Original Article

Can the shock index be a reliable predictor of early mortality after trauma in older patients? A retrospective cohort study

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Aim: Older patients have different physiological characteristics; thus, the reliability of the shock index (SI) to predict mortality could depend on age. We investigated whether the SI is a reliable predictor of early mortality in older patients and evaluated the clinical benefit of age in the interpretation of the SI.

Methods: Using data from the Japan Trauma Data Bank, we identified injured patients aged 20–84 years. Area under the receiver operating characteristic curve (AUC) was used to evaluate the discrimination ability of the SI to predict early mortality. A formula to determine the cut-off for each age was derived using linear regression analysis. Performance of the new method was compared with that of the traditional SI cut-off of ≥0.9 AUC.

Results: We analyzed data from 146,802 patients. Early mortality was observed in 4% of patients. The AUC showed a significant negative correlation with age (Spearman's $\rho = -0.97$, $P < 0.001$), and it decreased from 0.788 (95% confidence interval [CI], 0.761–0.815) in the 20–24 years age group to 0.660 (95% CI, 0.643–0.676) in those aged 80–84 years. By adjusting for age in the SI interpretation, AUC significantly improved from 0.681 (95% CI, 0.675–0.688) to 0.695 (95% CI, 0.688–0.701) ($P < 0.001$).

Conclusions: The performance of the SI to predict mortality after trauma was significantly worse in older patients. Even if the SI cut-off value was adjusted based on age, the decrease in performance was not sufficiently prevented. Our results indicated that clinicians should be cautious when using the SI in older patients.

Key words: Emergency room (ER), shock, trauma

INTRODUCTION

TRAUMA IS A leading cause of mortality worldwide.[1] The use of reliable predictors of mortality can improve outcomes for trauma patients by providing accurate triage and referral of patients to centers capable of caring for the critically injured.

Outcome predictors include vital signs, blood test results, mechanism of injury, the Injury Severity Score (ISS),[2] radiological findings, and a combination of these.[3] Although scoring systems can quantify injury severity, they are not practical in acute settings because they are often based on predictive models using regression techniques or require complete knowledge of injuries before mortality can be predicted.

The shock index (SI), defined as heart rate (HR) divided by systolic blood pressure (BP), has been shown to be a better predictor of various outcomes.[4,5] The SI is currently widely used by physicians because of its attractive features, such as simplicity, great interobserver reliability,[6] and ability to assess hemodynamic status unaffected by compensation.[7] An SI threshold of ≥0.9 has been previously used to predict mortality after trauma in adult patients.[4,5,8] However, because patients have decreased maximum HR,[9] relatively high baseline BP,[10] and reduced physiological compensatory mechanisms as they age,[11] some studies have shown that the optimal SI cut-off value should be adjusted based on age and that the SI multiplied by age (Age SI) is a better predictor of mortality following traumatic injury of an elderly patient.[12]

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This study aimed to investigate whether the SI can be a reliable predictor of early mortality in older patients and evaluate the clinical benefit of age in the interpretation of SI.

METHODS

Data source

WE UNDERTOOK A retrospective cohort study using data from the Japan Trauma Data Bank (JTDB), which was established in 2003 by the Japanese Association for the Surgery of Trauma (Trauma Registry Committee) and the Japanese Association for Acute Medicine (Committee for Clinical Care Evaluations). The JTDB aims to collect nationwide data on trauma patients in Japan, including patient characteristics, vital signs on hospital arrival, information on inspection and treatment, diagnosis, and information on hospital discharge.

During 2004–2015, a total of 256 emergency hospitals, including >95% of tertiary emergency medical centers in Japan, participated in the JTDB.[13] Registry data collected from the JTDB are compiled annually and disseminated in the form of research datasets.

Study population and definition of variables

This study included injured patients aged 20–84 years. The exclusion criteria were as follows: (i) burn injuries, (ii) cardiac arrest (systolic BP = 0 or HR = 0) on hospital arrival, (iii) missing values for systolic BP and/or HR on arrival, (iv) outliers in systolic BP or HR on arrival, (v) unknown final outcome (early mortality). Patients with burn injuries were excluded to avoid heterogeneity in trauma etiology. Patients with systolic BP = 0 or HR = 0 were excluded as their expected survival rate was extremely low. Patients with missing values or outliers for systolic BP, HR, and/or mortality were excluded because the discriminatory ability of SI to predict mortality could not be calculated in these cases.

