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Predictive performance of prehospital trauma triage tools for resuscitative interventions within 24 hours in high-risk or life-threatening prehospital trauma patients

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Abstract

Introduction Several prehospital trauma triage tools have been recently developed, but no standardized tools currently exist to identify trauma patients at risk of requiring resuscitative interventions (RIs) within the first 24 h post-injury and to prioritize their transport to high-level trauma facilities.

Methods This prognostic study employed a retrospective cohort design to evaluate the predictive performance of the Triage Revised Score (T-RTS), Glasgow Coma Scale, Age, and Systolic Blood Pressure Score (GAP), Mechanism, Glasgow Coma Scale, Age, and Systolic Blood Pressure Score (MGAP), National Early Warning Score 2 (NEWS-2), Shock Index (SI), and Reverse Shock Index multiplied by Glasgow Coma Scale (rSIG) in predicting the need for RIs within 24 h. Data was retrieved from the electronic medical records of Ramathibodi Hospital, and the study included patients aged ≥ 15 years who were categorized as high-risk or life-threatening and subsequently transported to the emergency department. We used Area Under the Receiver Operating Characteristic (AUROC) curve and calibration plots to assess the performance of prehospital trauma triage tools.

Results There were 440 traumatic injury patients enrolled in the study, with 44 (10%) receiving RIs. T-RTS, GAP, MGAP, and NEWS-2 demonstrate good discriminative and predictive performance for RIs within 24 h after an injury (AUROC of 0.969, 0.949, 0.971, and 0.929, respectively, with the O:E ratio of 1). With the predefined standard cut-off values, the GAP score of less than 19 results in the highest accuracy for ruling out patients who do not need RIs (Specificity = 94.4% and NPV = 94.1%, *p*-value < 0.001).

Conclusions Several commonly used prehospital trauma triage tools demonstrate good predictive abilities for identifying the need for RIs. Among these, the GAP score with a threshold value of 19 serves as an optimal tool for identifying patients who require transfer to high-level trauma facilities.

Keywords Traumatic injury, Trauma triage tool, Triage, Resuscitation, Intervention

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Introduction

Traumatic injuries are among the leading causes of morbidity and mortality worldwide. Global death rates have remained steady at approximately 8% of all deaths over the past few decades. From 1990 to 2019, road traffic injuries were the leading cause of injury-related deaths, followed by interpersonal violence and self-inflicted injuries [1]. Road traffic injuries alone contribute significantly to fatalities and disabilities, with an estimated 1.2 million deaths globally [2]. Thailand has one of the highest road traffic injuries mortality rates, estimated at 25.68 deaths per 100,000 population.

In a prehospital emergency medical services (EMS) setting, on-scene triage is critical in optimizing medical care and guiding transport decisions. However, making accurate decisions is challenging due to limited diagnostic information and the complexity of dynamic trauma pathologies [3]. Prehospital providers must make timely decisions under high pressure and in stressful situations, which can lead to either under or overtriage [4]. Prehospital trauma triage tools rely on clinical information, such as the mechanism of injury and physiological parameters obtained at the scene to quickly identify severely injured patients and determine the appropriate level of care [5].

In recent decades, numerous studies have focused on prehospital trauma triage tools. The Abbreviated Injury Scale, introduced in 1971, was the first scoring system based on anatomical injury. Since then, additional scoring systems have been developed and validated, including the Revised Trauma Score (RTS)/Triage-Revised Trauma Score (T-RTS), Trauma Score-Injury Severity Score (TRISS), Glasgow Coma Scale, Age, and Systolic Blood Pressure (GAP), Mechanism, Glasgow Coma Scale, Age, and Systolic Arterial Pressure (MGAP), National Early Warning Score 2 (NEWS-2), Shock Index (SI), and Reverse Shock Index multiplied by Glasgow Coma Scale (rSIG) [5, 6].

The most current prehospital trauma triage tools aim to identify and predict patients at high mortality risk or clinical deterioration [7]. Studies in southern Iran and Taiwan have shown that the TRISS has the highest predictive accuracy for mortality compared to the RTS, rSIG, SI, and NEWS-2 [8, 9]. In some studies, the MGAP score has shown the highest predictive accuracy when compared with other tools [10, 11]. Previous studies, including a systematic review, indicate that elevated NEWS in prehospital patients is associated with a higher risk of 48-h mortality following hospital admission [12, 13]. NEWS has also shown superior predictive accuracy compared to the SI and the rSIG in assessing severity in the emergency department (ED), particularly for initiating massive transfusion protocols and determining intensive care unit (ICU) admission requirements [14].

In Thailand, trauma centers are designated according to guidelines from the World Health Organization and the American College of Surgeons Committee on Trauma. Severely injured patients should ideally be transported to high-level trauma centers (levels I and II), equipped to deliver resuscitative interventions (RIs) and comprehensive resources to improve patient outcomes [3, 15]. Decisions regarding the transport of trauma patients rely on prehospital trauma triage tools that help predict the need for specialized interventions at trauma centers.

Despite the development of several trauma triage tools aimed at improving triage accuracy through standardized criteria, no definitive evidence currently exists to identify the optimal tool for determining which patients require RIs [4]. Thus, further research is needed to evaluate the effectiveness of prehospital trauma triage tools in predicting the likelihood of a patient requiring RIs upon arrival at the ED. Such research could enhance resource allocation for trauma patients [16]. The objective of this study was to compare the prognostic performance of prehospital trauma triage tools in predicting the need for RIs within 24 h post-injury among high-risk or life-threatening prehospital patients.

