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소아 외상 환자에서 나이 보정 쇼크지수와 사망의 연관: 한국 단일기관 연구

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Association of age-adjusted shock index with mortality in children with trauma: a single-center study in Korea

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Purpose: This study was performed to investigate the association of high age-adjusted shock index (AASI) with mortality in Korean children with trauma.

Methods: The data of children (aged < 15 years) with trauma who visited a university hospital in Korea from 2010 through 2018 were reviewed. High AASI was defined by age groups as follows: < 12 months, ≥ 2.7; 12-23 months, ≥ 2.1; 2-4 years, ≥ 1.9; 5-11 years, ≥ 1.5; and 12-14 years, ≥ 1.1. Age, sex, transfer status, injury mechanism, hypotension, tachycardia, base deficit, hemoglobin concentration, trauma scores, hemorrhage-related procedures (transfusion and surgical interventions), and severe traumatic brain injury were compared according to high AASI and in-hospital mortality. The association of high AASI with the mortality was analyzed using logistic regression.

Results: Of the 363 enrolled children, 29 (8.0%) had high AASI and 24 (6.6%) died. The children with high AASI showed worse trauma scores and underwent hemorrhage-related procedures more frequently, without a difference in the rate of the traumatic brain injury. High AASI was associated with in-hospital mortality (survivors, 6.5% vs. non-survivors, 29.2%; P = 0.001). This association remained significant after adjustment (adjusted odds ratio, 6.42; 95% confidence interval, 1.38-29.82). The other predictors were Glasgow Coma Scale (for increment of 1 point; 0.62; 0.53-0.72) and age (for increment of 1 year; 0.84; 0.73-0.97). High AASI showed a 29.2% sensitivity and 93.5% specificity for the mortality.

Conclusion: High AASI is associated with mortality, and have a high specificity but low sensitivity in Korean children with trauma. This predictor of mortality can be used prior to obtaining the results of laboratory markers of shock.

Key words: Accidental Injuries; Age Groups; Child; Mortality; Multiple Trauma; Shock, Hemorrhagic

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Introduction

The shock index (SI), calculated as heart rate divided by systolic blood pressure, is associated with injury severity, need for transfusion, and mortality in adults with trauma[1]. This simple clinical marker partially compensates for the inaccurate prediction of trauma outcomes using isolated hypotension and tachycardia, particularly in adults with normal blood pressure and heart rate[2]. In children, SI has been shown its utility in settings of sepsis and trauma[3-5]. A recent study on trauma showed good performances in mortality prediction of lactate and base deficit (BD) with the areas under the curve (AUCs) of 0.87 and 0.86, respectively[6]. However, point-of-care testing for such laboratory markers of shock is variously available across institutions.

Furthermore, emergency physicians or pediatricians need a simple predictor of trauma mortality prior to obtaining results of the laboratory markers. A United States study based on the National Trauma Data Bank (NTDB) reported that age-adjusted shock index (AASI) is the strongest predictor of mortality (adjusted odds ratio [aOR], 22.0; 95% confidence interval, 15.1-31.9)[3]. Because the features of children with trauma vary by regions, we aimed to investigate the association of high AASI with mortality in Korean children with trauma to test the utility of AASI as a predictor of mortality.

Methods

1. Study design and setting

This was a planned secondary analysis of the trauma dataset-based studies conducted at a university hospital in Korea[6,7]. The dataset comprised children with trauma who underwent assays for BD at the trauma bay or emergency department. The methods used in the aforementioned studies are described elsewhere[6,7]. This study was approved by the Institutional Review Board of Ajou University School of Medicine with a waiver for informed consent (IRB no. AJIRB-MED-MDB-20-393).

2. Study population

We included all children younger than 15 years with trauma who visited the center from 2010 through 2018 and had data on trauma scores, including the SI, Glasgow Coma Scale (GCS), Revised Trauma Score (RTS), Pediatric Trauma Score (PTS), BIG score, and Injury Severity Score (ISS). The exclusion criteria were missing data on such scores, environmental injury or poisoning, transfer to outside hospitals, being dead on arrival, and transfer to our center after transfusion or surgical interventions performed elsewhere.

3. Data collection

The eligible population was identified using the International Classification of Diseases, 10th Revision codes for trauma. In this process, the environmental injury and poisoning were excluded because they are not directly linked to hemorrhagic shock. This query was cross-referenced against the institutional codes for BD and International Normalized Ratio, which are components of BIG score. The medical records were then reviewed using a standardized form.