For each eligible patient, the SI was calculated by dividing admission HR (b.p.m.) by the admission systolic BP (mmHg). The primary end-point of early mortality, a death that occurred within 2 days after admission, was defined on the basis of a previous study.[12]

Statistical analysis

First, we calculated the area under the receiver operating characteristic (ROC) curve (AUC), sensitivities, specificities, and corresponding 95% confidence intervals (CIs) of the SI with a cut-off ≥0.9, which has been reported to predict mortality after trauma in adult patients,[4,5] with no adjustment for age, for 5-year age increments (20–24, 25–29, 30–34, . . ., 80–84 years). Second, ROC curve analysis was used to determine the optimal SI cut-off value that maximizes the sum of sensitivity and specificity for the prediction of mortality for 5-year age increments. The calculated optimal cut-off values were then plotted against the midpoint of the interval (i.e., 22 for 20–24 years, 27 for 25–29 years, . . ., 82 for 80–84 years). Linear regression analysis was used to derive a formula that determined the cut-off value for each age. Finally, we calculated and compared the AUCs of the three methods (SI with a cut-off ≥0.9, Age SI, and SI with a cut-off based on the formula) to predict mortality. For the Age SI, we used the cut-off values of ≥35.6 and ≥48.8 for the analysis of patients aged ≤55 years and >55 years, respectively.[12] We used Delong's test to compare the AUCs of two correlated curves.

Outliers were identified using the Smirnov–Grubbs test. Correlation between two nonparametric variables were estimated using Spearman's rank correlation test. For descriptive statistics, numeric variables were presented as medians with interquartile ranges (IQRs) and compared using the Mann–Whitney *U*-test. Categorical variables were presented as counts and percentages and tested for significance using the χ^2-test or Fisher's exact test. Missing data were handled using the pairwise method. All statistical tests were two-tailed, and a *P*-value of <0.05 was considered significant. All statistical analyses were undertaken using EZR, a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria).[14]

RESULTS

BETWEEN 2004 AND 2015, a total of 236,698 patients were registered in the JTDB, of whom 184,654 met the initial study criteria. After 37,852 patients were excluded, 146,802 were ultimately eligible for analysis (Fig. 1). Patient characteristics are shown in Table 1. The median age was 60 years (IQR, 41–73), and the majority (66%) of patients were men. Most cases were blunt injuries (94%). The cause of trauma was accident in most cases (90%), and suicide attempts and assault injuries were rare, accounting for 6% and 2%, respectively. The most frequent etiology was falls (46%), followed by traffic accidents (40%). The median ISS was 13 (IQR, 9–20). The median SI was 0.61 (IQR, 0.50–0.75), and 19,489 (13%) had an SI ≥0.9. Of the 146,802 included patients, 5,911 (4%) died within 2 days after admission.

The performance of the SI with a cut-off of ≥0.9 to predict early mortality after trauma is summarized in Table 2, and AUCs are plotted against age in Figure 2. The AUC showed a significant negative correlation with age (Spearman's

