scientific reports

OPEN

Age-specific assessment of initial hemoglobin levels and shock index for predicting life-saving interventions in pediatric blunt liver and spleen injuries

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This study aimed to evaluate the effectiveness of combining initial hemoglobin levels with the shock index for predicting the need for life-saving interventions (LSI) in pediatric patients with blunt liver and spleen injuries (BLSI), specifically tailored to different age groups. This was a multicenter retrospective cohort study of pediatric patients with BLSI in Japan. The area under the receiver operating characteristic curve (AUROC) were used to assess predictive accuracy. The study included 1,370 patients. LSI was required in 59 of 247 (23.9%) aged 1 to 6 years, 100 of 402 (24.9%) aged 7 to 12 years, and 125 of 297 (42.1%) patients aged 13 to 16 years. Within each specific age group, the predictability was categorized as fair and appeared higher than that of the entire cohort or when using either parameter alone. Notably, in the 1 to 6-year age group, the combined values showed the highest predictability, which was statistically superior to the shock index alone (AUROC of 0.770 vs. 0.671, P = 0.025). Tailoring initial hemoglobin levels and shock index to specific age groups enhances predictability of LSI in pediatric BLSI, showing a fair level of predictive accuracy.

Keywords Abdominal injuries, Blood transfusions, Hemoglobin, Hemostasis, Shock index

Abdominal injuries represent about 25% of major trauma incidents in pediatric patients. The majority of these abdominal traumas are of a blunt nature, predominantly affecting the liver and spleen[1,2]. Delayed intervention may lead to fatal consequences. Therefore, it is critical to identify simple, reliable, and objective predictors that can be used for the early identification of patients who will most benefit from timely and effective management[3,4].

An earlier study suggested that a lower initial hematocrit was associated with intra-abdominal injuries following pediatric blunt trauma[5]. A recent large study also emphasized that initial low hemoglobin level was linked to failure of non-operative management, as well as the need for blood transfusions, in pediatric patients with blunt liver and spleen injuries (BLSI)[6]. Importantly, normal hemoglobin values vary across different age groups, necessitating the evaluation of hemoglobin based on specific age categories[7].

The shock index, defined as the heart rate to systolic blood pressure ratio, is commonly employed as a predictor of mortality in trauma patients. In pediatric trauma cases, the shock index pediatric age-adjusted (SIPA) has proven to be superior to shock index unadjusted for age in identifying severely injured children who require early transfusion, emergency surgery, or are at risk for death[8,9]. Of note, SIPA has been demonstrated to

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be useful in the management of children with BLSI[10]. Considering age-related variations in shock index is crucial for a more accurate assessment in pediatric trauma care, especially in predicting need for urgent interventions.

Given these findings, we hypothesized that the combination of hemoglobin levels and shock index in age-specific groups would be more useful in predicting the need for life-saving interventions (LSI) in pediatric BLSI.

Accordingly, we seek to analyze the utility of initial hemoglobin levels in conjunction with the shock index based on age-specific categories, as predictors for LSI, using a cohort study of pediatric BLSI cases in Japan.

Methods
Study design
This was a pre-planned sub-analysis of the SHIPPs (Splenic and Hepatic Injury in Pediatric Patients) study, which was a multicenter retrospective cohort study. The SHIPPs study involved 83 institutions and included 1,462 pediatric patients (≤ 16 years of age) with BLSI from 2008 to 2019 in Japan[11]. The SHIPPs study included patients admitted to an emergency care setting with at least an Abbreviated Injury Scale (AIS) grade ≥ I BLSI, as detected by any imaging method or operative findings. This study conforms to the principles outlined in the Declaration of Helsinki. Okayama University Hospital Ethics Committee approved the study on December 23, 2022. The approval was for the study titled 'Age-specific assessment of initial hemoglobin levels and shock index for predicting life-saving interventions in pediatric blunt liver and spleen injuries', under Study ID: K2302-006. Furthermore, the committee waived the requirement for written informed consent. The study followed the Standards for Reporting of Diagnostic Accuracy (STARD) reporting guidelines for diagnostic accuracy studies[12].

Study participants
Among the study candidates, we excluded those who had duplicated records due to inter-hospital transfers, as well as cases with an AIS of 6 in any body region or treatment limitations due to severe traumatic brain injury (TBI), defined as a head AIS ≥ 5[11] we further excluded patients who were younger than 1 year old because the SIPA was not defined for this age group[13]. Additionally, we excluded those with missing data on systolic blood pressure, heart rate at arrival, or initial hemoglobin levels.

