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Prehospital shock index predicts 24-hour mortality in trauma patients with a normal shock index upon emergency department arrival

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ABSTRACT

Background: The shock index (heart rate divided by systolic blood pressure) of trauma patients upon emergency department arrival predicts blood loss and death. However, some patients with normal shock indices (0.4 < shock index < 0.9) upon emergency department arrival also have poor prognoses. This study aimed to determine whether abnormal prehospital shock indices in trauma patients with normal shock indices upon emergency department arrival were predictors of a high risk of mortality.

Methods: We conducted a retrospective cohort study of emergency department-admitted trauma patients from 2004 to 2017. The study included 89,495 consecutive trauma patients aged ≥ 16 years, with Abbreviated Injury Scale score of ≥ 3, who were transported to the emergency department directly from the field and had a normal shock index upon emergency department arrival. According to the prehospital shock index scores, the patients were categorized into low shock index (≤ 0.4), normal shock index, and high shock index (≥ 0.9) groups. Odds ratios and 95% confidence intervals were calculated using logistic regression analysis.

Results: The 89,495 patients had a median age of 64 (interquartile range: 43–79) years, and 55,484 (62.0%) of the patients were male. There were 1,350 (1.5%) 24-hour deaths in total; 176/4,263 (4.1%), 1,017/78,901 (1.3%), and 157/6,331 (2.5%) patients were in the low, normal, and high prehospital shock index groups, respectively. The adjusted odds ratios for 24-hour mortality compared with the normal shock index group were 1.63 (95% confidence interval: 1.34-1.99) in the low shock index group and 1.62 (95% confidence interval: 1.31–1.99) in the high shock index group.

Conclusion: Trauma patients with abnormal prehospital shock indices but normal shock indices upon emergency department arrival are at a higher risk of 24-hour mortality. Identifying these indices could improve triage and targeted care for patients.

BACKGROUND

Approximately 4.4 million people die from traumatic injuries each year[1] accounting for approximately 8% of all annual deaths worldwide. The main causes of trauma deaths include road accidents, suicides, homicides, and falls. There are nearly 70,000 yearly trauma-related deaths in Japan, accounting for about 5% of all deaths, [2] and their main causes are unintentional accidents and suicide. According to the Tokyo Fire and Disaster Management Agency, trauma accounts for 27% of emergency transportation cases. [3] Therefore, identifying trauma patients with a higher risk of mortality or patients who need immediate diagnosis and treatment in the emergency department (ED) is crucial. Vital signs are used to predict the severity of injury and prognosis of trauma patients.[4,5] The shock index (SI; heart rate divided by systolic blood pressure) [6] is a predictor of visible and hidden blood loss, a need for blood transfusion, injury severity, and mortality.[7] The SI is useful in patients without obvious vital sign abnormalities,[8,9] has a greater predictive ability than any vital sign, [5,10,11] and is easier to calculate than the other indices, such as the age shock index, [10,12] the reverse shock index, [13] or the Trauma and Injury Severity Score. [14] It is known that a high SI (e.g., ≥ 0.9) at prehospital or upon ED arrival is associated with increased mortality risk, [15-17] whereas a low SI (e.g., ≤ 0.4; high blood pressure and low heart rate) has been suggested as a predictor of a serious head injury, leading to an increased mortality risk.[18,19] However, a low SI cut-off value has rarely been considered in previous studies.

The middle SI range (0.4 < SI < 0.9) could be considered "normal" and may indicate a good prognosis. However, some patients may have a normal SI range upon ED arrival but have a poor prognosis. Vital sign changes over time due to physiological compensatory mechanisms could help detect patients at high risk of mortality.[20] The SI may also vary depending on when the vital signs are measured.[21] Sometimes, an abnormal SI measured immediately after an injury could become normal upon ED arrival. Therefore, prehospital SI might be useful to further stratify mortality risk among patients with normal SI upon ED arrival. However, the association between prehospital SI and prognosis in such patients has not been examined. Therefore, this study aimed to determine whether an abnormal prehospital SI (SI ≥ 0.9 or ≤ 0.4) was associated with a higher risk of 24-hour mortality than normal prehospital SI (0.4 < SI < 0.9) among trauma patients with normal SI upon ED arrival.

METHODS

Study design and participants

We performed a retrospective cohort study of ED-admitted trauma patients using anonymized data from the Japan Trauma Data Bank (JTDB). The JTDB was approved by the ethics committee of the National Defence Medical College. The ethics committee of Kyoto University approved our research (approval number: R2601). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement was used to ensure the proper reporting of methods, results, and discussion.

The eligibility criterion was as follows: trauma patients aged ≥16 years, transported to the ED directly from the field and had normal SI upon arrival. The exclusion criteria were as follows: burn injury,[4,22] prehospital cardiopulmonary arrest, prehospital fluid infusion, hypotension (systolic blood pressure < 90 mm Hg) [11,23] upon ED arrival, bradycardia (heart rate ≤ 40 bpm) [24] upon ED arrival, as well as missing data for the systolic blood pressure, heart rate, or outcome. We excluded patients with burns according to the methods of previous studies because their treatment differs from that for other causes of trauma. [4,22] Patients who presented with hypotension and bradycardia upon ED arrival were excluded because they usually needed prompt examination or intervention.

Setting and data sources

We used the JTDB registry data from 2004–2017.[25] The JTDB is a nationwide prospective registry of trauma cases in Japan, established by the Japanese Association for the Surgery of Trauma and the Japanese Association for Acute Medicine. A total of 264 emergency hospitals across Japan participate in the registry, comprising approximately 70% of the government-certified tertiary emergency and critical care centers.[26] This registry enrolled approximately 300,000 trauma patients who presented to an ED with an Abbreviated Injury Scale (AIS) score of ≥ 3 for any part of their body. Paramedics and medical staff measured the prehospital vital signs and those upon ED arrival, treatments, diagnoses, injury severity, and in-hospital mortality, and compiled to form the registry data.

