%, while the patients included in our study had an ISS of 17 (IQR, 9–26) and MT of 7.7%.

To the best of our knowledge, there have been no studies that evaluated the utility of preMSI in trauma patients, and ours is the first study to evaluate the value of preMSI in such patients. MSI has shown better results than SI in trauma patients at the hospital level [14,15]. We therefore hypothesized that preMSI would have better predictive power than preSI. However, preMSI did not have higher predictive power for MT and hospital mortality than preSI. While the reason is not clear, one

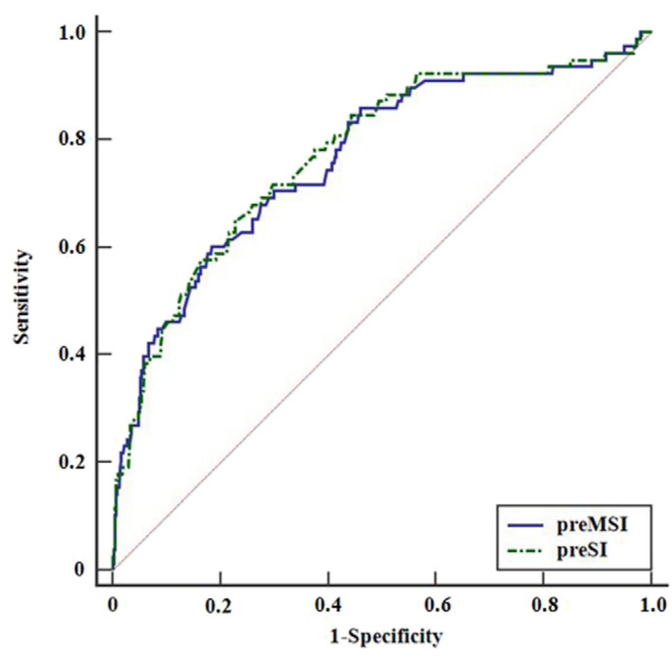

Fig. 1. Receiver operating curve of preSI and preMSI to predict massive transfusion. preSI, prehospital shock index; preMSI, prehospital modified shock index.

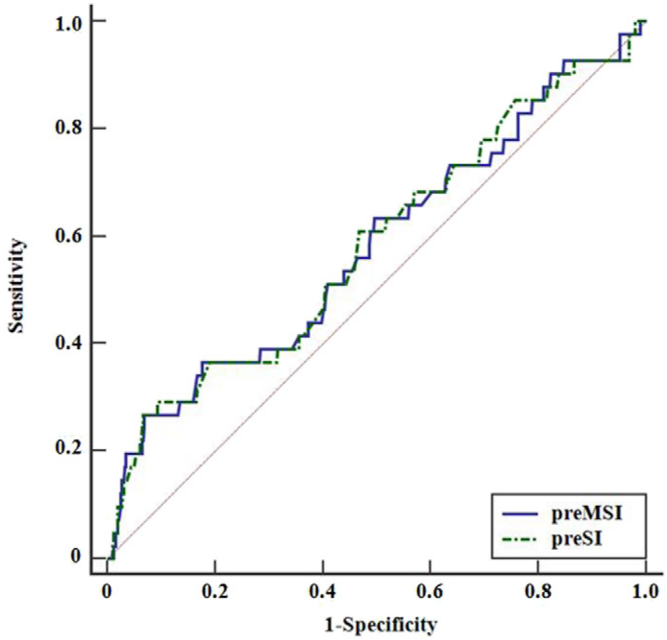

Fig. 2. Receiver operating curve of preSI and preMSI to predict 24-hour mortality. preSI, prehospital shock index; preMSI, pre-hospital modified shock index.

possible reason was that DBP in severe hypovolemic patients at the prehospital stage may have been too low to measure accurately, and the patients without DBP records were excluded from our study. Other possible reason is that patients with traumatic brain injury were not excluded. These patients have high ISS but relatively narrow alterations in vital signs compared to hemorrhagic patients. In addition, traumatic brain injury showed a bimodal relationship between SI and mortality [23]. The relationship between prognosis and DBP in patients with traumatic brain injury has not been clearly established.

Our study had several limitations. First, this study was an observational study; therefore a potential bias can exist as a result of missing data. Second, because it was a single center study, these results may be difficult to generalize in clinical practice. Third, clear indications for transfusion, emergency surgery, and angioembolization were not established during the study period; treatment was administered per the clinical judgment of the attending physicians. Lastly, we did not calculate the Assessment of Blood Consumption (ABC), or Trauma Associated Severe Hemorrhage (TASH) scores which have been studied to predict MT [24,25].

In conclusion, these results show that preMSI was not superior to preSI in predicting MT and hospital mortality. Considering these results, preSI may be more useful because it can be more easily calculated than preMSI. However, this study had certain limitations, and additional multicenter prospective studies are needed.

Funding

The authors have no funding to declare.