Methods

Study design and setting

This study employed a prognostic test accuracy approach with a retrospective cohort design to assess the predictive ability of existing trauma triage tools in determining the likelihood of RIs within 24 h post-injury among prehospital trauma patients. Conducted in the ED of Ramathibodi Hospital, Faculty of Medicine, Mahidol University—a super-tertiary, university-affiliated hospital in Bangkok, Thailand. The ED manages approximately 6,000 trauma cases annually, with around 700 triaged as emergency severity index (ESI) levels 1 and 2. Of these cases, 20% involve patients transported by the EMS system.

The EMS system in the ED of Ramathibodi Hospital operates a tiered response model, with ambulance services divided into a Paramedic-Led Team (PLT) and a Doctor-Led Team (DLT). The PLT, led by paramedics, provides both Basic Life Support (BLS) and Advanced Life Support (ALS) services. In contrast, the DLT, led by emergency physicians (EP), offers Comprehensive Life Support (CLS) services for critical cases.

Patient triage begins with a criteria-based dispatch system that assesses incoming reports to classify trauma cases. Patients flagged as life-threatening or high-risk receive on-scene care within 10 min of the initial call. CLS services manage more severe cases requiring advanced interventions, such as endotracheal intubation, rapid sequence intubation, cricothyroidotomy, needle thoracostomy, high-alert drug administration, and advanced cardiopulmonary resuscitation for cardiac arrest patients. There is currently no standardized triage tool for on-scene triage used nationwide. Patients with life-threatening or high-risk injuries are transported to the nearest high-level trauma center.

Data on prehospital trauma care is recorded in a trauma record form. The completeness of each record form is periodically reviewed during the shift, ensuring accuracy and thorough documentation. Subsequently, the data is entered into the hospital's electronic medical record (EMR) system.

Participants

Data for this study was obtained from a review of the EMR system at Ramathibodi Hospital. Retrospective data were collected on prehospital traumatic injury patients treated by the EMS system and transported to the ED of Ramathibodi Hospital between January 2020 and April 2024. All adult trauma patients, defined as those aged 15 years and older, categorized as life-threatening or high-risk during prehospital triage, were included. Patients with prehospital traumatic cardiac arrests and pregnant patients were excluded.

Data gathering and outcome measures

The study variables on baseline characteristics, including sex, age, body mass index (BMI), comorbidities, and patient disposition status, were electronically retrieved from the health informatics database. Additional data, including estimated time of injury, mechanism of injury, EMS level of care, prehospital interval time, and initial prehospital assessments e.g., respiratory rate (RR), oxygen saturation, pulse rate (PR), blood pressure (BP), body temperature (BT), and Glasgow Coma Scale (GCS) score, along with details of prehospital and RIs, were reviewed and obtained from the EMR system.

The selected trauma triage tools T-RTS, GAP, MGAP, NEWS-2, SI, and rSIG were retrospectively calculated based on the first recorded vital signs at the scene by EMS personnel. The outcome measurement was the performance of any resuscitative intervention within 24 h following the injury. Key RIs included chest decompression, administration of blood products, emergency surgery, and advanced resuscitation techniques performed in the hospital [17].

A standardized data collection sheet, along with comprehensive guidance, was utilized for acquiring the data. The principal investigator held regular meetings with the data collectors to identify and address any issues encountered during this process to ensure the validity of the collected data.

Definitions

Prehospital trauma triage tools

- The Triage Revised Trauma Score (T-RTS) utilizes three specific physiological parameters: RR, systolic blood pressure (SBP), and GCS score. Each parameter is divided into five intervals, with values assigned from 0 to 4 to indicate the severity level within each interval (supplementary file 1). For triage purposes, the values of these RTS parameters are summed, resulting in a total score ranging from 0 to 12. Patients with a total score of 11 or less should be triaged for transfer to a trauma center [18].
- The Glasgow Coma Scale, Age, and Systolic Blood Pressure (GAP) score includes three independent factors: GCS score, age, and systolic arterial pressure (supplementary file 1). The GAP score is calculated by assigning points to each variable, enabling classification into three risk groups: low risk (23–29 points), intermediate risk (18–22 points), and high risk (< 18 points) [11].
- The Mechanism of Injury, Glasgow Coma Scale, Age, and Systolic Blood Pressure (MGAP) score includes four independent factors: mechanism of injury, GCS score, age, and systolic arterial pressure (supplementary file 1). According to the study by Sartorius D. et al., points are assigned to each variable to calculate the MGAP score, allowing classification into three risk groups: low risk (23–29 points), intermediate risk (18–22 points), and high risk (< 18 points). These groups are associated with respective mortality rates of 2.8%, 15%, and 48%, helping to inform the severity of injury and guide critical care decisions [10].
- The National Early Warning Score 2 (NEWS-2) comprises six physiological parameters: RR, oxygen saturation, SBP, PR, level of consciousness, and BT, all of which are routinely measured in clinical settings. Each parameter is scored based on its deviation from normal values (supplementary file 1), and the scores are summed to obtain the total NEWS-2 score. For patients requiring supplemental oxygen to maintain their target oxygen saturation, an additional 2 points are added to the aggregate score, enhancing the score's sensitivity in identifying patients at risk of clinical deterioration [14, 19].
- Shock Index (SI) is calculated by dividing the heart rate (HR) by the SBP. A normal SI is less than 0.7. An elevation above this threshold indicates cardiovascular instability and may suggest the presence of shock [20].
- The Reverse Shock Index multiplied by Glasgow Coma Scale (rSIG) is calculated by reversing the SI (dividing the SBP by HR) and then multiplying it

by the GCS score. This tool has demonstrated high discriminative ability for assessing mortality risk in trauma patients [21].