Grouping and definitions
Patients were divided into three age-groups based on previous studies regarding SIPA: 1 to 6 years old, 7–12 years old, and 13 to 16 years old[8,9,13–15]. Abnormal SIPA was defined as greater than 1.2 for the 1 to 6-year-old age group, greater than 1.0 for the 7 to 12-year-old age group, and greater than 0.9 for the 13 to 16-year-old age group, based on these studies. In cases where patients were transferred from another hospital, their vital signs and laboratory data from the first-visit facility were used if available.

Outcomes
Our primary outcome was the necessity for LSI. LSI was defined as the requirement for any component of blood transfusion or the need for transcatheter arterial embolization or laparotomy due to bleeding from BLSI[10,14,16]. Blood transfusion components included packed red blood cells, fresh frozen plasma, platelets, cryoprecipitate, or fibrinogen administered within 24 h of hospital arrival, regardless of BLSI severity. We examined two secondary outcomes: 1) hemostatic interventions for bleeding due to BLSI including transcatheter arterial embolization or laparotomy, and 2) blood transfusions within 24 h of hospital arrival.

Statistical analysis
Continuous variables are shown as median and interquartile range values, unless otherwise described. Categorical variables are presented as frequencies and percentages. Comparisons between two groups were made using the Mann–Whitney U test for continuous variables and chi-square test for categorical variables. We evaluated the predictability of the need for LSI by analyzing initial hemoglobin levels and shock index values for all ages and across three age groups. The predictive accuracy in each of these categories was determined using the area under the receiver operating characteristic curve (AUROC). The cut-off value for prediction was established using the Youden index. Next, we performed a binary logistic regression analysis with the need for LSI as the dependent variable and initial hemoglobin levels and shock index as covariates. This analysis yielded predicted probabilities, from which we derived the AUROC to assess the combined predictability of initial hemoglobin levels and the shock index for determining the need for LSI. To interpret the AUROC values, we adopted the following standard categorical ratings: 0.5 to 0.6 as failed, 0.6 to 0.7 as poor, 0.7 to 0.8 as fair, 0.8 to 0.9 as good, and 0.9 to 1.0 as excellent[17,18]. When evaluating the performance of two or more diagnostic tests, a higher AUROC value generally indicates better diagnostic accuracy[18]. To conduct statistical comparisons between the AUROCs of different models within the same cohort, we employed the Z statistic for pairwise comparisons, thereby determining any significant differences in their diagnostic accuracy[19].

As sensitivity analyses, we excluded patients transferred to or from other hospitals. Additionally, we conducted another sensitivity analysis excluding those who had severe TBI, defined as a head Abbreviated Injury Scale score of 4 or 5, which can potentially affect the shock index[20].

All tests were two-tailed, and a P value of < 0.05 was considered statistically significant. We performed all statistical analysis using IBM SPSS Statistics 26 (IBM SPSS, Chicago, IL), Prism 10.0.3 (GraphPad, San Diego, CA), and Microsoft Excel for Mac Version 16.79.2.

Results
Among 1,462 patients registered in the SHIPPs study, 1,370 were included in the final analysis as shown in Fig. 1. Of these, 365 were aged 1 to 6 years, 619 were aged 7 to 12 years, and 386 were aged 13 to 16 years.

Patient characteristics

The baseline characteristics of each age category patient cohort are presented in Table 1 and Table S1. Initial hemoglobin levels were significantly lower in the LSI group compared to the no LSI group: 10.7 vs. 12.1 g/dL in the 1 to 6-year age group; 11.8 vs. 12.6 g/dL in the 7 to 12-year age group; and 12.9 vs. 13.6 g/dL in the 13 to 16-year age group, with $P < 0.001$ for each comparison, respectively. Meanwhile, the shock index was significantly higher in the LSI group: 1.27 vs. 1.10 in the 1 to 6-year age group; 0.96 vs. 0.85 in the 7 to 12-year age group; and 0.83 vs. 0.69 in the 13 to 16-year age group, with $P < 0.001$ for each comparison, respectively. There were no patients who died from hemorrhagic shock due to BLSI without receiving any LSI.