Measurement

Exposure

The exposure was prehospital SI measured by the emergency medical services in the field. The SI was categorized into low (≤ 0.4), normal ($0.4 < SI < 0.9$), and high (≥ 0.9) SI groups. These categories were selected because the association between SI upon ED arrival and mortality has been reported to follow a U-shaped curve, with SIs of 0.4 and 0.9 being associated with approximately equal mortality rates with the lowest mortality rate found in between these values.[19]

Outcome

The primary outcome was mortality within 24 hours of ED arrival. The secondary outcomes were invasive hemostatic interventions (thoracoabdominal surgery, endoscopic surgery, surgical hemostasis, angiostomy, and transcatheter arterial embolisation), blood transfusion within 24 hours, head surgery, and in-hospital mortality.

Other factors to be adjusted

In the multivariable analyses, adjustment was performed using the factors below: the patients' sex, age, Glasgow Coma Scale (GCS) upon ED arrival, respiratory rate upon ED arrival, year of ED arrival, transportation time (time of departure from the field to ED arrival), type of injury (blunt, penetrating, unknown, and other injuries), cause of injury (unintentional accident, occupational accident, suicide attempt, assault by others, unknown, and other causes), and comorbidities (respiratory, cardiovascular, digestive, metabolic, central nervous system, mental, or immunodeficiency diseases and cancer). All the variables were recorded by paramedics and medical staff at each participating hospital.

Statistical analysis

Descriptive analysis

The eligible patient characteristics were summarized for the entire cohort and each SI group. The continuous variables were presented as the medians and interquartile ranges (IQRs), while the categorical variables were presented as numbers and percentages.

Primary analysis

We calculated the odds ratios (ORs) and 95% confidence intervals (CIs) for the 24-hour mortality of the prehospital low and high SI groups and compared them with those of the normal SI group using a logistic regression analysis after adjusting for the abovementioned factors. Model 1 included the covariates usually available at the time of patients' ED arrival: sex, age, GCS, respiratory rate, year of ED arrival, transportation time, and type of injury. The other factors, such as the cause of injury and comorbidities, were not necessarily available during ED arrival. These respective factors were added in Model 2 and Model 3.

Secondary analysis

We used logistic regression analyses to calculate the ORs for the secondary outcomes: invasive hemostatic interventions, blood transfusion within 24 hours, head surgery, and in-hospital mortality. The same independent variables used in the primary analysis were used to determine whether the prehospital SI could predict the secondary outcomes.

Subgroup analysis

We also performed the same analysis performed in the primary analysis for the following subgroups: patients with isolated serious head injuries (defined as a head AIS score ≥ 3 and AIS score < 3 in other body parts) and patients without serious head injuries (AIS score ≥ 3 in other body parts and a head AIS score < 3).

Sensitivity analysis

We performed three sensitivity analyses. Firstly, we changed the normal SI definition to 0.4 < SI < 1.0 and 0.5 < SI < 0.7. No definite criterion exists for a normal SI range; however, an SI "below 1.0" or "0.5 to 0.7" has also been considered to be a normal range in clinical settings and previous studies. [8,23,27] Secondly, we added the adjustment for SI upon ED arrival as a covariate into Model 1, 2 and 3 of the primary multivariable logistic regression analysis. This analysis was undertaken in consideration of the possibility that the level of SI upon ED arrival may be a stronger predictor than prehospital SI, despite the study population falling within the normal range of SI upon ED arrival. Thirdly, we performed a multiple imputation (MI) for the missing adjusted variables in the primary multivariable logistic regression analysis, based on the assumption that the data were missing at random. The MI procedure imputed the missing values using chained equations with factors of all the variables used in Model 1. We created 20 imputed datasets and performed a logistic regression analysis for each. The results were integrated using Rubin's rule.

All the analyses were conducted using STATA/MP, Version 15.1 (StataCorp, TX, USA). Except for the sensitivity analysis with MI, only the cases without any missing covariate values were included in the analyses (complete case analysis).

RESULTS

Patient characteristics

A total of 113,494 adult (age ≥ 16) trauma patients were transported directly to the ED from the field and had an SI within the normal range upon ED arrival (Figure 1). The eligibility criteria were met by 89,495 (78.9%) patients, of whom 55,484 (62.0%) were male. The median age was 64 (IQR: 43–79) years (Table 1). Blunt and penetrating injuries accounted for 96.7% and 1.9% of all trauma cases, respectively. In total, 87.4% of the patients had unintentional accidents, 5.6% had occupational accidents, and 3.0% attempted suicide. The proportions of the low, normal, and high SI groups were 4.8%, 88.2%, and 7.1%, respectively.

Primary analysis: Association between prehospital SI and 24-hour mortality

Overall, 1,350 (1.5%) 24-hour deaths occurred, including 176/4,263 (4.1%), 1,017/78,901 (1.3%), and 157/6,331 (2.5%) in the low, normal, and high SI groups, respectively (Figure 2A). Compared with the normal SI group, the unadjusted ORs for 24-hour mortality in the low and high SI groups were 3.30 (95% CI: 2.80–3.88) and 1.95 (95% CI: 1.64–2.31), respectively. The corresponding adjusted ORs for 24-hour mortality were 1.63 (95% CI: 1.34–1.99) and 1.62 (95% CI: 1.31–1.99) in Model 1 (Figure 2B), 1.65 (95% CI: 1.35–2.01) and 1.50 (95% CI: 1.21–1.85) in Model 2, and 1.63 (95% CI: 1.34–2.00) and 1.49 (95% CI: 1.21–1.85) in Model 3. The ORs and 95% CIs for the adjusted factors are shown in the Supplementary (Table S1).

Secondary Analysis: Association between prehospital SI and invasive hemostatic interventions, blood transfusion within 24 hours, head surgery, and in-hospital mortality

Similar to the primary analysis, the low and high SI groups showed higher ORs for in-hospital mortality than the normal SI group (Figure S1). Compared with the normal SI group, the ORs for invasive hemostatic interventions were higher in the high SI group but lower in the low SI group (Figure 3A). The OR for blood transfusion within 24 hours was higher in the high SI group than in the normal SI group (Figure 3B). The low SI group showed a higher OR for head surgery, and the high SI group showed a lower OR than the normal SI group (Figure 3C).