The key resuscitative interventions [17]

- Chest decompression including needle thoracostomy and chest tube insertion.
- Blood products administration including packed red blood cells, massive transfusion protocol.
- Emergency surgery including hemorrhage-controlling, limb-conserving, and neurological intervention.
- Advanced resuscitation techniques including pericardiocentesis, Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA), resuscitative thoracotomy.
- Aggressive fluid resuscitation is defined as the administration of more than 1 L of fluid during the prehospital phase.

Statistical analysis

Sample size estimation

The sample size for this study was calculated from previously reported data by Martín-Rodríguez F et al., which aims to assess the performance of prehospital triage tools, including NEWS2, SI, GAP, and RTS, in predicting mortality within 48 h following prehospital care. The study revealed that among traumatic injury patients, the GAP score exhibited the highest predictive capacity for early mortality, with an area under receiver operating characteristic curves (AUROC) of 0.975, followed by NEWS-2 with an (AUROC) of 0.834. RTS and SI had lower predictive capacities, with AUC of 0.957 and 0.481, respectively [22].

For each trauma triage tool, the (AUROC) (which is equivalent to the Concordance (C) statistic), the outcome proportion of 0.1, and the standard error (SE) of 0.0255 were used to calculate the sample size according to the formula proposed by Newcombe RG [23]. Using the STATA command provided by Riley RD et al., the required sample size for this study was calculated to be 142 patients who underwent RIs [24].

Statistical analysis

Statistical analyses were performed with STATA software version 16.0 (StataCorp, College Station, TX, USA). The exact probability test was used to compare independent categorical variables. Student's t-test was used for parametric variables to compare two independent numerical variables, while the Wilcoxon rank-sum test was used for non-parametric variables.

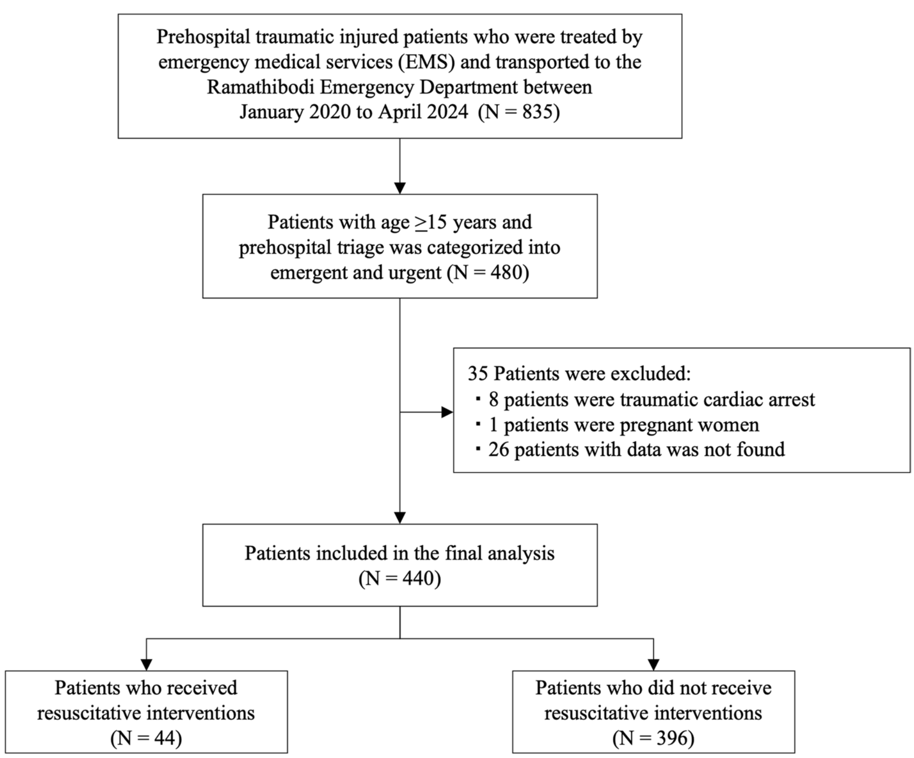

Fig. 1 Flow diagram of included and excluded patients in the study

The AUROC with their 95% confidence intervals (CIs) were used to determine the discriminative performance of prehospital trauma triage tools. DeLong's test was then used to compare the calculated AUROC to each other. Calibration plots were used to determine the predictive ability of study variables. Sensitivity, specificity, predictive values, and likelihood ratios of predefined standard cut-off values were calculated to assess the prognostic accuracy. All results were considered statistically significant at a P-value of <0.05. A complete case analysis approach was used for all study variables without data imputation.

Results

During the study period from January 2020 to April 2024, a total of 835 prehospital traumatic injury patients were treated by the EMS system and transported to the ED of Ramathibodi Hospital. Out of these, 440 patients were eligible for inclusion in the study (Fig. 1).

Table 1 Baseline characteristics of the study participants according to the receiving of resuscitative intervention