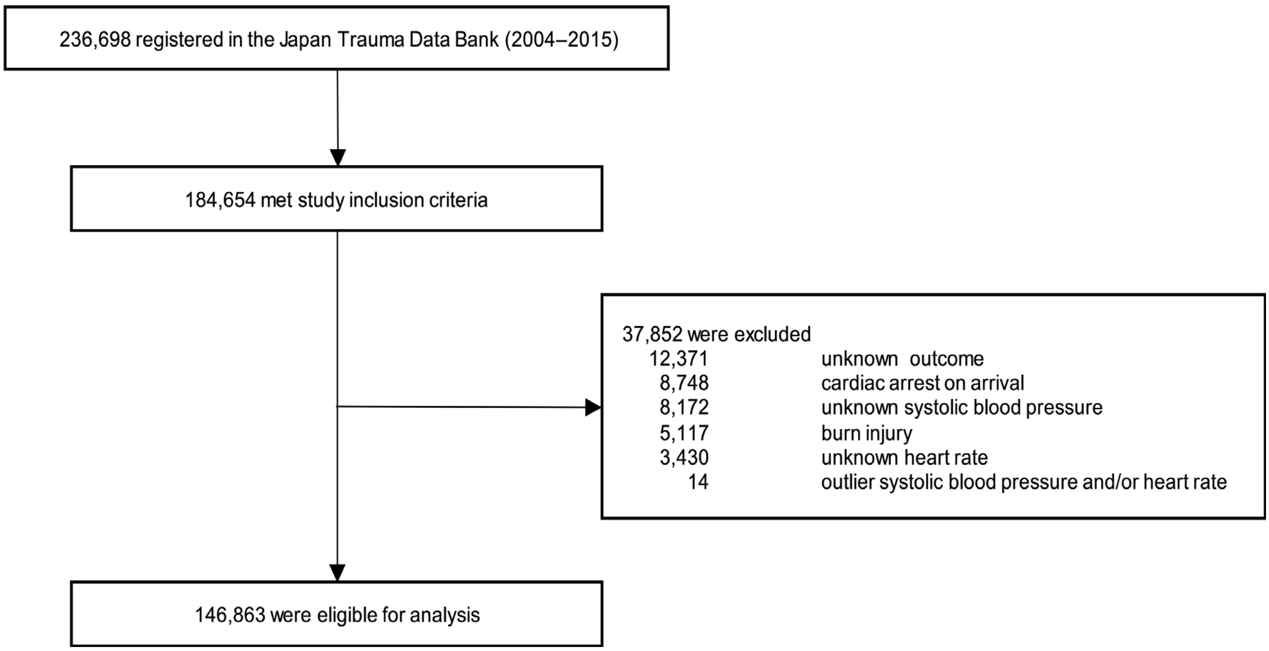

Fig. 1. Flowchart showing the enrollment of trauma patients.

Table 1. Baseline characteristics of injured patients aged 20–84 years

No. of patients	146,802
Age, years	60 [41–73]
Male	97,440 (66)
Blunt injury	138,004 (94)
Cause of trauma	
Accident	131,482 (90)
Suicide attempt	8,477 (6)
Assault	2,545 (2)
Other	686 (0)
Unknown	3,612 (2)
Etiology of trauma	
Fall	64,634 (44)
Traffic accident	58,555 (40)
Other	18,702 (13)
Unknown	4,911 (3)
Systolic blood pressure on arrival, mmHg	135 [116–156]
Heart rate on arrival, b.p.m.	83 [72–96]
Injury Severity Score	13 [9–20]
Shock index	0.61 [0.50–0.75]
Shock index ≥0.9	19,489 (13)
Early mortality	5,911 (4)

Data are presented as number (%) or median [interquartile range Q1–Q3].

$\rho = -0.97$, $P < 0.001$), and it decreased from 0.788 (95% CI, 0.761–0.815) in 20–24 years to 0.660 (95% CI, 0.643–0.676) in 80–84 years. The results of same analyses but with early mortality defined as a death that occurred on the day of admission or the day after admission are shown in Table S1 and Figure S1.

Results of the ROC curve analysis are summarized in Table 3. The linear regression analysis showed that optimal SI cut-off values can be expressed by "SI cut-off value = 1.035 − 0.0035 × age" with a good model fit, with the adjusted R^2 value of 0.73. The results of the ROC curve analysis with early mortality defined as a death that occurred on the day of admission or the day after admission are shown in Table S2.

Table 4 shows the results of the AUC analyses. The AUC of SI with a cut-off based on the new formula (0.695 [95% CI, 0.689–0.702]) was significantly higher than those of SI with a cut-off of ≥0.9 (0.681 [95% CI, 0.675–0.688]) and Age SI (0.683 [95% CI, 0.677–0.690]) ($P < 0.001$ for each comparison). There was no significant difference between the AUCs of SI with a cut-off of ≥0.9 and Age SI ($P = 0.56$).

DISCUSSION

WE FOUND THAT the discrimination ability of the SI was significantly lower in older patients. The benefit

Table 2. Performance of the shock index with a cut-off of ≥0.9 to predict early mortality after trauma