Subgroup analysis: Association between prehospital SI and 24-hour mortality in patients with and without head injury

The low SI group in the subpopulation of patients with isolated serious head injuries was associated with a higher risk of 24-hour mortality than the normal SI group; however, there were no substantial differences between the high and normal SI groups in this subgroup analysis (Figure 4A). Among the patients without serious head injuries, the high but not the low SI group showed a higher risk of 24-hour mortality than the normal SI group (Figure 4B).

Sensitivity analysis: Prehospital SI and 24-hour mortality with altered cut-off values, additional adjustment for SI upon ED arrival as a covariate, and MI

Sensitivity analyses with the normal range of the SI set to 0.4–1.0 or 0.5–0.7, additional adjustment for the SI upon ED arrival, and MI for the missing values showed results similar to those of the primary analysis (Figure S2-S4). In the analysis of the entire cohort with the MI, 20.4% of the patients had missing values, with the most common factors being respiratory rate (9.2%), transportation time (7.9%), and GCS (5.7%; Table

1).

DISCUSSION

In this retrospective cohort study of 89,495 patients with a normal SI upon ED arrival recorded in the JTDB, we found an association between prehospital SI abnormalities (SI ≤ 0.4 or ≥ 0.9) and 24-hour mortality (Figure 2). We confirmed the robustness of the results using three sensitivity analyses; alternative definitions of the normal SI, additional adjustment for the SI upon ED arrival, and analysis with MI showed results similar to those of the primary analysis (Figure S2-S4). Invasive hemostatic interventions and blood transfusion within 24 hours were performed more frequently in the high SI group than in the normal SI group, while head surgery was more frequent in the low SI group (Figure 3). The subgroup analysis of patients with isolated serious head injuries showed that the low SI group was associated with a higher risk of 24-hour mortality than the normal SI group, while the high SI group without serious head injuries had a higher risk of 24-hour mortality (Figure 4).

The two leading causes of trauma-related deaths were bleeding and neurological damage. When injuries in the body trunk or limbs cause massive bleeding, blood pressure drops due to hypovolaemia. Compensatory mechanisms work to maintain cardiac output and blood flow to vital organs.[20] The sympathetic nervous system is activated to increase the heart rate and, consequently, the cardiac output. This reaction increases the SI (high heart rate and low blood pressure), indicating an increased risk of death from haemorrhagic shock. Additionally, the sympathetic nervous system constricts the peripheral blood vessels to raise the blood pressure, resulting in normal SI values in some cases. In contrast, a serious head injury with intracranial haemorrhage could increase intracranial pressure, resulting in bradycardia and high blood pressure (low SI), known as the Cushing reflex, [18] potentially explaining the secondary analysis results, in which the low SI group was associated with a higher rate of head surgeries than the normal SI group (Figure 3). These mechanisms may temporarily alter the vital signs and SI, [21] sometimes normalizing the SI value, [20] leading clinicians to misestimate the risk of death.

Previous studies have attempted to improve the prognostic ability of the SI by considering the difference between the prehospital SI and ED arrival SI. [15,28,29] Patients with different prognoses may have been classified into the same group in these studies. Briefly, the prognosis in patients with a similar increase in SI but different prehospital SI values could be different. For example, the prognosis of patients with low prehospital SI and normal SI upon ED arrival might differ from that of patients with normal prehospital SI and high SI upon ED arrival. In clinical settings, physicians rush to treat patients with high SI upon ED arrival, regardless of their prehospital SI. Our study focused on patients with a normal SI upon ED arrival as they are generally considered to have a good prognosis. The results allowed us to identify patients at high risk of death, which may require therapeutic interventions based on their prehospital SI.

The SI was used to predict blood loss, indicating the need for blood transfusions following trauma, [7,17] and the risk of death. [7,11,23] In our study, patients with a high prehospital SI had a higher mortality risk, as reported previously; [17] furthermore, they had a higher risk of undergoing an invasive hemostatic intervention or blood transfusion within 24 hours than patients who had normal prehospital SI, possibly due to severe blood loss following organ injuries (Figure 3). Without a serious head injury, the 24-hour mortality in the low SI group was rare, and there were no substantial differences between the low and normal SI groups (Figure 4). Therefore, after excluding trauma patients with a serious head injury, a traditional single high SI cut-off value (e.g., 0.9) might be sufficient to predict mortality and the need for therapeutic interventions. However, patients in the low SI group required head surgery more frequently than those in the normal SI group. When trauma was confined to a serious head injury, mortality in the low but not high SI group was more frequent than in the normal SI group. This finding suggested that a low SI cut-off value should be set for trauma patients with isolated serious head injuries.

This study had several strengths. First, we used one of the largest multicenter trauma registries in the world, resulting in an adequately large sample. Second, we confirmed the robustness of the results associated the prehospital SI with 24-hour mortality using sensitivity analyses. Finally, unlike previous studies, we excluded patients with normal SI who were in shock states upon ED arrival. This eligibility criterion could identify patients whose prognoses were uncertain and who needed further risk estimations in clinical settings.

This study also had several limitations. First, the extrapolation of our results to populations with less serious injuries could be challenging because this registry enrolled only trauma patients with serious injuries (AIS score ≥ 3). Second, it was unclear whether our results may be applied to patients in countries where penetrating injuries are more common. [30] It is often difficult for physicians to determine whether patients require further examinations or interventions after a blunt injury with visible and hidden blood loss. Our findings may provide useful information for clinical decision-making in patients with blunt injuries. Third, there were missing covariates and outcomes in this study. However, we found no apparent differences in the patient characteristics among the eligible patients, those with missing covariate data, and those who were excluded due to missing outcomes (Table S2). Fourth, we did not have data on the use of drugs intimately associated with SI (e.g., vasoactive drugs such as beta blockers or calcium blockers). As a substitute, adjustment was performed using comorbidities, for which patients were likely to use such kinds of drugs. Last, this was an observational study; therefore, we cannot exclude the effect of unknown factors which may have affected the observed relationship.