Clinical and laboratory characteristics included age, sex, transfer status, injury mechanism, hypotension, tachycardia, BD, and hemoglobin concentrations. The severe injury mechanism was defined as pedestrian accident, high fall (age $<$ 2 years, fall height $>$ 0.9 m; ≥ 2 years, $>$ 1.5 m)[8], bicycle accident, assault or abuse, motorcycle accident, or penetrating injury. Considering that the reference ranges for vital signs vary by age groups, hypotension and tachycardia were age-adjusted (appendix 1, https://doi.org/10.22470/pemj.2020.00164).

4. Calculation of the trauma scores

A high AASI was defined according to age groups: $<$ 12 months, ≥ 2.7; 12-23 months, ≥ 2.1; 2-4 years, ≥ 1.9; 5-11 years, ≥ 1.5; and 12-14 years, ≥ 1.1 (Appendix 1, https://doi.org/10.22470/pemj.2020.00164)[3]. If GCS was unavailable, AVPU scale was converted as follows: A (alert), 15; V (verbal), 13; P (pain), 8; and U (unresponsive), 6[9]. RTS, PTS, and

BIG score were calculated using web-based calculators while ISS was manually calculated by a trained reviewer.

5. Outcomes

The primary outcome was in-hospital mortality. The secondary outcomes were the implemented hemorrhage-related procedures and severe traumatic brain injury (TBI; Abbreviated Injury Scale ≥ 3)[10]. The hemorrhage-related procedures comprised early (performed within 24 hours of the initial presentation) transfusion (overall and massive) and early surgical interventions for the torso or major vessels (See the definitions of terms in appendix 1, https://doi.org/10.22470/pemj.2020.00164). Because approximately 70% of injured children were hospitalized to the intensive care unit, we did not use the rate of hospitalization as an outcome variable.

6. Statistical analysis

Data are presented as means with standard deviations or medians with interquartile ranges for continuous variables and as numbers and percentages for categorical ones. Student t test or Mann-Whitney U tests for the former variables and chi-square or Fisher exact tests for the latter variables were used to compare the features according to in-hospital mortality. We calculated the sensitivity, specificity, predictive values, and likelihood ratios for each outcome. All statistical analyses were performed using IBM SPSS Statistics for Windows, ver. 25.0 (IBM Corp., Armonk, NY) and MedCalc Statistical Software ver. 19.5.1 (MedCalc Software Ltd., Ostend, Belgium). A P value < 0.05 was considered significant.

Multivariable logistic regression was conducted to identify independent predictors of in-hospital mortality after adjusting for potential confounders, such as the injury mechanism. Variables with P < 0.05 in the univariable analysis were put into a regression model. The laboratory findings, BIG score, ISS, and secondary outcomes were not used because we intended to investigate only predictors that are available prior to obtaining laboratory and imaging findings. Using this procedure, a priori sensitivity analysis was carried out to confirm the robustness of the model by examining the effect of adding the severe TBI, which is the leading cause of trauma mortality[11].