Outcomes

Table 2 presents the outcomes for specific age groups. LSI were required in 92 out of 365 patients (25.2%) aged 1 to 6 years, 139 out of 619 patients (22.5%) aged 7 to 12 years, and 154 out of 386 patients (39.9%) aged 13 to 16 years, respectively. In terms of hemostatic procedures, transcatheter arterial embolization was more commonly performed than laparotomy across all age groups. A majority of patients in each group received blood transfusions within 24 h of hospital arrival.

Primary outcome

Table 3 shows the predictability for all ages and for specific age groups of hemoglobin levels, shock index values, and their combination in predicting the need for LSI. The ROC curves for hemoglobin, shock index, and their combination for the entire cohort and age-specific groups are illustrated in Fig. 2. Both initial hemoglobin levels and shock index demonstrated improved predictive performance for LSI in age-specific groups compared to the entire cohort encompassing all ages. Cut-off values for hemoglobin, determined by the Youden index, were 10.8 g/dL for the 1 to 6-year age group, 11.9 g/dL for the 7 to 12-year age group, and 12.1 g/dL for the 13 to 16-year age group. Similarly, cut-off values for the shock index were 1.20 for the 1 to 6-year age group, 1.03 for the 7 to 12-year age group, and 0.93 for the 13 to 16-year age group. When combining hemoglobin levels and the shock index, the predictability for the entire cohort was categorized as poor, with an AUROC of 0.665 (95% CI, 0.630 to 0.700). In contrast, predictability was categorized as fair within each specific age group. In the 1 to 6-year