CONCLUSION

Among the trauma patients with normal SI upon ED arrival ($0.4 < SI < 0.9$), abnormal prehospital SI ($SI \geq 0.9$ or $SI \leq 0.4$) was associated with higher 24-hour mortality than normal prehospital SI. This study contributes to a more effective triage of trauma patients with normal SI upon ED arrival.

Declaration of Competing Interest:

None.

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Ethics approval:

The ethics committee of Kyoto University approved this study (approval number: R2601). This study was conducted in accordance with Japan’s ethical guidelines for medical and biological research involving human subjects.

Patient consent for publication:

Not applicable.

Data availability statement:

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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Figure legends

Figure 1. Patient selection flowchart

Abbreviations: ED, emergency department

[Model 1] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury.

[Model 2] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, and cause of injury.

[Model 3] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, cause of injury, and comorbidities.

Figure 2. Primary analysis: odds ratios of the prehospital shock index for 24-hour mortality based on the logistic regression analysis

Abbreviations: OR, odds ratio; CI, confidence interval

Graph A is from the unadjusted model, and Graph B is from the model adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury [Model 1].

Figure 3. Secondary Analysis: adjusted odds ratios of the prehospital shock index for each treatment based on the logistic regression analysis

Abbreviations: OR, odds ratio; CI, confidence interval

Adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury [Model 1].

“Invasive hemostatic interventions” comprised thoracoabdominal surgery, endoscopic surgery, surgical hemostasis, angiostomy, and transcatheter arterial embolisation.

Graph A, B and C are from independent logistic regression models, see "Primary analysis" in Method section.

Figure 4. Subgroup analysis: adjusted odds ratios of the prehospital shock index for 24-hour death with/without serious head injury based on the logistic regression analysis

Abbreviations: OR, odds ratio; CI, confidence interval

Adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury [Model 1].

Graph A and B are from different populations; Graph A is from the population with isolated serious head injury defined as a head Abbreviated Injury Scale (AIS) score ≥ 3 and AIS score < 3 for the other body parts, and Graph B is from the population without serious head injury defined as a head AIS score < 3 and AIS score ≥ 3 for the other body parts.

Table 1. Patient characteristics

Parameter	Total	Prehospital SI SI ≤ 0.4	0.4 < SI < 0.9	SI ≥ 0.9
	N = 89,495	N = 4,263	N = 78,901	N = 6,331
Male	55,484 (62.0)	2,456 (57.6)	48,821 (61.9)	4,207 (66.5)
Missing	27 (0.0)	1 (0.0)	23 (0.0)	3 (0.0)
Age [year][a]	64 [43-79]	74 [62-83]	65 [44-79]	50 [31-69]
At prehospital				
Shock index [bpm/mm Hg][a]	0.60 [0.51-0.72]	0.37 [0.34-0.39]	0.60 [0.52-0.70]	1.00 [0.94-1.10]
Heart rate [bpm][a]	84 [73-95]	66 [60-72]	84 [74-93]	102 [90-115]
Systolic blood pressure [mm Hg][a]	139 [120-160]	180 [161-200]	140 [121-159]	100 [87-111]
At ED arrival				
Shock index [bpm/mm Hg][a]	0.58 [0.50-0.69]	0.48 [0.43-0.55]	0.58 [0.50-0.68]	0.74 [0.64-0.82]
Heart rate [bpm][a]	82 [73-93]	75 [67-86]	82 [73-92]	92 [81-104]
Systolic blood pressure [mm Hg][a]	140 [124-159]	155 [136-173]	140 [124-159]	129 [115-144]
Glasgow Coma Scale[a]	15 [14-15]	15 [13-15]	15 [14-15]	14 [13-15]
Missing	5075 (5.7)	245 (5.7)	4,565 (5.8)	265 (4.2)

Respiratory rate [/min][a]	20	[17-24]	20	[16-24]	20	[17-24]	21	[18-26]
Missing	8,224	(9.2)	425	(10.0)	7,353	(9.3)	446	(7.0)
Year								
2004–2009	14,842	(16.6)	687	(16.1)	12,870	(16.3)	1,285	(20.3)
2010–2014	48,751	(54.5)	2,324	(54.5)	42,979	(54.5)	3,448	(54.5)
2015–2017	25,902	(28.9)	1,252	(29.4)	23,052	(29.2)	1,598	(25.2)
Transportation time [min][a]	13.1	[6.6-19.7]	13.1	[8.7-19.7]	10.9	[6.6-19.7]	13.1	[8.7-19.7]
Missing	7,063	(7.9)	347	(8.1)	6,244	(7.9)	472	(7.5)
Type of injury								
Blunt injury	86,582	(96.7)	4,152	(97.4)	76,523	(97.0)	5,907	(93.3)
Penetrating injury	1,672	(1.9)	44	(1.0)	1,282	(1.6)	346	(5.5)
Unknown	533	(0.6)	35	(0.8)	468	(0.6)	30	(0.5)
Others	136	(0.2)	3	(0.1)	119	(0.2)	14	(0.2)
Missing	572	(0.6)	29	(0.7)	509	(0.6)	34	(0.5)
Cause of injury								
Unintentional accident	78,252	(87.4)	3,828	(89.8)	69,477	(88.1)	4,947	(78.1)
Occupational accident	5,015	(5.6)	227	(5.3)	4,436	(5.6)	352	(5.6)
Suicide attempt	2,716	(3.0)	46	(1.1)	1,965	(2.5)	705	(11.1)