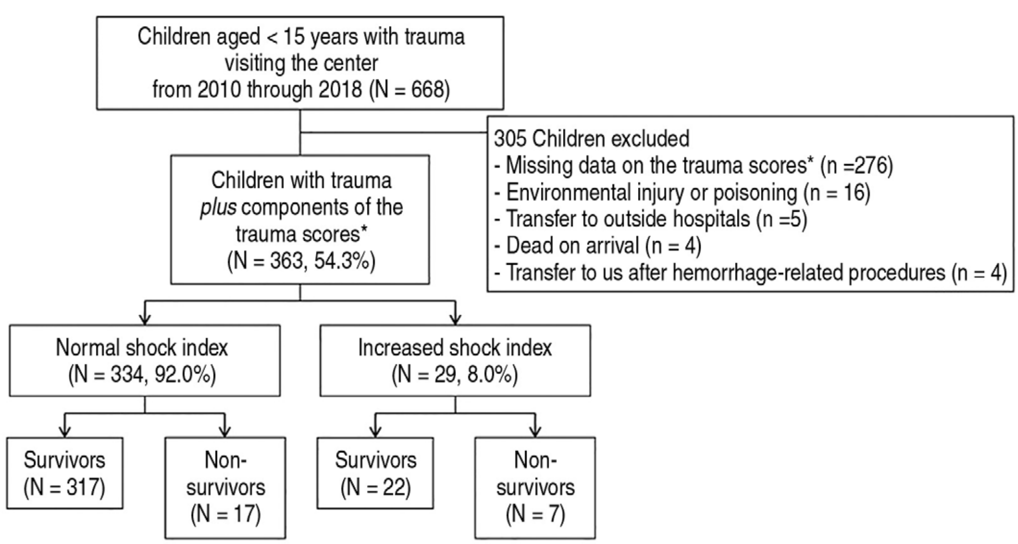

Fig. 1. Flowchart for the selection of study population. In this figure, shock index refers to the age-adjusted one (See the definition in available from appendix 1, https://doi.org/10.22470/pemj.2020.00164). *Shock index, Glasgow Coma Scale, Revised Trauma Score, Pediatric Trauma Score, BIG score, and Injury Severity Score.

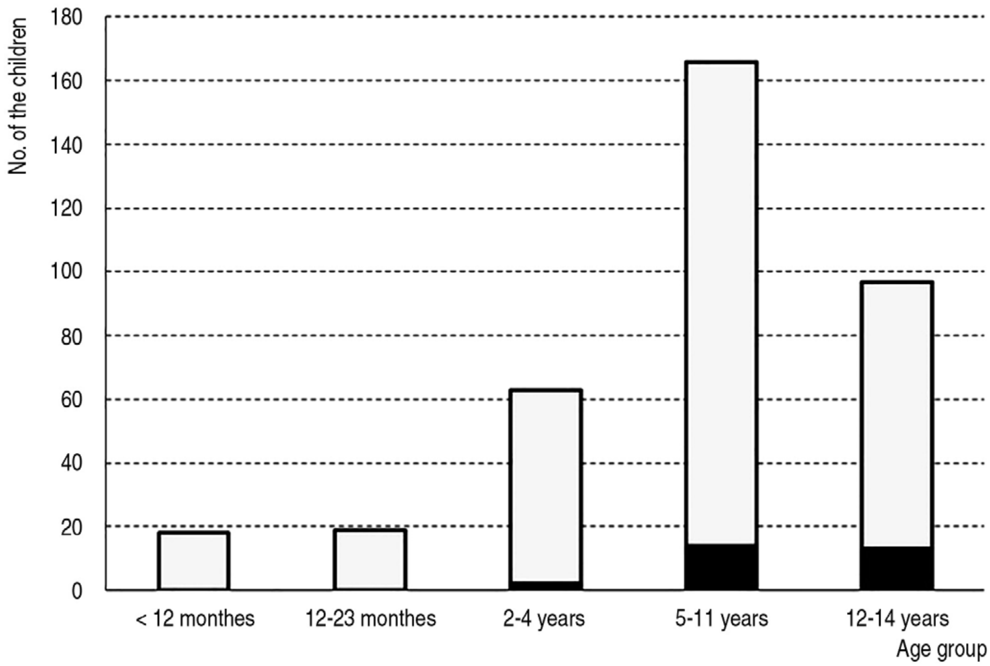

Fig. 2. Age group distribution of high age-adjusted shock index (AASI) (black shaded bar; n = 363). The rate of high AASI was highest in the children aged 12-14 years (13.4% [13/97]), followed by the rates in the children aged 5-11 years (8.4% [14/166]) and in those aged 2-4 years (3.2% [2/63]). The absence of high AASI in the children younger than 2 years might be related to a paucity of severe trauma other than brain injury in the age group.