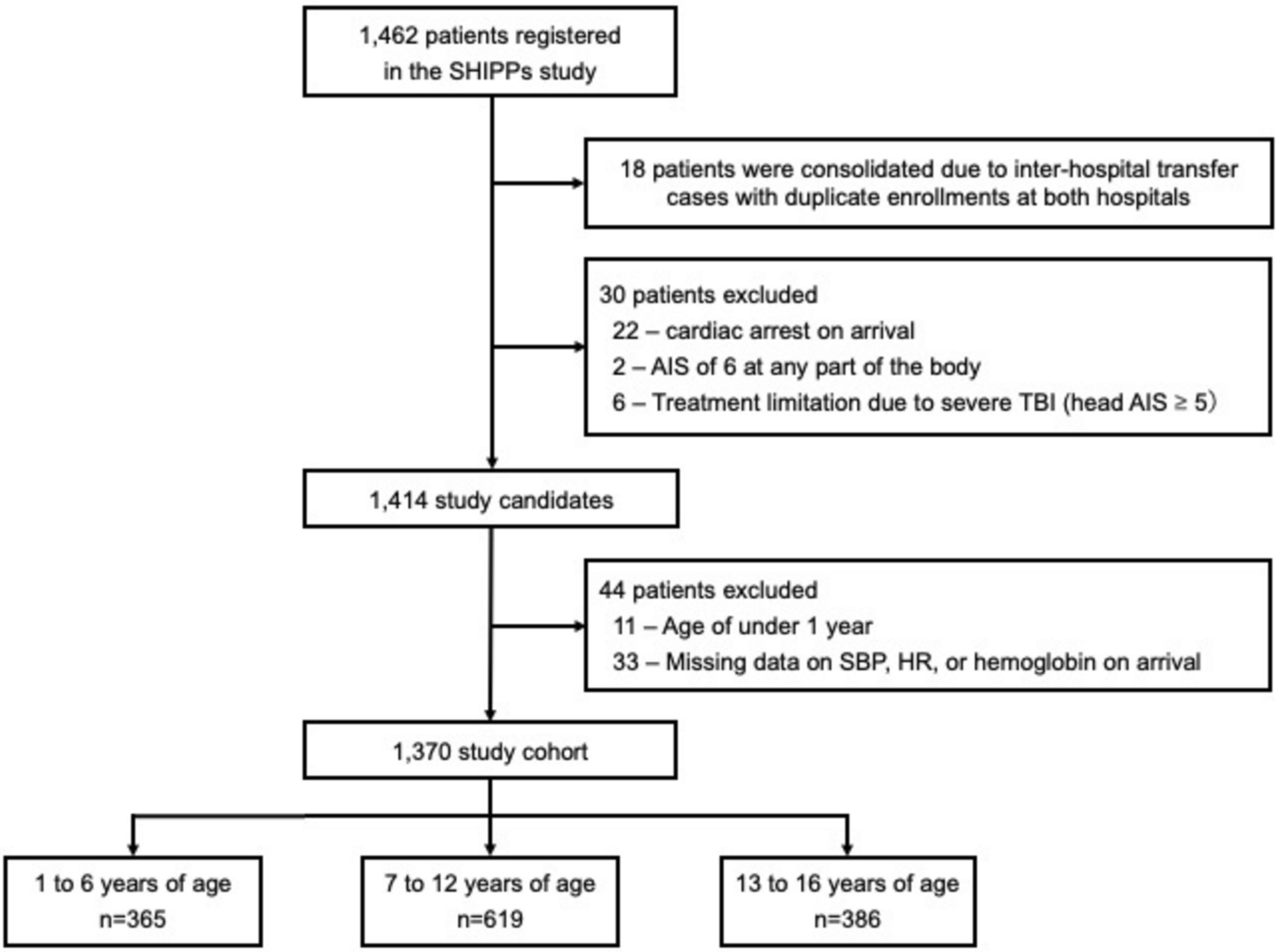

Fig. 1. Flow chart of the study participants. AIS: Abbreviated Injury Scale, TBI: traumatic brain injury, SBP: systolic blood pressure, HR: heart rate

	All ages			1 to 6 years of age			7 to 12 years of age			13 to 16 years of age		
	LSI	no LSI		LSI	no LSI		LSI	no LSI		LSI	no LSI	
	n = 385	n = 985	P value	n = 92	n = 273	P value	n = 139	n = 480	P value	n = 154	n = 232	P value
Age (years), median [IQR]	11 (7, 15)	9 (6, 12)	< 0.001	4 (3, 6)	4 (3, 6)	0.794	10 (8, 11)	9 (8, 11)	0.012	15 (14, 16)	15 (14, 16)	0.196
00000Male sex, n (%)	261 (67.8)	659 (66.9)	0.753	58 (63.0)	156 (57.1)	0.320	95 (68.3)	333 (69.4)	0.817	108 (70.1)	170 (73.3)	0.500
Transfer cases			0.207			0.176			0.599			0.237
Transfer to another hospital, n (%)	1 (0.3)	6 (0.6)		0 (0)	3 (1.1)		0 (0)	3 (0.6)		1 (0.6)	0 (0)	
Transfer from another hospital, n (%)	109 (28.3)	289 (29.3)		29 (31.5)	76 (27.8)		45 (32.4)	161 (33.5)		35 (22.7)	52 (22.4)	
Bi-directional transfer cases, n (%) [a]	8 (2.1)	10 (1.0)		5 (5.4)	5 (1.8)		2 (1.4)	5 (1.0)		1 (0.6)	0 (0)	
Vital signs on arrival												
Glasgow Coma Scale, median [IQR]	12 (9, 13)	13 (13, 13)	< 0.001	11 (8, 13)	13 (12, 13)	< 0.001	13 (11, 13)	13 (13, 13)	< 0.001	12 (9, 13)	13 (13, 13)	< 0.001
Respiratory rate (/min), median [IQR]	24 (20, 30)	24 (20, 28)	0.001	28 (24, 36)	26 (22, 30)	0.020	24 (20, 30)	23 (20, 27)	0.001	23 (18, 28)	20 (18, 24)	0.016
Heart rate (beats/min), median [IQR]	110 (93, 134)	100 (85, 117)	< 0.001	140 (117, 154)	121 (109, 141)	< 0.001	108 (93, 130)	98 (87, 110)	< 0.001	100 (82, 114)	84 (74, 97)	< 0.001
Systolic blood pressure (mmHg), median [IQR]	112 (95, 126)	115 (104, 127)	< 0.001	103 (90, 120)	110 (100, 121)	0.001	112 (96, 124)	115 (106, 126)	0.008	117 (97, 130)	121 (110, 134)	0.007
Temperature (℃), median [IQR]	36.6 (36.0, 37.1)	36.8 (36.5, 37.2)	< 0.001	36.5 (36.0, 37.2)	36.8 (36.5, 37.4)	0.001	36.8 (36.2, 37.2)	36.8 (36.6, 37.2)	0.053	36.6 (35.9, 37.0)	36.9 (36.5, 37.2)	< 0.001
Shock index, median [IQR]	0.98 (0.78, 1.30)	0.86 (0.72, 1.01)	< 0.001	1.27 (1.09, 1.59)	1.10 (0.93, 1.30)	< 0.001	0.96 (0.80, 1.21)	0.85 (0.74, 0.95)	< 0.001	0.83 (0.67, 1.09)	0.69 (0.60, 0.81)	< 0.001
Abnormal SIPA, n (%)b	184 (47.8)	199 (20.2)	< 0.001	59 (64.8)	98 (35.9)	0.001	63 (45.3)	72 (15.0)	< 0.001	62 (40.3)	29 (12.5)	< 0.001
Hemoglobin (g/dL), median [IQR]	11.8 (10.2, 13.1)	12.6 (11.7, 13.4)	< 0.001	10.7 (9.8, 11.9)	12.1 (11.2, 12.7)	< 0.001	11.8 (10.2, 12.6)	12.6 (11.9, 13.3)	< 0.001	12.9 (10.9, 13.9)	13.6 (12.5, 14.8)	< 0.001
Type of injury			< 0.001			0.423			< 0.001			0.002
Liver injury, n (%)	181 (47.0)	613 (62.2)		59 (64.1)	189 (69.2)		45 (32.4)	290 (60.4)		77 (50.0)	134 (57.8)	
Spleen injury, n (%)	171 (44.4)	351 (35.6)		26 (28.3)	72 (26.4)		81 (58.3)	184 (38.3)		64 (41.6)	95 (40.9)	
Both liver and spleen injury, n (%)	33 (8.6)	21 (2.1)		7 (7.6)	12 (4.4)		13 (9.4)	6 (1.3)		64 (41.6)	3 (1.3)	
Injury Severity Score, median [IQR]	20 (12, 33)	9 (4, 14)	< 0.001	22 (13, 29)	9 (5, 17)	< 0.001	17 (9, 29)	9 (4, 14)	< 0.001	23 (14, 36)	9 (4, 14)	< 0.001
Injury grade [b]												< 0.001
Liver injury, n (%)			< 0.001			< 0.001			< 0.001			< 0.001
I/II	77 (20.0)	460 (46.7)		17 (18.5)	163 (59.7)		20 (14.4)	202 (42.1)		40 (26.0)	95 (40.9)	
III	64 (16.6)	139 (14.1)		21 (22.8)	33 (12.1)		17 (12.2)	70 (14.6)		26 (16.9)	36 (15.5)	
VI	62 (16.1)	34 (3.5)		26 (28.3)	5 (1.8)		18 (12.9)	23 (4.8)		18 (11.7)	6 (2.6)	
V	11 (2.9)	1 (0.1)		2 (2.2)	0 (0)		3 (2.2)	1 (0.2)		6 (3.9)	0 (0)	
Spleen injury, n (%)			< 0.001			< 0.001			< 0.001			< 0.001
I/II	42 (11.0)	201 (20.4)		10 (10.9)	54 (19.8)		14 (10.1)	95 (19.8)		18 (11.7)	52 (22.4)	
III	59 (15.3)	128 (13.0)		5 (5.4)	24 (8.8)		30 (21.6)	69 (14.4)		24 (15.6)	35 (15.1)	
VI	71 (18.4)	38 (3.9)		11 (12.0)	5 (1.8)		32 (23.0)	24 (5.0)		28 (18.2)	9 (3.9)	
V	32 (8.3)	5 (0.5)		7 (7.6)	1 (0.4)		18 (12.9)	2 (0.4)		7 (4.5)	2 (0.9)	