Assault by others	993	(	1.1	)	23	(	0.5	)	824	(	1.0	)	146	(	2.3	)
Unknown	1,161	(	1.3	)	65	(	1.5	)	997	(	1.3	)	99	(	1.6	)
Others	644	(	0.7	)	39	(	0.9	)	575	(	0.7	)	30	(	0.5	)
Missing	714	(	0.8	)	35	(	0.8	)	627	(	0.8	)	52	(	0.8	)
Comorbidities																
Respiratory	4,147	(	4.6	)	157	(	3.7	)	3,655	(	4.6	)	335	(	5.3	)
Cardiovascular	27,116	(	30.3	)	1,837	(	43.1	)	24,112	(	30.6	)	1,167	(	18.4	)
Digestive	7,055	(	7.9	)	378	(	8.9	)	6,210	(	7.9	)	467	(	7.4	)
Metabolic	12,094	(	13.5	)	704	(	16.5	)	10,801	(	13.7	)	589	(	9.3	)
Central nervous system / mental	15,340	(	17.1	)	782	(	18.3	)	13,349	(	16.9	)	1,209	(	19.1	)
Immunodeficiency / cancer	9,151	(	10.2	)	508	(	11.9	)	8,159	(	10.3	)	484	(	7.6	)
Body part with serious injury																
Isolated serious head injury	24,925	(	27.9	)	1,560	(	36.6	)	22,119	(	28.0	)	1,246	(	19.7	)
Without serious head injury	55,032	(	61.5	)	2,235	(	52.4	)	48,714	(	61.7	)	4,083	(	64.5	)
Head and other body part injury	9,538	(	10.7	)	468	(	11.0	)	8,068	(	10.2	)	1,002	(	15.8	)

Abbreviations: SI, shock index; ED, emergency department

n (%), unless otherwise specified.

[a] Median [interquartile range].

“Isolated serious head injury” was defined as a head Abbreviated Injury Scale (AIS) score ≥ 3 and AIS score < 3 for other body parts.

“Without serious head injury” was defined as a head AIS score < 3 and AIS score ≥ 3 for other body parts.

“Head and other body part injury” were defined as AIS score ≥ 3 for both the head and other body parts.

Supplemental Material

Prehospital shock index predicts 24-hour mortality in trauma patients with a normal shock index upon emergency department arrival

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Table S1. Odds ratios of the adjusted factors in the primary analysis

Parameters	OR [95% CI]		
	Model1	**Model2**	**Model3**
	N=71,270	**N=70,822**	**N=70,822**
SI ≤ 0.4	1.63 [1.34 - 1.99]	1.65 [1.35 - 2.01]	1.63 [1.34 - 2.00]
SI = 0.4-0.9	Ref	Ref	Ref
SI ≥ 0.9	1.62 [1.31 - 1.99]	1.50 [1.21 - 1.85]	1.49 [1.21 - 1.85]
Male (Ref. female)	1.18 [1.03 - 1.36]	1.21 [1.05 - 1.39]	1.19 [1.03 - 1.37]
Age [year][a]	1.04 [1.03 - 1.04]	1.04 [1.03 - 1.04]	1.04 [1.04 - 1.05]
At ED arrival			
Glasgow Coma Scale[a]			
3	239.0 [173.4 - 329.3]	236.5 [171.4 - 326.2]	230.7 [167.1 - 318.6]
4	193.5 [135.4 - 276.5]	191.8 [134.1 - 274.4]	187.3 [130.8 - 268.3]
5	166.8 [110.2 - 252.4]	164.2 [108.3 - 249.0]	160.6 [105.7 - 244.0]
6	103.8 [73.5 - 146.6]	103.5 [73.2 - 146.2]	100.4 [71.0 - 142.1]
7	53.5 [36.3 - 78.9]	53.5 [36.3 - 78.8]	51.7 [35.1 - 76.4]
8	45.9 [30.3 - 69.7]	45.6 [30.0 - 69.2]	44.1 [29.0 - 67.1]
9	26.9 [16.7 - 43.3]	26.5 [16.4 - 42.7]	26.3 [16.3 - 42.5]
10	30.6 [19.8 - 47.5]	30.3 [19.5 - 47.0]	30.2 [19.5 - 46.9]
11	21.2 [13.3 - 34.0]	20.8 [13.0 - 33.4]	20.8 [13.0 - 33.4]
12	16.1 [10.1 - 25.7]	15.9 [10.0 - 25.5]	16.0 [10.0 - 25.6]
13	9.77 [6.54 - 14.58]	9.71 [6.50 - 14.49]	9.75 [6.53 - 14.57]

14	4.86	[	3.33	-	7.11	]	4.82	[	3.30	-	7.05	]	4.90	[	3.35	-	7.16	]
15	Ref						Ref						Ref					
Respiratory rate [bpm][a]	1.03	[	1.02	-	1.04	]	1.03	[	1.02	-	1.04	]	1.03	[	1.02	-	1.04	]
Year																		
2004	Ref						Ref						Ref					
2005	1.26	[	0.74	-	2.16	]	1.29	[	0.76	-	2.21	]	1.30	[	0.76	-	2.22	]
2006	0.76	[	0.43	-	1.33	]	0.77	[	0.44	-	1.35	]	0.77	[	0.44	-	1.36	]
2007	0.73	[	0.45	-	1.18	]	0.74	[	0.46	-	1.19	]	0.75	[	0.47	-	1.21	]
2008	0.53	[	0.33	-	0.86	]	0.55	[	0.34	-	0.88	]	0.55	[	0.34	-	0.90	]
2009	0.59	[	0.37	-	0.94	]	0.59	[	0.37	-	0.94	]	0.60	[	0.38	-	0.95	]
2010	0.47	[	0.30	-	0.74	]	0.47	[	0.30	-	0.75	]	0.48	[	0.31	-	0.76	]
2011	0.50	[	0.32	-	0.77	]	0.50	[	0.32	-	0.77	]	0.50	[	0.32	-	0.78	]
2012	0.49	[	0.32	-	0.75	]	0.49	[	0.32	-	0.76	]	0.50	[	0.33	-	0.77	]
2013	0.42	[	0.27	-	0.65	]	0.42	[	0.28	-	0.65	]	0.43	[	0.28	-	0.67	]
2014	0.38	[	0.24	-	0.58	]	0.38	[	0.25	-	0.58	]	0.39	[	0.25	-	0.59	]
2015	0.39	[	0.26	-	0.60	]	0.40	[	0.26	-	0.61	]	0.41	[	0.27	-	0.62	]
2016	0.30	[	0.19	-	0.48	]	0.31	[	0.19	-	0.49	]	0.32	[	0.20	-	0.52	]
2017	0.31	[	0.19	-	0.50	]	0.30	[	0.19	-	0.49	]	0.31	[	0.19	-	0.50	]
Transportation time [min][a]	1.00	[	1.00	-	1.00	]	1.00	[	1.00	-	1.00	]	1.00	[	1.00	-	1.00	]
Type of injury																		
Blunt injury	Ref						Ref						Ref					
Penetrating injury	0.51	[	0.27	-	0.96	]	0.36	[	0.18	-	0.71	]	0.35	[	0.18	-	0.69	]
Unknown	0.53	[	0.31	-	0.93	]	0.56	[	0.30	-	1.06	]	0.56	[	0.30	-	1.05	]