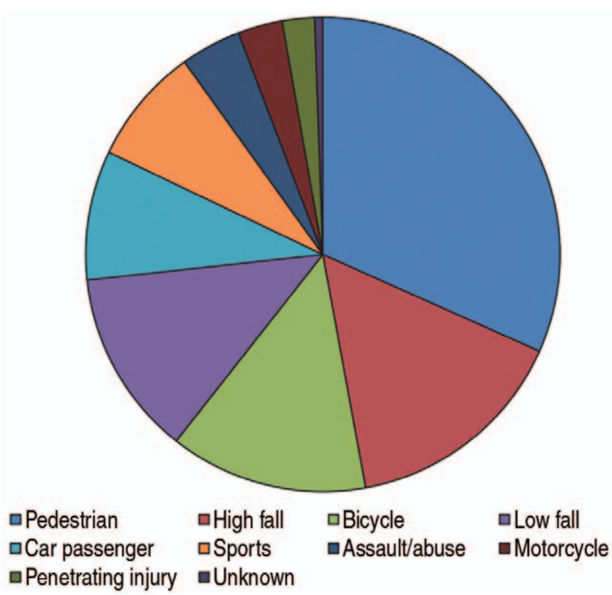

Fig. 3. Injury mechanisms (n = 363). Pedestrian accident was most common (115 children [31.7%]), followed by high fall (56 [15.4%]), bicycle accident (49 [13.5%]), low fall (46 [12.7%]), car passenger (32 [8.8%]), sports (29 [8.0%]), assault or abuse (15 [4.1%]), motorcycle accident (11 [3.0%]), penetrating injury (8 [2.2%]), and unknown mechanism (2 [0.6%]).

Results

1. Clinical features of the study population

Of the 668 eligible children, 363 were enrolled (Fig. 1). Of the 363 children, 29 (8.0%) had high AASI and 24 (6.6%) died. As shown in Fig. 2, the high AASI was most frequently observed in the children aged 12-14 years (13.4%), followed by those aged 5-11 years. The causes of mortality (n = 24) and the corresponding numbers of children were as follows: isolated TBI, 11; isolated hemorrhage, 6; TBI plus hemorrhage, 5; and others, 2 (1 sepsis and 1 airway obstruction). Pedestrian accident was the most common injury mechanism (Fig. 3).

Table 1 shows the clinical features. The children with high AASI showed significantly higher rates of severe injury mechanism, hypotension, and tachycardia, and a higher median BD than those with normal AASI. In the former group of children, all trauma scores were worse, and all outcomes except severe TBI occurred more frequently than in the latter. With respect to in-hospital mortality, the non-survivors showed a higher rate of high AASI (6.5% vs. 29.2%; P = 0.001). Meanwhile, the other variables showed patterns similar to those observed in Table 1 (Table 2).

Table 1. Clinical features of the study children (N = 363)

Characteristic	Total (N = 363)	Normal AASI* (N = 334)	High AASI (N = 29)	P value
Age, y	8.0 (4.0-12.0)	7.0 (4.0-12.0)	10.0 (6.5-13.0)	0.012
Girl	102 (28.1)	93 (27.8)	9 (31.0)	0.714
Transfer to the center	152 (41.9)	139 (41.6)	13 (44.8)	0.737
Severe injury mechanism*	254† (70.0)	229 (68.6)	25 (86.2)	0.047
Hypotension*	15 (4.1)	6 (1.8)	9 (31.0)	< 0.001
Tachycardia*	103 (28.4)	77 (23.1)	26 (89.7)	< 0.001
Base deficit, mmol/L	3.4 (1.6-5.6)	3.1 (1.4-5.2)	7.2 (4.8-12.3)	< 0.001
Hemoglobin, g/dL	12.0 ± 1.9	12.1 ± 1.9	11.1 ± 2.5	0.051
Glasgow Coma Scale	13.2 ± 3.3	13.4 ± 3.1	11.4 ± 4.4	0.024
Revised Trauma Score	7.32 ± 0.99	7.39 ± 0.89	6.53 ± 1.59	0.007
Pediatric Trauma Score	8.6 ± 2.8	8.8 ± 2.7	6.0 ± 3.3	< 0.001
BIG score	7.0 (4.9-11.2)	6.8 (4.8-10.0)	12.4 (8.1-23.1)	< 0.001
Injury Severity Score	16.0 (9.0-25.0)	14.0 (9.0-25.0)	22.0 (15.0-34.0)	0.002
Transfusion, overall	152 (41.9)	128 (38.3)	24 (82.8)	< 0.001
Transfusion, massive*	40 (11.0)	27 (8.1)	13 (44.8)	< 0.001
Surgical intervention*	45 (12.4)	36 (10.8)	9 (31.0)	0.005
Severe TBI*	82 (22.6)	76 (22.8)	6 (20.7)	0.799
In-hospital mortality	24 (6.6)	17 (5.1)	7 (24.1)	0.001

Values are expressed as median (interquartile range), number (%) or mean ± standard deviation.
* See the definitions in appendix 1, https://doi.org/10.22470/pemj.2020.00164.
† The injury mechanisms were as follows: pedestrian, 115; high fall, 56; bicycle, 49; assault or abuse, 15; motorcycle, 11; and penetrating injury, 8.
AASI: age-adjusted shock index, TBI: traumatic brain injury.