Table 1. Characteristics of the overall study population and age-specific groups. [a] Cases recorded as transfers to and from another hospital within the database. [b] The American Association for the Surgery of Trauma Organ Injury Scale grade (2018 revision). IQR: interquartile range, SIPA: shock index pediatric age-adjusted, AIS: Abbreviated Injury Scale.

age group, the shock index in conjunction with the initial hemoglobin levels demonstrated statistically superior predictive performance compared to the shock index alone (AUROC of 0.770 vs. 0.671, $P = 0.025$; $Z = 2.245$).

Secondary outcomes

As for the secondary outcomes, hemostatic interventions including transcatheter arterial embolization or laparotomy due to BLSI was required in 61/365 (16.7%) for the 1 to 6-year age group, 110/619 (17.8%) for the 7 to 12-year age group, and 110/386 (28.5%) for the 13 to 16-year age group. While any blood transfusions within 24 h of hospital arrival was required in 75/365 (20.5%) for the 1 to 6-year age group, 84/619 (13.6%) for the 7 to 12-year age group, and 99/386 (25.6%) for the 13 to 16-year age group. The AUROC appeared to decrease when utilized to predict the need for hemostatic interventions including transcatheter arterial embolization or laparotomy for BLSI, in comparison to predicting the need for LSI (Table S2 & Figure S1). Conversely, the AUROC appeared to increase when predicting the necessity for blood transfusions within 24 h of hospital arrival, in comparison to predicting the need for LSI (Table S3 & Figure S2).