Others	1.05 [0.23 - 4.74]	1.05 [0.22 - 4.98]	1.02 [0.21 - 4.95]
Cause of injury			
Unintentional accident		Ref	Ref
Occupational accident		1.12 [0.76 - 1.66]	1.10 [0.75 - 1.63]
Suicide attempt		1.96 [1.38 - 2.77]	2.17 [1.53 - 3.09]
Assault by others		0.78 [0.39 - 1.59]	0.79 [0.39 - 1.60]
Unknown		1.06 [0.75 - 1.50]	1.10 [0.77 - 1.55]
Others		0.51 [0.20 - 1.29]	0.53 [0.21 - 1.36]
Past medical history			
Respiratory			1.33 [0.89 - 1.99]
Cardiovascular			1.34 [1.14 - 1.57]
Digestive			1.06 [0.83 - 1.35]
Metabolic			1.20 [0.97 - 1.48]
Central nervous system / mental			1.41 [1.18 - 1.68]
Immunodeficiency / cancer			0.74 [0.61 - 0.91]

Abbreviations: SI, shock index; ED, emergency department

[a] Continuous variable, unless otherwise specified categorical variable

[Model 1] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury.

[Model 2] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, and cause of injury.

[Model 3] was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, cause of injury, and comorbidities.

Table S2. Eligible patient characteristics, missing outcomes and covariates

Parameter	Eligible patients N = 89,495	Missing outcomes n = 3,869	Missing covariates n = 18,225
Male	55,484 (62.0)	2,328 (60.2)	10,072 (55.3)
Missing	27 (0.0)	2 (0.1)	27 (0.1)
Age [year][a]	64 [43–79]	65 [42–79]	70 [50–82]
At prehospital			
SI ≤ 0.4	4,263 (4.8)	207 (5.4)	911 (5.0)
0.4 < SI < 0.9	78,901 (88.2)	3,333 (86.1)	16,228 (89.0)
SI ≥ 0.9	6,331 (7.1)	329 (8.5)	1,086 (6.0)
Shock index [bpm/mmHg][a]	0.60 [0.51–0.72]	0.61 [0.51–0.73]	0.59 [0.50–0.70]
Heart rate [bpm][a]	84 [73–95]	84 [72–95]	83 [73–94]
Systolic blood pressure [mmHg][a]	139 [120–160]	138 [118–159]	140 [121–161]

At ED arrival

Shock index [bpm/mmHg][a]	0.58	[	0.50–0.69	]	0.59	[	0.50–0.69	]	0.58	[	0.50–0.68	]
Heart rate [bpm][a]	82	[	73–93	]	82	[	73–94	]	82	[	73–93	]
Systolic blood pressure [mmHg][a]	140	[	124–159	]	140	[	123–158	]	142	[	125–160	]
Glasgow Coma Scale[a]	15	[	14–15	]	15	[	14–15	]	15	[	14–15	]
Missing	5075	(	5.7	)	225	(	5.8	)	5,075	(	27.8	)
Respiratory rate [/min][a]	20	[	17–24	]	20	[	17–24	]	20	[	17–24	]
Missing	8,224	(	9.2	)	361	(	9.3	)	8,224	(	45.1	)
Year												
2004–2009	14,842	(	16.6	)	920	(	23.8	)	2,718	(	14.9	)
2010–2014	48,751	(	54.5	)	1,709	(	44.2	)	10,838	(	59.5	)
2015–2017	25,902	(	28.9	)	1,240	(	32.0	)	4,669	(	25.6	)

Transportation time [min][a]	13.1	[	6.6–19.7	]	10.9	[	6.6–17.5	]	10.9	[	6.6–17.5	]
Missing	7,063	(	7.9	)	392	(	10.1	)	7,063	(	38.8	)
Type of injury												
Blunt trauma	86,582	(	96.7	)	3,684	(	95.2	)	17,193	(	94.3	)
Penetrating trauma	1,672	(	1.9	)	80	(	2.1	)	295	(	1.6	)
Unknown	533	(	0.6	)	25	(	0.6	)	133	(	0.7	)
Others	136	(	0.2	)	14	(	0.4	)	32	(	0.2	)
Missing	572	(	0.6	)	66	(	1.7	)	572	(	3.1	)
Cause of injury												
Unintentional accident	78,252	(	87.4	)	3,395	(	87.7	)	16,265	(	89.2	)
Occupational accident	5,015	(	5.6	)	193	(	5.0	)	809	(	4.4	)
Suicide attempt	2,716	(	3.0	)	129	(	3.3	)	387	(	2.1	)
Assault by others	993	(	1.1	)	26	(	0.7	)	176	(	1.0	)
Unknown	1,161	(	1.3	)	40	(	1.0	)	228	(	1.3	)