Characteristics	Receiving RIs (*N* = 44)	Non-receiving RIs (*N* = 396)	*p*-value
Gender – Female	11 (25.0)	182 (46.0)	0.010
Age – years	50.4 ± 20.4	59.0 ± 24.0	0.022
Body mass index – Kg/m^2	22.9 ± 6.2	24.1 ± 5.3	0.475
Comorbidities	9 (28.1)	198 (63.7)	< 0.001
Prehospital level of care			
Basic life support	5 (11.6)	205 (63.9)	< 0.001
Advanced life support	38 (88.4)	116 (36.1)	
Prehospital time interval – minutes			
Response time	11 (7–17)	16 (9–26)	0.067
Scene time	15 (10–28)	18 (12–26)	0.382
Transportation time	7 (4–15)	10 (5–17)	0.198
Mechanism of injury			
Firearm penetrating injury	2 (4.8)	10 (2.8)	0.004
Motor vehicle / motorcycle crash	21 (50.0)	123 (34.0)	
Pedestrian injury	4 (9.5)	6 (1.7)	
Fall from height	5 (11.9)	95 (26.2)	
Physical assault	2 (4.8)	13 (3.6)	
Other blunt injury	8 (19.1)	115 (31.8)	
Blunt mechanisms	40 (95.2)	352 (97.2)	0.360
History of intoxication	3 (7.9)	33 (9.7)	1.000
Prehospital initial assessment			
Respiratory rate – bpm	22.6 ± 4.1	20.0 ± 3.6	< 0.001
Oxygen saturation—%	91.6 ± 8.9	96.5 ± 6.3	< 0.001
Pulse rate – bpm	103.0 ± 24.9	90.0 ± 17.5	< 0.001
Systolic blood pressure	125.1 ± 31.9	138.4 ± 28.1	0.011
Systolic blood pressure < 90 mmHg	6 (17.7)	5 (2.0)	0.001
Body temperature—°C	36.7 ± 0.6	36.7 ± 0.7	0.942
Glasgow Coma Scale score	10 (7–14)	15 (15–15)	< 0.001
Mild (13–15)	14 (37.8)	233 (92.8)	< 0.001
Moderate (9–12)	9 (24.3)	12 (4.8)	
Severe (3–8)	14 (37.8)	6 (2.4)	
Prehospital interventions			
Endotracheal intubation	1 (2.6)	1 (0.3)	< 0.001
Positive pressure ventilation	6 (15.0)	1 (0.3)	< 0.001
Aggressive fluid administration	13 (35.1)	8 (2.8)	< 0.001
Tranexamic acid administration	2 (5.3)	0 (0)	0.013
Pelvic immobilization	2 (5.3)	7 (2.4)	0.280

Abbreviations: *RIs* Resuscitative interventions, *Kg/m^2* Kilogram/meter^2, *bpm* Beats per minute

Baseline characteristics of the study participants

Among the 440 eligible patients, 44 (10%) received RIs within 24 h following their injuries. The analysis identified several statistically significant differences in demographics, mechanisms of injury, prehospital assessments, and prehospital interventions (Table 1).

Among patients who received RIs, the proportion of females was lower at 25%, and their average age was younger, with a mean age of 50.39 ± 20.43 years compared to those who did not receive the interventions. The mechanism of injury differed significantly between groups, with motor vehicle collisions being more frequent in the receiving RIs group (50% vs 33.98%, p-value = 0.004). Prehospital initial assessment revealed that patients in the receiving RIs group had more severe injuries, as reflected in lower oxygen saturation levels, higher pulse rates compensating for hypotension, and alterations in consciousness, resulting in more critical prehospital interventions, such as positive pressure ventilation and aggressive fluid administration.

Study variables and clinical outcomes of the study participants

Table 2 illustrates a comparison of study variables among participants based on their receipt of RIs. The distribution of RIs and clinical outcomes for the study participants who received RIs is shown in Table 3.

Across all the trauma triage tools, participants in the receiving RIs group demonstrated lower scores in T-RTS, GAP, MGAP, and rSIG but higher scores in NEWS-2 and SI. This finding indicates that patients with more severe trauma who needed RIs tended to have abnormal scores that differed from normal values.

Table 2 Comparison of study variables among participants based on their receipt of resuscitative intervention

Trauma Triage Tools		Values[a]		*p*-value
T-RTS	Receiving RIs	*N* = 33	11 (10–12)	< 0.001
	Non-receiving RIs	*N* = 234	12 (12–12)	
GAP	Receiving RIs	*N* = 33	17 (15–21)	< 0.001
	Non-receiving RIs	*N* = 239	21 (21–24)	
MGAP	Receiving RIs	*N* = 32	20.5 (17–24)	< 0.001
	Non-receiving RIs	*N* = 238	24 (24–29)	
NEWS-2	Receiving RIs	*N* = 6	10 (5–11)	0.003
	Non-receiving RIs	*N* = 109	1 (1–3)	
SI	Receiving RIs	*N* = 34	0.8 (0.6–1.0)	0.003
	Non-receiving RIs	*N* = 255	0.7 (0.6–0.8)	
rSIG	Receiving RIs	*N* = 33	12.4 (7.1–15.5)	< 0.001
	Non-receiving RIs	*N* = 238	22.1 (18.5–27.2)	

Abbreviations: *RIs* Resuscitative interventions, *T-RTS* Triage Revised Trauma Score; *GAP* Glasgow Coma Scale, Age and Systolic Blood Pressure, *MGAP* Mechanism of Injury, Glasgow Coma Scale, Age, and Systolic Blood Pressure, *NEWS-2* National Early Warning Score2, *SI* Shock Index, *rSIG* Reverse Shock Index multiplied by Glasgow Coma Scale Score

[a] Data present as median and interquartile range

Table 3 Distribution of resuscitative interventions and clinical outcomes for the study participants who received resuscitative interventions

Variables	Number of Cases (Total = 44)
Resuscitative interventions within 24 h following an injury – N (%)	
Chest decompression	15 (34.1)
Cardiopulmonary resuscitation	6 (13.6)
Emergency thoracotomy	1 (2.3)
Operative management	12 (34.1)
Blood products administration	22 (50.0)
Total unit of PRBCs in 1 h[a]	1 (1–3)
Total unit of PRBCs in 24 h[a]	1 (1–4)
Disposition status – N (%)	
ED mortality	3 (6.8)
ICU admission	23 (52.3)
In-hospital mortality	9 (20.5)

Abbreviations: PRBCs: packed red blood cell; ED: emergency department; ICU: intensive care unit

[a] Data presented as a median and interquartile range

Predictive performances of the study variables

To determine the discriminative ability of each selected trauma triage tool, the receiver operating characteristic (ROC) curve was drawn using the true positive rate (sensitivity) and the false positive rate (1—specificity) (Fig. 2). Therefore, the area under the ROC curve with a 95% confidence interval was calculated for each selected tool (Table 4).