Age category, years (midpoint)	No. of patients	Mortality rate, %	AUC (95% CI)	Sensitivity	Specificity
20–24 (22)	9,707	2.7	0.788 (0.761–0.815)	0.739 (0.682–0.792)	0.837 (0.830–0.845)
25–29 (27)	7,784	2.8	0.761 (0.730–0.791)	0.692 (0.627–0.752)	0.829 (0.820–0.837)
30–34 (32)	7,432	2.5	0.757 (0.723–0.790)	0.689 (0.616–0.755)	0.825 (0.816–0.833)
35–39 (37)	8,475	2.7	0.758 (0.727–0.788)	0.690 (0.626–0.749)	0.825 (0.817–0.833)
40–44 (42)	9,037	2.9	0.737 (0.707–0.767)	0.627 (0.565–0.686)	0.847 (0.840–0.855)
45–49 (47)	8,873	3.0	0.744 (0.714–0.773)	0.633 (0.572–0.691)	0.854 (0.846–0.861)
50–54 (52)	9,141	3.1	0.712 (0.683–0.741)	0.553 (0.493–0.612)	0.871 (0.864–0.878)
55–59 (57)	10,857	3.4	0.676 (0.651–0.702)	0.463 (0.412–0.516)	0.889 (0.883–0.895)
60–64 (62)	14,118	3.9	0.675 (0.654–0.696)	0.452 (0.411–0.495)	0.898 (0.892–0.903)
65–69 (67)	14,066	4.9	0.662 (0.644–0.681)	0.419 (0.381–0.456)	0.906 (0.901–0.911)
70–74 (72)	14,816	5.4	0.659 (0.642–0.677)	0.408 (0.373–0.442)	0.911 (0.906–0.916)
75–79 (77)	16,204	5.8	0.650 (0.634–0.665)	0.379 (0.348–0.411)	0.920 (0.916–0.924)
80–84 (82)	16,292	5.3	0.660 (0.643–0.676)	0.390 (0.357–0.423)	0.930 (0.926–0.934)

AUC, area under the receiver operating characteristic curve; CI, confidence interval.

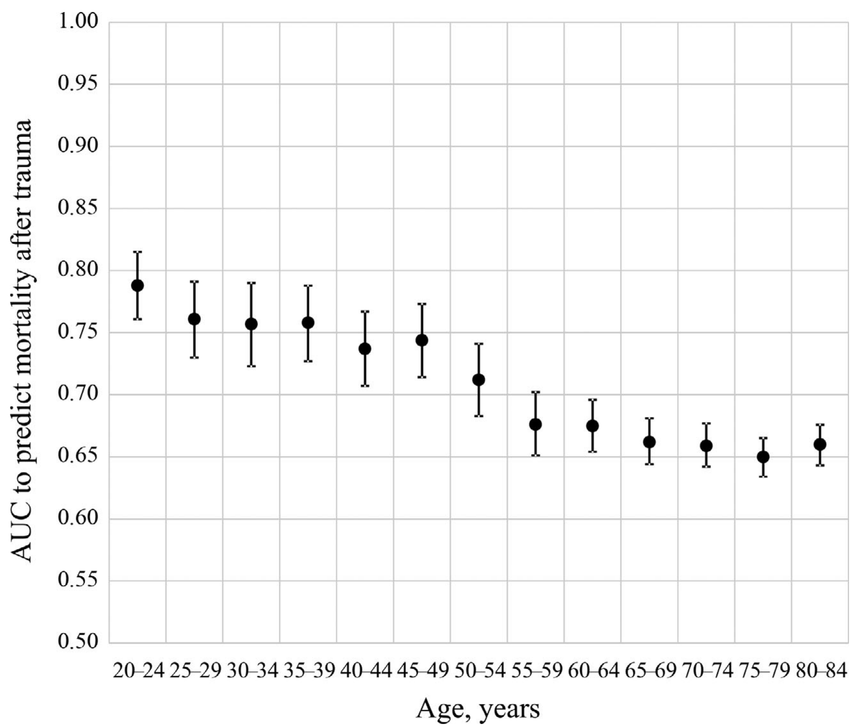

Fig. 2. Plot of the area under receiver operating characteristic curve (AUC) analysis of the shock index with a cut-off of ≥0.9 in predicting early mortality after trauma versus age.

of age in the interpretation of the SI was marginal, thus the SI was not a reliable predictor of early mortality, even when adjusted for age.

The results showed that the lower discrimination ability in older patients was attributable to lower sensitivity in older patients. Because older patients tended to have fatal

Table 3. Results of the receiver operating characteristic curve analysis to determine the optimal shock index cut-off value to predict early mortality after trauma

Age category, years	Mortality rate, %	Cut-off value of shock index	AUC (95% CI)
20–24	2.7	0.946	0.820 (0.784–0.856)
25–29	2.8	0.992	0.766 (0.680–0.844)
30–34	2.5	0.876	0.788 (0.743–0.833)
35–39	2.7	0.897	0.786 (0.746–0.826)
40–44	2.9	0.959	0.761 (0.722–0.799)
45–49	3.0	0.837	0.773 (0.735–0.811)
50–54	3.1	0.840	0.735 (0.695–0.774)
55–59	3.4	0.809	0.689 (0.654–0.724)
60–64	3.9	0.850	0.680 (0.651–0.710)
65–69	4.9	0.820	0.657 (0.630–0.683)
70–74	5.4	0.736	0.673 (0.649–0.697)
75–79	5.8	0.750	0.674 (0.652–0.696)
80–84	5.3	0.792	0.692 (0.670–0.714)

AUC, area under the receiver operating characteristic curve; CI, confidence interval.