Others	644 (0.7)	14 (0.4)	94 (0.5)
Missing	714 (0.8)	72 (1.9)	266 (1.5)
Comorbidities			
Respiratory	4,147 (4.6)	137 (3.5)	815 (4.5)
Cardiovascular	27,116 (30.3)	1,126 (29.1)	6,329 (34.7)
Digestive	7,055 (7.9)	263 (6.8)	1,515 (8.3)
Metabolic	12,094 (13.5)	524 (13.5)	2,702 (14.8)
Central nervous system / mental	15,340 (17.1)	545 (14.1)	3,655 (20.1)
Immunodeficiency / cancer	9,151 (10.2)	397 (10.3)	2,065 (11.3)
Body part with serious injury			
Isolated serious head injury	24,925 (27.9)	956 (24.7)	4,747 (26.0)
Without serious head injury	55,032 (61.5)	2,558 (66.1)	12,061 (66.2)
Head and other body part injury	9,538 (10.7)	355 (9.2)	1,417 (7.8)

Abbreviations: SI, shock index; ED, emergency department

n (%), unless otherwise specified

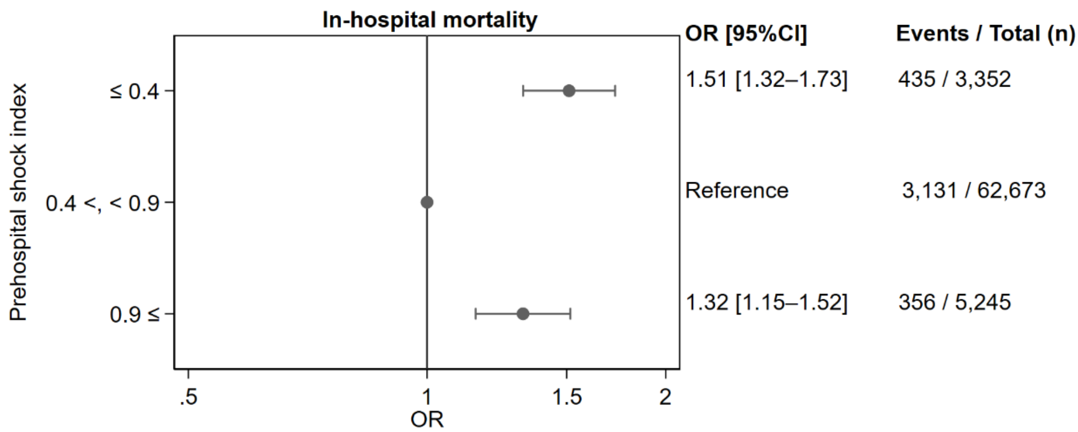
[a] Median [interquartile range]

"Isolated serious head injury" was defined as a head Abbreviated Injury Scale (AIS) score ≥ 3 and AIS scores < 3 for other body parts.

"Without serious head injury" was defined as a head AIS score < 3 and AIS scores ≥ 3 for other body parts.

"Head and other body part injury" were defined as AIS scores ≥ 3 for both the head and other body parts.

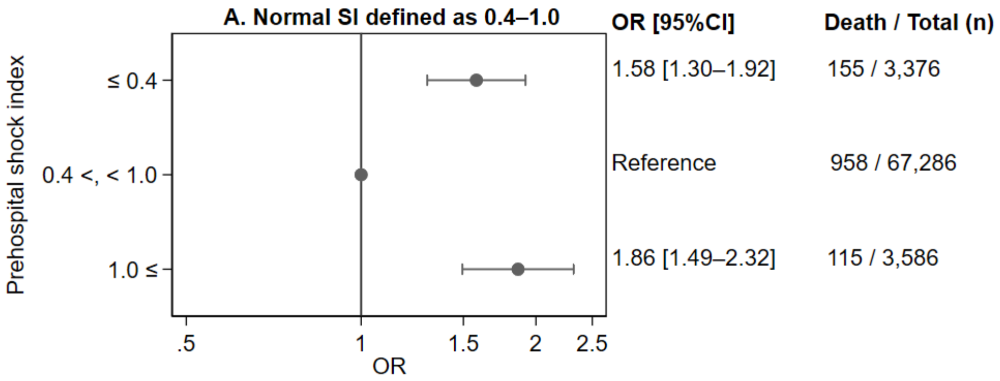
Figure S1. Secondary Analysis: Adjusted odds ratio of the prehospital shock index for the in-hospital mortality based on the logistic regression analysis

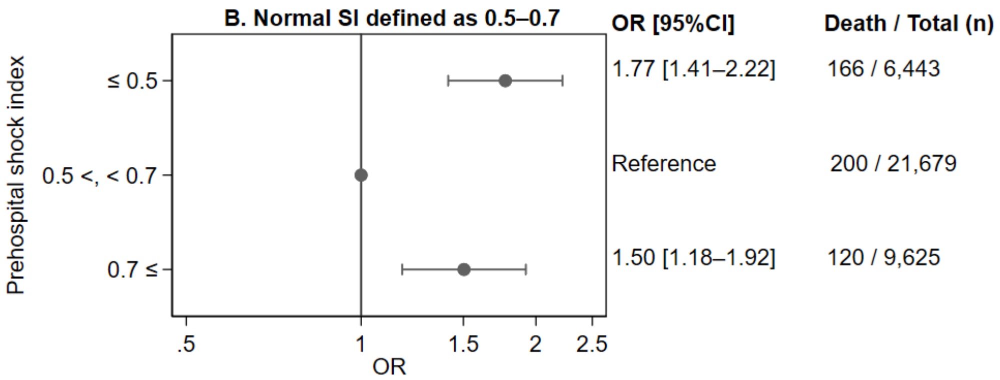


Abbreviations: OR, odds ratio; CI, confidence interval

Adjusted for age, sex, Glasgow Coma Scale, respiratory rate, transportation time, year of emergency department arrival, and type of injury [Model 1].