Additionally, accuracy indices—including sensitivity, specificity, predictive values, and likelihood ratios of predefined standard cut-off values—were calculated to assess the prognostic accuracy of selected trauma triage tools. The analyses revealed that the GAP tool has relatively high specificity and negative predictive value (NPV), making it effective for ruling out patients who do not require RIs (Table 5). The GAP also demonstrates the highest positive predictive value (PPV), indicating that this tool could reduce overtriage and improve resource utilization at trauma facilities.

To compare the calculated AUROC values across all study variables within the same participant, DeLong's test was applied using the complete case analysis approach. A total of 114 remaining study participants were included in the final analysis. Differences between all study variables were statistically significant ($p < 0.001$), with the MGAP demonstrating the highest discriminative ability to predict the probability of requiring RIs (Table 6 and Fig. 3). Additionally, pairwise comparisons were

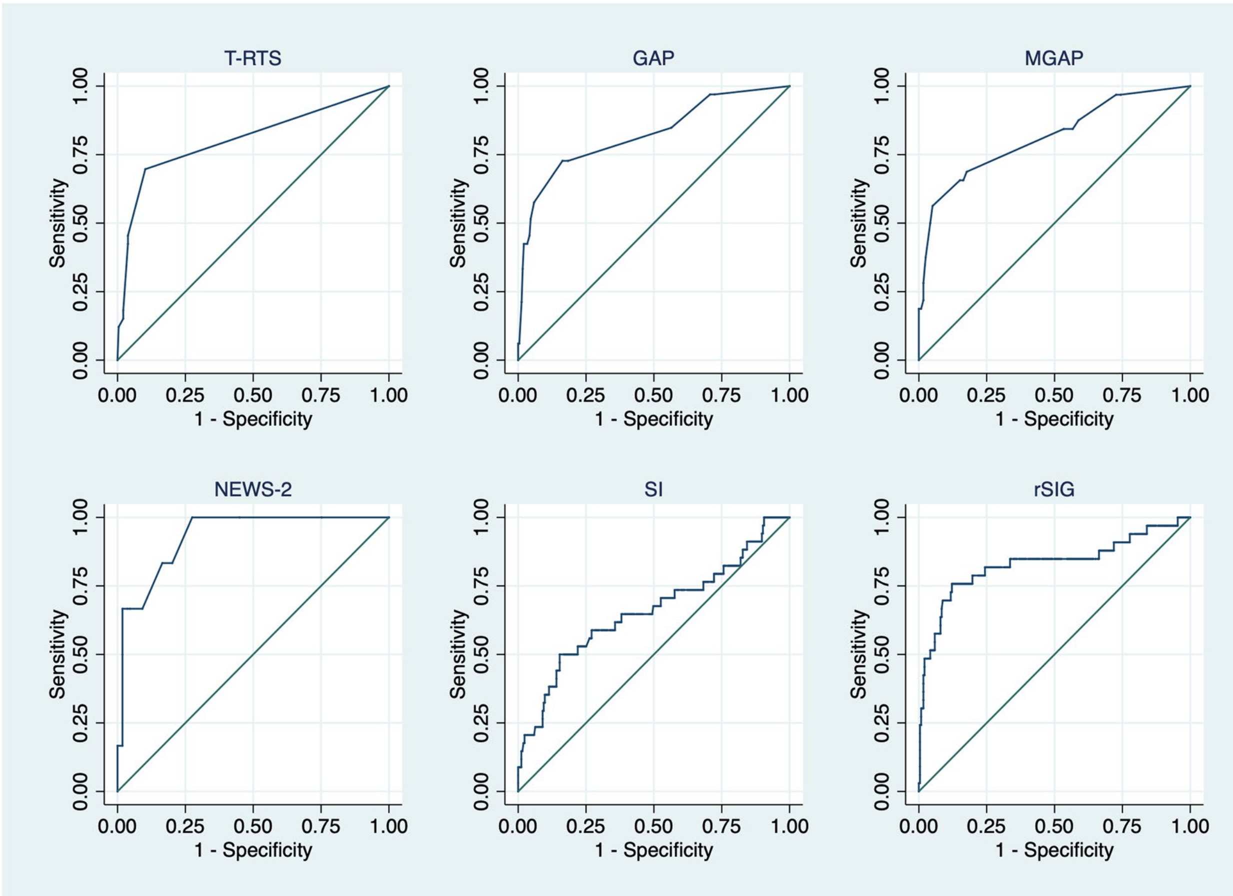

Fig. 2 Receiver operating characteristic (ROC) curve of selected trauma triage tools

conducted to assess differences in AUROC among the study variables (Table 7).

Calibration plots were used for selected trauma triage tools to assess their predictive ability for receiving RIs. The Observed-to-Expected (O/E) ratio represents the relationship between the observed events (actual outcomes) and the expected events (predicted outcomes) as determined by the prediction model. An O/E ratio of 1 indicates perfect calibration, meaning the model's predicted probabilities are well-aligned with actual outcomes. Figure 4 demonstrates that the T-RTS, GAP, MGAP, and NEWS-2 are well-calibrated, with an O/E ratio of 1. In contrast, the SI and rSIG, with an O/E ratio greater than 1, underestimate the actual risk of requiring RIs.