Table 4. Comparison of the area under the receiver operating characteristic curves (AUC) of three versions of the shock index (SI) to predict early mortality after trauma

	AUC (95% CI)	*P* versus Age SI	*P* versus SI ≥ cut-off[†]
SI ≥ 0.9	0.681 (0.675–0.688)	0.56	<0.001
Age SI	0.683 (0.677–0.690)	–	<0.001
SI ≥ cut-off[†]	0.695 (0.689–0.702)	–	–

[†]Cut-off = 1.035 − 0.0035 × age.
–, not applicable; CI, confidence interval.

outcomes even if the SI was lower than the cut-off, we attempted to prevent the decrease in the discrimination ability by determining the optimal cut-off value according to age. The results of our study showed that interaction between age and physiological compromise could be well captured by a simple linear regression model. Actually, the model provided lower cut-off values for older patients and improved the accuracy of the SI in predicting mortality. However, the improvement in the discrimination ability of the SI to predict early mortality using the SI cut-off value based on age was marginal. It indicates that outcomes of older patients were determined by other factors that were not related to the SI on arrival.

It is well known that patients have different baseline vital sign characteristics and reduced physiological compensatory mechanisms as they age.[11] Older patients have decreased physiological tolerance, a higher prevalence of comorbidities, and tend to have poor outcomes after injury.[15] Considering the effects of age on vital signs and outcomes, it is plausible that performance of the SI as a predictive factor depends on age.

One of the methods to address the effects of age on SI is Age SI. Age SI was reported to be a significantly better predictor than SI alone for predicting mortality following traumatic injury of elderly patients.[12,16] In the present study, however, there was no significant improvement in the performance of mortality prediction using Age SI compared to SI with a cut-off ≥0.9, whereas our new method did. Although our method and Age SI both capture a mathematical interaction between age and physiological compromise, the results of our study indicated a linear relationship between the optimal SI cut-off value and age and using a simple linear regression model could be a better way to capture the effects of age on physiological compromise. Nevertheless, it should be noted again that the benefit of age in the interpretation of the SI was clinically marginal, even if the SI was interpreted using our method. Thus, SI might not be a reliable indicator, especially in older patients.

Given the age-related decreases in the SI ability for predicting early mortality, it should be noted that physicians and emergency medical service personnel should not be quick to judge patients with low SI on admission as "low risk," especially in older patients, because older patients can be at risk of early mortality irrespective of the SI on admission.

This study had potential limitations. First, penetrating injuries accounted for only 6% of included patients, even though we included all patients in the database with injuries other than burns. Although penetrating injuries are responsible for no more than 15% of traumatic deaths worldwide,[17] our results warrant external validation in other cohorts. Second, the JTDB did not provide information regarding medication use before injury. Considering that detailed information is often unavailable immediately after severe injury, this study estimated the accuracy of predictors in the real-world setting of emergency medicine. However, it could be desirable to adjust for the effect of medications that might influence vital signs, such as beta-blockers or calcium channel blockers. Finally, the outcome and performance of the SI after trauma can be influenced by demographic, medical, economic, and social circumstances. Hence, our results warrant external validation.

CONCLUSIONS

THE PERFORMANCE OF the SI to predict mortality after trauma was significantly worse in older patients. Even if the SI cut-off value was adjusted based on age, the decrease in performance was not sufficiently prevented. Our results indicated that clinicians should be cautious when using the SI in older patients.

DISCLOSURE

Approval of the research protocol: The protocol for this research project was approved by a suitably constituted Ethics Committee of Tokyo Metropolitan Bokutoh Hospital (approval no. 30-037) and it conforms to the provisions of the Declaration of Helsinki.
Informed consent: The need for informed consent was waived because data were collected from existing patient records, and the De-identification Standard was followed to protect the confidentiality of personal information.
Registry and registration no. of the study/trial: N/A.
Animal studies: N/A.
Conflict of interest: None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1. Plot of the area under the receiver operating characteristic curve analysis of the shock index with a cut-off of ≥0.9 in predicting mortality after trauma versus age.

In this analysis, early mortality was defined as a death that occurred on the day of admission or the day after admission.

Table S1. Performance of the shock index with a cut-off of ≥0.9 to predict early† mortality after trauma

Table S2. Results of the receiver operating characteristic curve analysis to determine the optimal shock index cut-off value to predict early† mortality