References

[1] Sauaia A, Moore FA, Moore EE, Moser KS, Brennan R, Read RA, et al. Epidemiology of trauma deaths: a reassessment. J Trauma Acute Care Surg 1995;38:185–93.
[2] Murray CJ, Lopez AD. Alternative projections of mortality and disability by cause 1990–2020: global burden of disease study. Lancet 1997;349:1498–504.
[3] Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. J Trauma Acute Care Surg 2006;60:S3–11.
[4] Tisherman SA, Schmicker RH, Brasel KJ, Bulger EM, Kerby JD, Minei JP, et al. Detailed description of all deaths in both the shock and traumatic brain injury hypertonic saline trials of the resuscitation outcomes consortium. Ann Surg 2015;261:586.
[5] Hwang K, Kwon J, Cho J, Heo Y, Lee JC-J, Jung K. Implementation of trauma center and massive transfusion protocol improves outcomes for major trauma patients: a study at a single institution in Korea. World J Surg 2017:1–9.
[6] Vandromme MJ, Griffin RL, Kerby JD, McGwin Jr G, Rue III LW, Weinberg JA. Identifying risk for massive transfusion in the relatively normotensive patient: utility of the prehospital shock index. J Trauma Acute Care Surg 2011;70:384–90.
[7] Patton K, Funk DL, McErlean M, Bartfield JM. Accuracy of estimation of external blood loss by EMS personnel. J Trauma Acute Care Surg 2001;50:914–6.
[8] Pacagnella RC, Souza JP, Durocher J, Perel P, Blum J, Winikoff B, et al. A systematic review of the relationship between blood loss and clinical signs. PLoS One 2013;8:e57594.
[9] Olaussen A, Blackburn T, Mitra B, Fitzgerald M. Shock index for prediction of critical bleeding post-trauma: a systematic review. Emerg Med Australas 2014;26:223–8.
[10] McNab A, Burns B, Bhullar I, Chesire D, Kerwin A. A prehospital shock index for trauma correlates with measures of hospital resource use and mortality. Surgery 2012;152:473–6.
[11] Mitra B, Fitzgerald M, Chan J. The utility of a shock index ≥ 1 as an indication for prehospital oxygen carrier administration in major trauma. Injury 2014;45:61–5.
[12] Olaussen A, Peterson EL, Mitra B, O'Reilly G, Jennings PA, Fitzgerald M. Massive transfusion prediction with inclusion of the pre-hospital shock index. Injury 2015;46:822–6.
[13] Pottecher J, Ageron F-X, Fauché C, Chemla D, Noll E, Duranteau J, et al. Prehospital shock index and pulse pressure/heart rate ratio to predict massive transfusion after severe trauma: retrospective analysis of a large regional trauma database. J Trauma Acute Care Surg 2016;81:713–22.
[14] Y-c Liu, Liu J-h, Fang ZA, G-l Shan, Xu J, Qi Z-w, et al. Modified shock index and mortality rate of emergency patients. World J Emerg Med 2012;3:114.
[15] Singh A, Ali S, Agarwal A, Srivastava RN. Correlation of shock index and modified shock index with the outcome of adult trauma patients: a prospective study of 9860 patients. N Am J Med Sci 2014;6:450.
[16] Jung K, Huh Y, Lee JC-J, Kim Y, Moon J, Youn SH, et al. The applicability of trauma and injury severity score for a blunt trauma population in Korea and a proposal of new models using score predictors. Yonsei Med J 2016;57:728–34.
[17] Malone DL, Hess JR, Fingerhut A. Massive transfusion practices around the globe and a suggestion for a common massive transfusion protocol. J Trauma Acute Care Surg 2006;60:S91–6.
[18] Akobeng AK. Understanding diagnostic tests 3: receiver operating characteristic curves. Acta Paediatr 2007;96:644–7.
[19] Kotwal RS, Howard JT, Orman JA, Tarpey BW, Bailey JA, Champion HR, et al. The effect of a golden hour policy on the morbidity and mortality of combat casualties. JAMA Surg 2016;151:15–24.
[20] Guyette F, Suffoletto B, Castillo J-L, Quintero J, Callaway C, Puyana JC. Prehospital serum lactate as a predictor of outcomes in trauma patients: a retrospective observational study. J Trauma 2011;70:782–6.
[21] Peltan ID, Rowhani-Rahbar A, Vusse LKV, Caldwell E, Rea TD, Maier RV, et al. Development and validation of a prehospital prediction model for acute traumatic coagulopathy. Crit Care 2016;20:371.
[22] Chen L, Reisner AT, Gribok A, Reifman J. Exploration of prehospital vital sign trends for the prediction of trauma outcomes. Prehosp Emerg Care 2009;13:286–94.
[23] Odom SR, Howell MD, Gupta A, Silva G, Cook CH, Talmor D. Extremes of shock index predicts death in trauma patients. J Emerg Trauma Shock 2016;9:103.
[24] Motameni AT, Hodge RA, McKinley WI, Georgel JM, Strollo BP, Benns MV, et al. The use of ABC score in activation of massive transfusion: the yin and the yang. J Trauma Acute Care Surg 2018;85:298–302.
[25] Cantle PM, Cotton BA. Prediction of massive transfusion in trauma. Crit Care Clin 2017;33:71–84.