Table 2. Clinical features according to in-hospital mortality

Characteristic	Survivors (N = 339)	Non-survivors (N = 24)	P value
Age, y	8.0 (4.0-12.0)	6.0 (2.0-8.0)	0.010
Girl	96 (28.3)	6 (25.0)	0.727
Transfer to the center	140 (41.3)	12 (50.0)	0.404
Severe injury mechanism	235 (69.3)	19 (79.2)	0.309
Hypotension	8 (2.4)	7 (29.2)	< 0.001
Tachycardia	94 (27.7)	9 (37.5)	0.305
Base deficit, mmol/L	3.2 (1.4-5.2)	12.1 (7.2-19.6)	< 0.001
Hemoglobin, g/dL	12.2 ± 1.8	10.0 ± 3.1	0.003
High AASI	22 (6.5)	7 (29.2)	0.001
Glasgow Coma Scale	13.7 ± 2.7	6.5 ± 3.6	< 0.001
Revised Trauma Score	7.48 ± 0.70	5.08 ± 1.55	< 0.001
Pediatric Trauma Score	8.9 ± 2.6	4.0 ± 2.6	< 0.001
BIG score	6.8 (4.8-9.6)	24.6 (17.5-32.3)	< 0.001
Injury Severity Score	14.0 (8.8-25.0)	31.0 (25.0-42.5)	< 0.001

Values are expressed as median (interquartile range), number (%) or mean ± standard deviation.
AASI: age-adjusted shock index.

Table 3. Predictive performance of high age-adjusted shock index for the outcomes

Outcome	Sensitivity, %	Specificity, %	Predictive value		Likelihood ratio	
			Positive	Negative	Positive	Negative
In-hospital mortality	29.2 (12.6-51.1)	93.5 (90.3-95.9)	24.1 (13.1-40.1)	94.9 (93.5-96.0)	4.5 (2.1-9.4)	0.8 (0.6-1.0)
Overall transfusion	15.8 (10.4-22.6)	97.6 (94.6-99.2)	82.8 (65.2-92.5)	61.7 (60.0-63.4)	6.7 (2.6-17.1)	0.9 (0.8-0.9)
Massive transfusion	32.5 (18.6-49.1)	95.1 (92.1-97.1)	44.8 (29.7-61.0)	91.9 (90.2-93.4)	6.6 (3.4-12.6)	0.7 (0.6-0.9)
Surgical interventions	20.0 (9.6-34.6)	93.7 (90.5-96.1)	31.0 (17.9-48.1)	89.2 (87.7-90.6)	3.2 (1.5-6.5)	0.9 (0.7-1.0)
Severe TBI	7.3 (2.7-15.3)	91.8 (88.0-94.7)	20.7 (9.9-38.3)	77.2 (76.0-78.4)	0.9 (0.4-2.1)	1.0 (0.9-1.1)

Values are expressed as point estimates and 95% confidence intervals.
TBI: traumatic brain injury.

Table 4. Sensitivity analysis*

Variable	Adjusted odds ratio	P value
High age-adjusted shock index	6.42 (1.38-29.82)	0.018
Glasgow Coma Scale	0.62 (0.53-0.72)	< 0.001
Age	0.84 (0.73-0.97)	0.017

Values are expressed as point estimates and 95% confidence intervals.
* The severe traumatic brain injury was added to the original regression model.

High AASI had a 29.2% sensitivity and 93.5% specificity for predicting in-hospital mortality (Table 3). Likewise, high AASI showed a higher specificity than sensitivity for predicting the need for hemorrhage-related procedures. The likelihood ratios for severe TBI approached 1.0.

2. Association of high AASI with in-hospital mortality

Logistic regression analysis showed high AASI (aOR, 6.42; 95% confidence interval, 1.38-29.82; P = 0.018), GCS (for increment of 1 point; 0.62; 0.53-0.72; P < 0.001), and age (for increment of 1 year; 0.84; 0.73-0.97; P = 0.017) as the predictors of in-hospital mortality. Isolated hypotension and tachycardia, RTS, and PTS were not independently associated with in-hospital mortality. The sensitivity analysis showed the same findings (Table 4).