Sensitivity analysis

A sensitivity analysis is presented in Table S4 and Figure S3, where patients transferred to or from other hospitals were excluded. Another sensitivity analysis, which excluded patients with severe TBI, are detailed in Table S5 and Figure S4. Similar results were obtained: combined variables, categorized by age, improved predictive performance for LSI compared to either parameter alone or a combined assessment in the entire cohort.

Discussion

In this multicenter retrospective cohort study, we found that the combined use of initial hemoglobin levels and the shock index, when tailored to specific age groups, consistently yielded a fair level of predictive performance. This was in contrast to the lower predictive accuracy observed when applying either parameter alone or a combined assessment to the entire cohort for determining the need for LSI in pediatric patients with BLSI. Specifically, the predictability of combined values significantly improved in the 1 to 6-year age group compared to the shock index alone. The utility of this approach is highlighted by our findings that hemoglobin levels and shock index cutoff values vary among different age groups. These variations enhance the predictability of the need for LSI in these diverse pediatric populations.

Although normal hemoglobin levels vary among different races/ethnicities and regions[21], in general, pediatric populations tend to have lower normal hemoglobin values that increase with age: approximately 12.5 g/dL for ages 2 to 6 years; 13.5 g/dL for 6 to 12 years; and 14.5 g/dL for males and 14.0 g/dL for females between 12 to 18 years[7]. The observation that the highest predictive performance for the need for LSI is found in the 1 to 6-year age group suggests that children in this age group may reach critical thresholds more rapidly in the event of trauma, likely due to their generally lower hemoglobin levels. The cut-off values we obtained for the shock index are in near-perfect alignment with those previously suggested by SIPA: > 1.2 for the 1 to 6-year-old age group, > 1.0 for the 7 to 12-year-old age group, and > 0.9 for the 13 to 16-year-old age group[8,9,13,15,22]. In the 1 to 6-year age group, the potential reason that combined variables are statistically superior to shock index alone could be that tachycardia in younger children is more frequently induced by factors such as pain and agitation, rather than solely by hypovolemic shock[23]. The variation in AUROC across different age groups may be in part attributed to the fact that injury patterns differ among these groups. Analysis of baseline characteristics reveals significant demographic variability across age groups, as demonstrated in previous studies[24,25], which could markedly affect the AUROC. For instance, injury due to falls from height exhibit distinct patterns in various age cohorts. The proportion of pedestrian injuries is higher among younger children.

In our secondary outcome analyses, we observed a variation in the AUROC when predicting different outcomes: the combined AUROC of hemoglobin and shock index appeared higher for predicting the necessity of blood transfusions within 24 h of hospital arrival compared to the need for hemostatic interventions across any age-specific group. This may be due to the direct relationship between hemoglobin levels and the decision to administer blood transfusions. Our findings remained consistent even after excluding patients who were transferred between hospitals or those with severe TBI, indicating the robustness and validity of our results.

Our analysis revealed that the combination of initial hemoglobin levels and shock index, categorized by age, enhances predictive performance rather than applying either parameter alone or even a combined assessment in the entire cohort, aligning with our hypothesis. Although it is important to acknowledge that these two parameters alone cannot perfectly discriminate the need for LSI, their combined use considering age-specific groups and being readily and rapidly available, could aid physicians in making determinations and thereby enhance prompt management in pediatric BLSI patients.

This study has several limitations. First, the study cohort is restricted to pediatric patients with BLSI. While liver and spleen injuries are common in blunt abdominal trauma, our findings cannot be directly applied to all patients presenting to the emergency department with blunt abdominal injuries. Second, the decision regarding the timing and choice of LSI, such as transcatheter arterial embolization or laparotomy, was entirely at the discretion of the attending physician or institution. This variability could introduce a degree of bias and inconsistency in the treatment approach, potentially affecting the generalizability of our findings. Third, although prehospital fluid resuscitation for pediatric trauma patients is relatively uncommon in Japan[26], we lacked data on whether the patients received fluid resuscitation in the prehospital setting. This could affect the initial hemoglobin levels and vital signs[27], which are crucial parameters in our study. Additionally, nearly 30% of the study cohort were transferred from other hospitals. Although we used the vital signs and laboratory data from the original facility where available, the exact proportion of patients with original versus transfer-time data is unknown. Such data could differ significantly due to initial treatments such as fluid administration. Nonetheless, our results remained robust even after excluding patients who were transferred between hospitals.