Figure S2. Sensitivity analysis: adjusted odds ratios of the prehospital shock index for 24-hour mortality with various cut-off values based on the logistic regression analysis



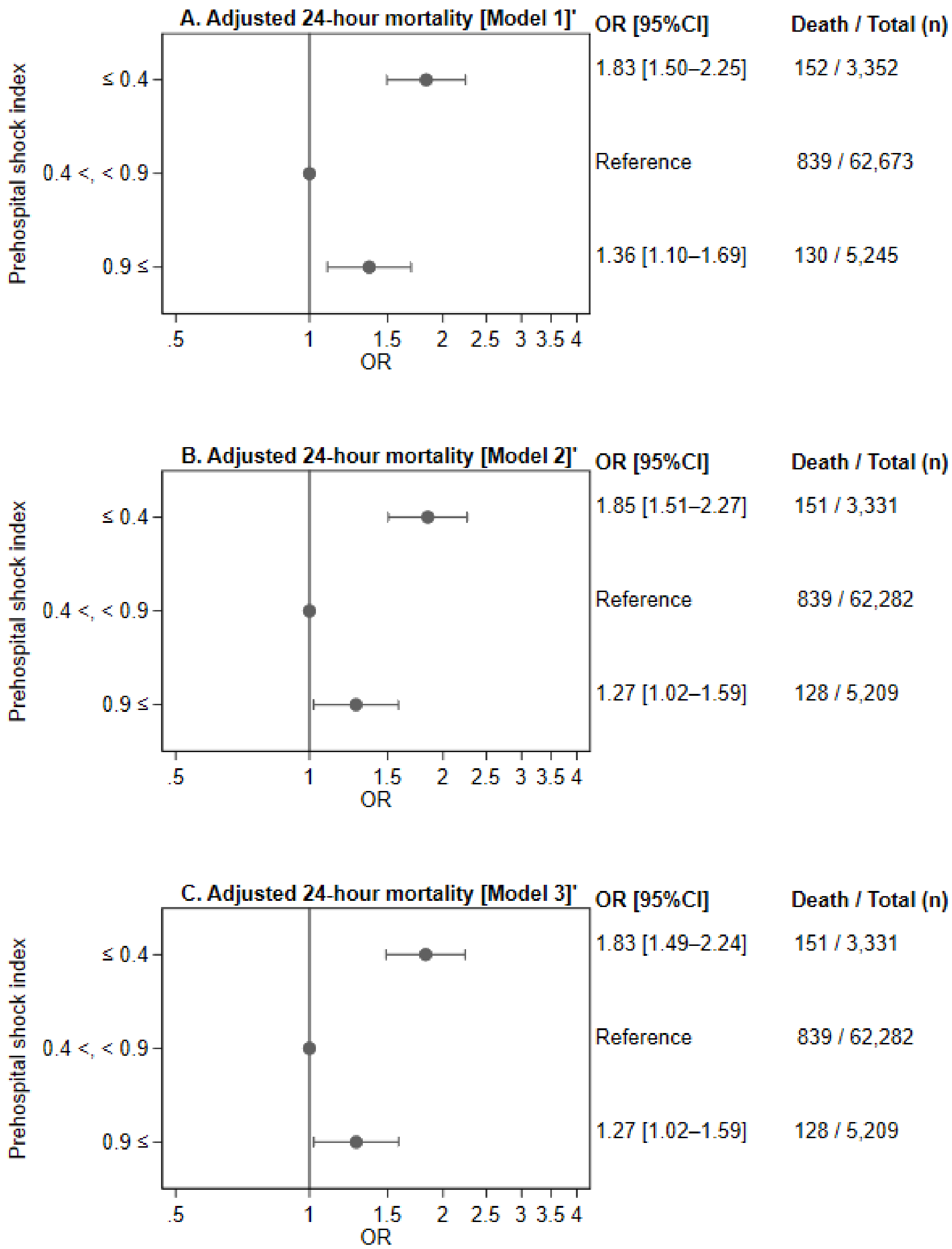


Abbreviations: OR, odds ratio; CI, confidence interval

Adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury [Model 1].

A and B are calculated from different logistic regression models, see Method sensitivity analysis section.

Figure S3. Sensitivity analysis: adjusted odds ratios of the prehospital shock index for 24-hour mortality with additional adjustment for the SI upon ED arrival as a covariate on the logistic regression analysis



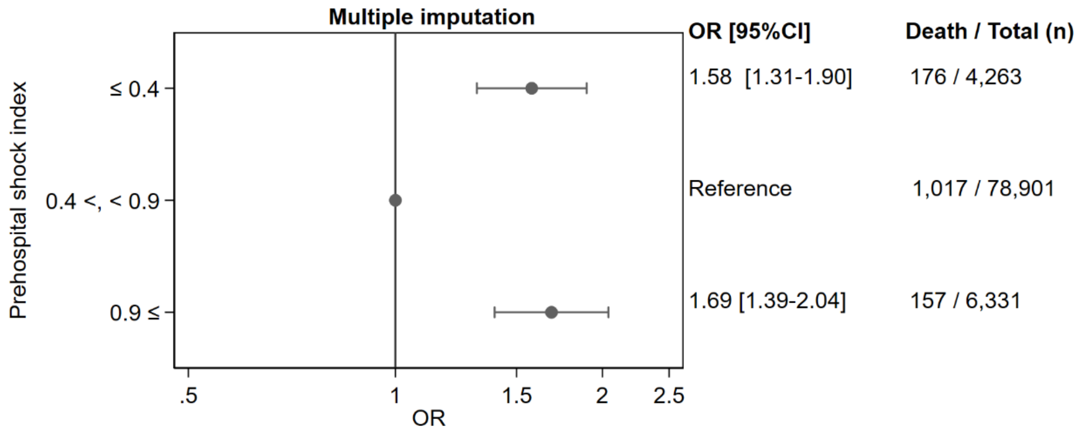
Abbreviations: OR, odds ratio; CI, confidence interval

[Model 1]' was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, and the SI upon ED arrival.

[Model 2]' was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, cause of injury, and the SI upon ED arrival.

[Model 3]' was adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, type of injury, cause of injury, comorbidities, and the SI upon ED arrival.

Figure S4. Sensitivity analysis: adjusted odds ratios of the prehospital shock index for 24-hour mortality with multiple imputation for the missing variables based on the logistic regression analysis



Abbreviations: OR, odds ratio; CI, confidence interval

Adjusted for age, sex, Glasgow Coma Scale, respiratory rate, year of emergency department arrival, transportation time, and type of injury [Model 1].