Table 4 Area under the receiver operating characteristic (AUROC) curve of selected trauma triage tools

Trauma Triage Tools		AUROC (95% Confidence Interval)
T-RTS	(*N* = 267)	0.806 (0.722 – 0.890)
GAP	(*N* = 272)	0.823 (0.736 – 0.910)
MGAP	(*N* = 270)	0.812 (0.723 – 0.902)
NEWS-2	(*N* = 115)	0.930 (0.849 – 1.000)
SI	(*N* = 289)	0.658 (0.544 – 0.771)
rSIG	(*N* = 271)	0.830 (0.733 – 0.927)

Abbreviations: *T-RTS* Triage Revised Trauma Score, *GAP* Glasgow Coma Scale, Age and Systolic Blood Pressure, *MGAP* Mechanism of Injury, Glasgow Coma Scale, Age, and Systolic Blood Pressure, *NEWS-2* National Early Warning Score2, *SI* Shock Index, *rSIG* Reverse Shock Index multiplied by Glasgow Coma Scale Score

Discussion

The study's results indicate that the SI demonstrated strong discriminative performance in predicting the need for RIs, with AUROC values exceeding 0.8. Additionally, SI showed a statistically significant difference when compared with T-RTS, GAP, MGAP, NEWS-2, and rSIG ($P < 0.001$). However, no significant differences were observed among the T-RTS, GAP, MGAP, NEWS-2, and rSIG when compared with each other. Calibration plots show that the T-RTS, GAP, MGAP, and NEWS-2 are well-calibrated, with an O/E ratio of 1.

This finding suggests that these scoring systems can predict the likelihood of requiring RIs in alignment with

Table 5 Prognostic accuracy indices of selected trauma triage tools with predefined standard cut-off values

Variables	T-RTS	GAP	MGAP	NEWS-2	SI	rSIG
	< 11	**< 19**	**< 23**	**> 4**	**> 0.8**	**< 19**
Sensitivity (95% CI)	69.7 (51.3—84.4)	57.6 (39.2—74.5)	65.6 (46.8—81.4)	83.3 (35.9—99.6)	50.0 (32.4—67.6)	78.8 (61.1—91.0)
Specificity (95% CI)	89.7 (85.1—93.3)	94.4 (90.4—96.8)	83.6 (78.3—88.1)	83.5 (75.2—89.9)	78.8 (73.3—83.7)	78.2 (72.4—83.2)
PPV (95% CI)	48.9 (34.1—63.9)	57.6 (39.2—74.5)	35.0 (23.1—48.4)	21.7 (7.5—43.7)	23.9 (14.6—35.5)	33.3 (23.1—44.9)
NPV (95% CI)	95.5 (91.8—97.8)	94.1 (90.4—96.8)	94.8 (90.8—97.4)	98.9 (94.1—100)	92.2 (87.8—95.4)	96.4 (92.7—98.5)
PLR (95% CI)	6.80 (4.37—10.56)	9.83 (5.47—17.67)	4.00 (2.74—5.86)	5.05 (2.90—8.78)	2.36 (1.57—3.56)	3.61 (2.68—4.86)
NLR (95% CI)	0.34 (0.20—0.57)	0.45 (0.30—0.67)	0.41 (0.25—0.67)	0.83 (0.67—1.00)	0.63 (0.45—0.89)	0.27 (0.14—0.53)
p-value	< 0.001	< 0.001	< 0.001	0.001	0.001	< 0.001

Abbreviations: *PPV* Positive predictive value, *NPV* Negative predictive value, *PLR* Positive likelihood ratio, *NLR* Negative likelihood ratio

Table 6 Comparison of area under the receiver operating characteristic (AUROC) curve of selected trauma triage tools

Trauma Triage Tools	AUROC (95% Confidence Interval)	*p*-value
T-RTS	0.969 (0.941 – 0.999)	< 0.001
GAP	0.949 (0.898 – 0.999)	
MGAP	0.971 (0.933 – 1.000)	
NEWS-2	0.929 (0.848 – 1.000)	
SI	0.671 (0.425 – 0.918)	
rSIG	0.951 (0.733 – 0.927)	

Abbreviation: *T-RTS* Triage Revised Trauma Score, *GAP* Glasgow Coma Scale, Age and Systolic Blood Pressure, *MGAP* Mechanism of Injury, Glasgow Coma Scale, Age, and Systolic Blood Pressure, *NEWS-2* National Early Warning Score2, *SI* Shock Index, *rSIG* Reverse Shock Index multiplied by Glasgow Coma Scale Score

actual outcomes. Predefined standard cut-off values were applied to determine the accuracy indices of these trauma triage tools to support clinical application. A GAP score with a threshold of 19 or more may serve as an effective tool for ruling out patients who do not require RIs, demonstrating high specificity and negative predictive values (94.4% and 94.1%, respectively). However, a GAP score below 19 has relatively poor sensitivity and positive predictive value (57.6% and 57.6%, respectively), which could increase the risk of overtriage, leading to overutilization of resources allocated to patients who require RIs.

A recent study by Uemura T. et al. found that the T-RTS and rSIG have good predictive accuracy for resuscitative procedures (AUC 0.746 and 0.777, respectively) and surgical procedures (AUC 0.700 and 0.731, respectively), whereas the SI has the lowest predictive ability among the tools for both resuscitative and surgical procedures (AUC 0.659 and 0.632, respectively) [25]. These findings closely align with our study, indicating that the SI may not be an effective predictor for RIs, defined as a composite of any resuscitative and surgical procedures, consistent with Uemura T. et al.'s findings. However, rSIG may be challenging to implement in prehospital settings due to its reliance on complex mathematical calculations involving division and multiplication of three clinical variables.