Discussion

This study shows that high AASI has a stronger association with in-hospital mortality in Korean children with trauma than does isolated vital signs, RTS, and PTS. This study also indicates the association of high AASI with the higher rate of implemented hemorrhage-related procedures, but not with the rate of TBI. The latter finding suggests that AASI chiefly reflects the effect of hemorrhagic shock rather than that of TBI. The high specificity and low sensitivity of AASI for mortality may be related to the relative paucity of a high AASI (8.0%) and hypotension (4.1%). Hence, AASI can be used to predict trauma mortality with a good rule-in capability at the expense of high false-negativity at the initial presentation.

Median age and proportion of boys of the study population were comparable with those in a recent NTDB-based study[3]. However, the rates of high AASI and mortality, and the median ISS were higher in the current study than in the U.S. study (high AASI, 8.0% vs. 1.7%; mortality, 6.6% vs. 0.7%; median ISS, 16 [interquartile range, 9-25] vs. 5 [4-9])[3]. Although such a disparity between the 2 populations indicates a higher severity in the Korean center, high AASI was the strongest predictor of mortality in both studies. The difference in severities might affect the lower aOR of our study (6.4 vs. 22.0) considering that the U.S. study showed a lower aOR in major trauma (ISS < 16 vs. ≥ 16, 72.0 vs. 7.4)[3]. The sensitivity and specificity of AASI for mortality were similar to the 25.3% sensitivity and 98.4% specificity reported in the NTDB-based study[3], supporting the robustness of our finding.

Regardless of AASI, children with low GCS or young age may need trauma team activation, damage control resuscitation or brain surgery. GCS is a strong predictor of mortality. The recent Korean and U.S. studies have shown the AUCs of GCS for mortality ranging from 0.90 to 0.95[7,12]. In addition, according to the former study, the AUC of GCS approached that of BIG score (GCS, 0.90 vs. BIG score, 0.94)[7]. The younger median age of the non-survivors in our study corresponds with the previously reported values (survivors, 9.0-9.3 vs. non-survivors, 7.0-7.2 years)[13,14].

The strengths of AASI offer a theoretical benefit over RTS and PTS in the early prediction of mortality. First, AASI has fewer components than the other scores. It is difficult to measure respiratory rate as a component of RTS, and to discern age-adjusted tachypnea in toddlers or infants[7]. This drawback of RTS may weaken its strength resulting from the inclusion of GCS. Although a PTS of less than 8 suggests the need for transfer to trauma centers[15], it is less pragmatic to apply such a complex scoring system at presentation. Second, AASI may have a better utility in the early phase of hemorrhagic shock than the other scores. This predictor is least affected by hypotension that becomes evident after at least 45% blood loss[16]. Unlike systolic blood pressure, heart rate is the unique component of AASI, and accelerates more prominently in children than in adults[17]. The association of mortality with BIG score or ISS was not analyzed because we focused on the utility of AASI prior to obtaining laboratory or imaging findings.

In this study, high AASI was also related to all trauma scores and implemented hemorrhage-related procedures. A German adult study based on a trauma dataset confirmed the associations of SI with ISS, infused volumes of fluids and blood products, drop in hemoglobin concentration, coagulopathy, and mortality[1]. The aforementioned NTDB-based study shows the associations of AASI with transfusion, surgical interventions, hospitalization to intensive care units, and mortality[3]. Thus, AASI may be used to predict hemorrhage-related outcomes other than mortality.

This study has some limitations. First, 41.3% of the eligible population was excluded due to missing data on the trauma scores. This flaw inadvertently led to the exclusion of trivial injury. Second, given the variable age-adjusted ranges of vital signs, we could not analyze SI as a continuous variable. As such, we were unable to compare the performance of SI to those of other scores using receiver operating characteristic curves. Third, measuring vital signs is technically difficult and readily affected by emotional stress, such as crying. Although this inherent feature might have lowered the utility of AASI, we could not repeat the measurement because it was not a routine practice in the center.

Briefly, AASI is associated with trauma mortality in Korean children, which makes it a useful initial predictor of mortality. This predictor has a good rule-in capability at the expense of high false-negativity. Emergency physicians or pediatricians can predict adverse outcomes of trauma using AASI, and subsequently amend the assessment with laboratory and imaging findings.

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Conflicts of interest

No potential conflicts of interest relevant to this article were reported.

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