	All ages			1 to 6 years of age			7 to 12 years of age			13 to 16 years of age		
	LSI	no LSI		LSI	no LSI		LSI	no LSI		LSI	no LSI	
	n = 385	n = 985	P value	n = 92	n = 273	P value	n = 139	n = 480	P value	n = 154	n = 232	P value
Life-saving interventions												
TAE for acute hemorrhage due to BLSI, n (%)	230 (59.7)	0 (0)		45 (48.9)	0 (0)		95 (68.4)	0 (0)		90 (58.4)	0 (0)	
Laparotomy for acute hemorrhage due to BLSI, n (%)	70 (18.2)	0 (0)		23 (25.0)	0 (0)		20 (14.4)	0 (0)		27 (17.5)	0 (0)	
Transfusion within 24 h, n (%)	258 (67.0)	0 (0)		75 (81.5)	0 (0)		84 (60.4)	0 (0)		99 (64.3)	0 (0)	
PRBC volume within 24 h (mL), mean [SD]	1173 (1543)			809 (974)			1009 (1328)			1573 (1921)		
FFP volume within 24 h (mL), mean [SD]	1054 (1325)			775 (1012)			785 (855)			1477 (1692)		
Platelet volume within 24 h (units), mean [SD]	5.1 (10.4)			4.4 (9.5)			3.5 (7.8)			6.9 (12.4)		
Cryoprecipitate within 24 h (units), mean [SD]	0.35 (2.38)			0.12 (1.03)			0.18 (1.02)			0.67 (3.56)		
Fibrinogen within 24 h (g), mean [SD]	0.56 (7.55)			0.12 (1.03)			0.06 (0.44)			0.06 (0.42)		
In-hospital mortality, n (%)	21 (5.5)	0 (0)	< 0.001	6 (6.5)	0 (0)	< 0.001	5 (3.6)	0 (0)	0.001	10 (6.5)	0 (0)	< 0.001
Death due to hemorrhage from BLSI, n (%)	7 (1.8)	0 (0)	< 0.001	3 (3.3)	0 (0)	0.003	1 (0.7)	0 (0)	0.063	3 (1.9)	0 (0)	0.063

Table 2. Outcomes for the overall study population and for specific age groups. TAE: transcatheter arterial embolization, BLSI: blunt liver and spleen injuries, SD: standard deviation, PRBC: packed red blood cells, FFP: fresh frozen plasma.

		AUROC (95% CI)	Cut-off value	Sensitivity (95% CI)	Specificity (95% CI)	Z statistic[a]	*P* value[b]
All ages	Hemoglobin	0.646 (0.611 to 0.681)	10.9 (g/dL)	0.348 (0.301 to 0.398)	0.893 (0.872 to 0.912)	0.729	0.466
	Shock index	0.619 (0.583 to 0.654)	1.01	0.481 (0.430 to 0.532)	0.751 (0.723 to 0.778)	1.809	0.070
	Combination	0.665 (0.630 to 0.700)					
1 to 6 years of age	Hemoglobin	0.739 (0.678 to 0.800)	10.8 (g/dL)	0.522 (0.415 to 0.627)	0.834 (0.806 to 0.893)	0.732	0.464
	Shock index	0.671 (0.607 to 0.736)	1.20	0.652 (0.546 to 0.749)	0.641 (0.581 to 0.698)	2.245	0.025
	Combination	0.770 (0.713 to 0.826)					
7 to 12 years of age	Hemoglobin	0.694 (0.643 to 0.745)	11.9 (g/dL)	0.532 (0.446 to 0.617)	0.727 (0.685 to 0.767)	0.656	0.512
	Shock index	0.660 (0.603 to 0.717)	1.03	0.432 (0.348 to 0.518)	0.875 (0.842 to 0.903)	1.473	0.141
	Combination	0.719 (0.665 to 0.773)					
13 to 16 years of age	Hemoglobin	0.652 (0.596 to 0.708)	12.1 (g/dL)	0.448 (0.368 to 0.530)	0.780 (0.721 to 0.832)	1.377	0.169
	Shock index	0.673 (0.616 to 0.730)	0.93	0.390 (0.312 to 0.471)	0.905 (0.860 to 0.940)	0.844	0.399
	Combination	0.706 (0.653 to 0.760)					