According to a previous study by Rahmani F. et al., which evaluated the performance of the GAP and MGAP scores in predicting the need for surgical intervention among multi-trauma patients, both trauma triage tools showed lower discriminative performance for predicting the need for surgical procedures (e.g., laparotomy and chest tube insertion), with AUC values of 0.740 for GAP and 0.750 for MGAP. In contrast, the GAP and MGAP scores in this study demonstrate excellent discriminative performance, with AUCs of 0.949 and 0.947, respectively. This discrepancy may be attributed to differences in cut-off values, which were set higher in Rahmani F.'s study (GAP < 21 and MGAP < 25).

The NEWS-2 is one of the selected trauma triage tools demonstrating excellent discriminative performance for predicting the need for RIs. This finding aligns with a previously published study by Medina-Lozano E. et al., which showed that the NEWS-2 score had good prognostic ability for predicting prehospital serious adverse events (e.g., performing life-saving interventions) among trauma patients at the scene or during transport, with an AUC of 0.956 (95% CI: 0.900–1.000) [3]. However, only 115 patients (26%) in this cohort had sufficient data to calculate the NEWS-2 score, leading to a wide confidence interval and reduced precision in AUROC interpretation.

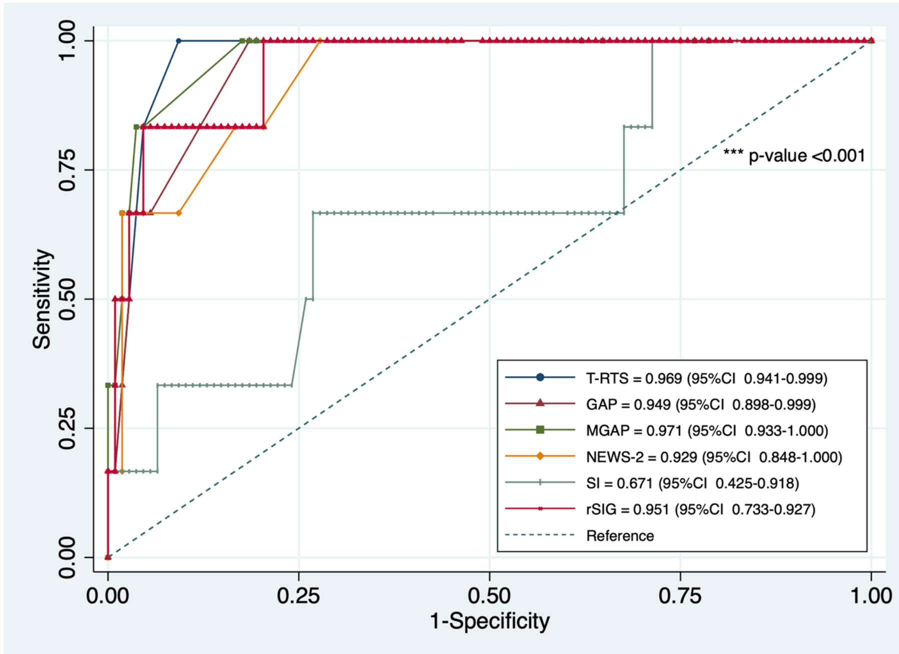

Fig. 3 Comparison of receiver operating characteristic (ROC) curve of selected trauma triage tools

Table 7 Pairwise comparisons of AUROC across the study variables

	T-RTS	GAP	MGAP	NEWS-2	SI	rSIG
T-RTS		d = 0.039 p = 0.286	d = 0.062 p = 0.127	d = 0.120 p = 0.159	d = 0.151 p = 0.009	d = 0.013 p = 0.728
GAP			d = 0.021 p = 0.518	d = 0.062 p = 0.127	d = 0.028 p = 0.855	d = 0.026 p = 0.595
MGAP				d = 0.074 p = 0.393	d = 0.092 p = 0.202	d = 0.051 p = 0.341
NEWS-2					d = 0.264 p = 0.021	d = 0.005 p = 0.828
SI						d = 0.139 p = 0.001

d Difference between AUROC, *p p*-value

The American College of Surgeons Committee on Trauma (ACS-COT) recommends that the undertriage rate should not exceed 5%, while the overtriage rate may range from 25 to 35%. When triaging severely injured patients to Level 1 trauma centers, it is essential to use a prognostic model with high sensitivity to ensure appropriate RIs and to avoid inadequate care associated with inappropriate care facilities [26]. However, in a setting where healthcare facilities may have insufficient resources (e.g., low- and middle-income countries), prognostic tools with high specificity may be useful to rule out patients who will not experience an interesting outcome [27]. This study revealed that the GAP score of less than 19 has relatively high specificity (94.4%) and negative predictive values (94.1%), indicating that it is an optimal tool for ruling out patients who do not require RIs, as well as reducing overtriage rate and prevent resource over-utilization of trauma facilities.

This study had several limitations. First, it did not include the complete prehospital cohort, as a substantial amount of data was excluded due to missing information. This resulted in an inadequate sample size, potentially reducing the statistical power and precision of the estimates. Second, the study variables were derived from prehospital recorded data, the accuracy of which may vary because it was not collected under controlled conditions specifically for this research. Third, as a retrospective study, it is prone to information bias. Fourth, only 20% of major trauma cases in ESI levels 1 and 2 involved patients transported by the EMS system, leading to a lack

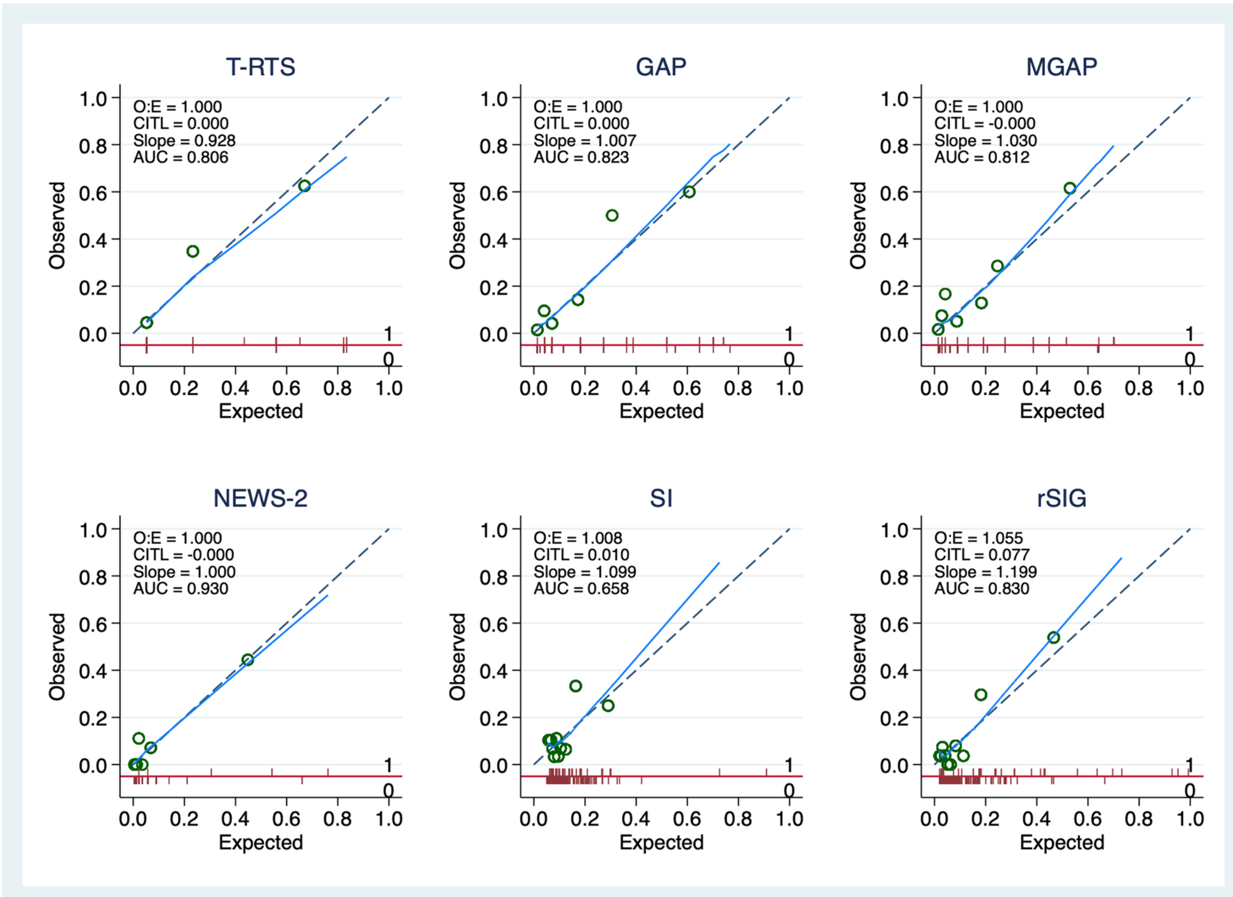

Fig. 4 Calibration plots of selected trauma triage tools

of data on the majority of injured patients who were not brought in by EMS. Finally, the findings may have limited generalizability to other areas in Thailand, as this was a single-center study conducted in a metropolitan setting, and the eligible cohort may not represent broader populations. To address these limitations, a multi-institutional prospective study should be conducted to validate the findings and improve their generalizability.

Conclusion

The results of this study suggest that among commonly used trauma triage tools, the T-RTS, the GAP score, MGAP score, as well as the NEWS-2, demonstrate good prognostic abilities in terms of accuracy, discrimination, and predictive performance for performing resuscitative interventions within 24 h of injury among prehospital trauma patients treated by the EMS system. Utilizing the GAP score with a threshold below 19 results in elevated specificity and negative predictive value, indicating that it may serve as an optimal tool for identifying patients necessitating transport to Level 1 trauma facilities.

Abbreviations

EMS	Emergency medical services
GAP	Glasgow coma scale, age, and systolic blood pressure
MGAP	Mechanism of injury, glasgow coma scale, age, and systolic blood pressure
NEWS	National early warning score
rSIG	Reverse shock index multiplied by glasgow coma scale
SI	Shock index
T-RTS	Triage revised trauma score
RI	Resuscitative Interventions
AUROC	Area under receiver operating characteristic curves

Supplementary Information

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Supplementary Material 1. Components of Selected Trauma Triage Tools. Table 1. Revised Trauma Score (RTS). Table 2. Glasgow Coma Scale, Age, and Systolic Blood Pressure (GAP) Score. Table 3. Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure (MGAP) Score. Table 4. National Early Warning Score 2 (NEWS-2).

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study fully complies with International Human Research Protection Guidelines such as the Declaration of Helsinki and the Belmont Report. This study was approved by the Faculty of Medicine, Committee on Human Rights Related to Research Involving Human Subjects, Ramathibodi Hospital, Mahidol University (COA. NO MURA2023/170). As the study is a retrospective observational study, the consent for participation was waived by the Institutional Review Boards.

Consent for publication
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Competing interests
The authors declare no competing interests.

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