Table 3. Predictability for all ages and for specific age groups of hemoglobin levels, shock index values, and their combination in predicting the need for LSI. [a] The Z statistic was calculated using the following formula: $(AUROC_2 - AUROC_1) / \sqrt{(SE^2\_AUROC_1 + SE^2\_AUROC_2)}$. Here, $AUROC_1$ refers to either hemoglobin or shock index, while $AUROC_2$ refers to the combination value. [b] The *P* value represents the comparison of AUROC between either hemoglobin or shock index and the combination value. The *P* value was calculated using the formula $P = 2*(1\text{-NORMSDIST}(Z))$ in Excel. LSI: life-saving interventions, AUROC: area under the receiver operating characteristic curve, CI: confidence interval, SE: standard error.

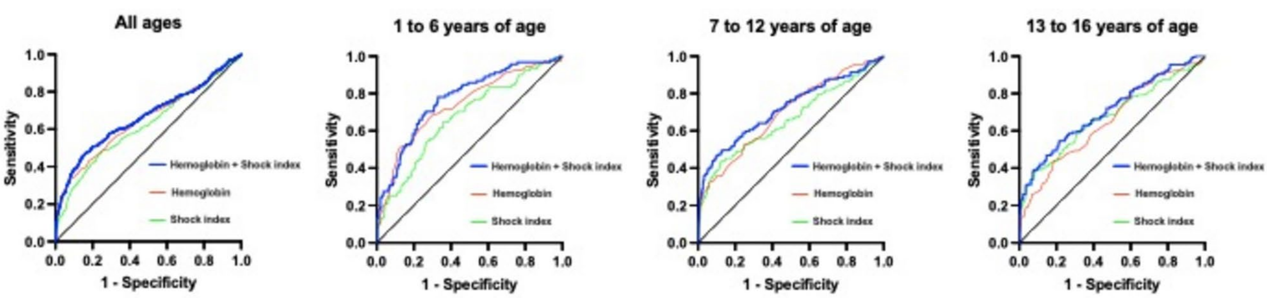

Fig. 2. Comparative ROC curves for hemoglobin, shock Index, and their combination for the entire cohort and across different age groups in predicting the need for LSI. ROC: receiver operating characteristic, LSI: life-saving interventions

Fourth, the number of patients registered varied significantly across institutions, which could affect robustness (**Figure S5**). Moreover, this study included patients with BLSI of any severity, from minor to critical injuries, as identified through imaging or operative findings. However, the higher-than-expected rate of LSI may be explained by differences in practice patterns between Japan and the United States, where significantly fewer angiographic procedures are performed[28]. Lastly, we did not perform external validation with other datasets, which may limit the applicability of our findings in other clinical settings.

Despite these limitations, our study, using a large cohort, provides important insights into the specific needs for LSI in pediatric BLSI patients. It emphasizes the usefulness of utilizing a combined approach of initial hemoglobin levels and shock index, especially considering their variability across different age groups. While the identified SIPA and hemoglobin cut-off values provide objective reference points, they should be interpreted alongside clinical assessment rather than used in isolation. These values may help clinicians rapidly identify pediatric patients with BLSI at risk for LSI; however, real-time decision-making should remain multifactorial, incorporating additional clinical parameters and assessments.

Conclusions

This multicenter retrospective study revealed that an age-specific approach, combining initial hemoglobin levels with the shock index, consistently improves the predictability of LSI to a fair level in pediatric patients with BLSI, compared to using each parameter independently or a general assessment across the entire cohort. Notably, this combined approach showed statistical superiority over the shock index alone, particularly in the 1 to 6-year age group. These findings suggest that our method is a more useful tool for physicians, facilitating timely and accurate decision-making, and thus may enhance the management of pediatric BLSI.

Data availability

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

Received: 20 December 2024; Accepted: 3 March 2025
Published online: 12 March 2025

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Acknowledgements

The authors thank collaborators of SHIPPs (Splenic and Hepatic Injury in Pediatric Patients) Study Group.

Author contributions

TYu, TO, TH, AI, KT, HN, and AN conceived and designed the study. TYu, TO, and TH analyzed the data. TYu prepared the first draft. MK, YK, HY, and SK participated in data collection and interpretation. TYo provided statistical advice on study design. All authors contributed substantially to its critical revision and approved the final manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-92673-7.

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