

# Development and internal validation of a nomogram for predicting outcomes in children with traumatic subdural hematoma

Anukoon Kaewborisutsakul, Thara Tunthanathip

*Division of Neurosurgery, Department of Surgery, Faculty of Medicine, Prince of Songkla University, Songkhla, Thailand*

**Background:** A subdural hematoma (SDH) following a traumatic brain injury (TBI) in children can lead to unexpected death or disability. The nomogram is a clinical prediction tool used by physicians to provide prognosis advice to parents for making decisions regarding treatment. In the present study, a nomogram for predicting outcomes was developed and validated. In addition, the predictors associated with outcomes in children with traumatic SDH were determined.

**Methods:** In this retrospective study, 103 children with SDH after TBI were evaluated. According to the King's Outcome Scale for Childhood Head Injury classification, the functional outcomes were assessed at hospital discharge and categorized into favorable and unfavorable. The predictors associated with the unfavorable outcomes were analyzed using binary logistic regression. Subsequently, a two-dimensional nomogram was developed for presentation of the predictive model.

**Results:** The predictive model with the lowest level of Akaike information criterion consisted of hypotension (odds ratio [OR], 9.4; 95% confidence interval [CI], 2.0–42.9), Glasgow coma scale scores of 3–8 (OR, 8.2; 95% CI, 1.7–38.9), fixed pupil in one eye (OR, 4.8; 95% CI, 2.6–8.8), and fixed pupils in both eyes (OR, 3.5; 95% CI, 1.6–7.1). A midline shift  $\geq 5$  mm (OR, 1.1; 95% CI, 0.62–10.73) and co-existing intraventricular hemorrhage (OR, 6.5; 95% CI, 0.003–26.1) were also included.

**Conclusions:** SDH in pediatric TBI can lead to mortality and disability. The predictability level of the nomogram in the present study was excellent, and external validation should be conducted to confirm the performance of the clinical prediction tool.

**Key Words:** head injury; prediction; prognosis; subdural hematoma

## INTRODUCTION

Traumatic brain injury (TBI) is a cause of mortality and functional disability in children, particularly in low- and medium-income countries [1-3]. Following TBI, a subdural hematoma (SDH) is a common intracranial injury that requires intensive care. Binder et al. [4] reported a prognosis of traumatic SDH in 47 children with a mortality rate and vegetative state of 11% and 2%, respectively. In addition, Beni-Adani et al. [5] reported 20% mortality in children with SDH in their study cohort.

## Original Article

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### Corresponding author

Thara Tunthanathip

Division of Neurosurgery, Department of Surgery, Faculty of Medicine, Prince of Songkla University, Songkhla 90110, Thailand

Tel: +66-92-5495994

Fax: +66-74-429384

E-mail: tsus4@hotmail.com

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Prognostic factors for traumatic SDH studied in which literature review include age, Glasgow coma scale (GCS) score, and pupillary abnormalities. The maximal thickness of SDH, presence of subarachnoid hemorrhage (SAH), presence of parenchymal lesions, degree of midline shift, and basal cistern effacement are additional factors [6-9]. Based on literature review, evidence is lacking for predictors associated with prognosis in children with traumatic SDH, which is problematic due to unexpected death, disability, and low health-related quality of life.

In an era of disruptive technology, various clinical prediction tools have been developed and used for prognosis in various conditions including TBI [10], oncology [11], and surgical complications [12]. A nomogram is a prediction instrument used for outcome prediction, especially TBI. Tunthanathip et al. [13] proposed a clinical nomogram for predicting traumatic intracranial injury in children. The tool had an area under the receiver operating characteristic curve (AUC) of 0.71. Cui et al. [10] developed a nomogram for predicting prognosis in TBI patients after decompressive craniectomy and showed an AUC of 0.83. Furthermore, Parmontree et al. [14] proposed a nomogram for prediction of early posttraumatic seizure, with an AUC of 0.77. Predictors associated with prognosis in pediatric SDH have been reported in a limited number of studies. Therefore, in the present study, a nomogram was developed and validated for predicting such outcomes. In addition, the predictors associated with outcomes in children with traumatic SDH were determined.

## MATERIALS AND METHODS

This clinical investigation was approved by the Institutional Review Board Ethics Committee of Prince of Songkla University (REC.64-250-10-1). Informed consent was not required from patients due to the retrospective study design. In addition, patient identification numbers were encoded before analysis.

### Study Design and Study Population

The patients in this study were treated at a trauma center in southern Thailand. The subjects were <15 years of age when enrolled from January 1, 2009, to December 31, 2020. However, patients who died before arrival, died within the first 24 hours following injury, or had unavailable cranial computed tomography were excluded. The clinical information and imaging finding of the children were collected with a structured form, including age, sex, signs, symptoms, GCS score, and mecha-

### KEY MESSAGES

- Subdural hematoma (SDH) in pediatric traumatic brain injury is associated with mortality and disability resulting in disease burden in developing nations.
- The prognostic factors for traumatic SDH were hypotension, Glasgow coma scale score 3–8, pupillary light reflex, midline shift  $\geq 5$  mm, and co-existing intraventricular hemorrhage.
- The nomogram is a prediction tool used to help physicians make treatment decisions.

nism of injury. The severity of TBI was classified based on GCS score as follows: mild TBI (GCS scores 13–15), moderate TBI (GCS scores 9–12), and severe TBI (GCS scores 3–8) [2,3]. The co-existing intracranial injuries including epidural hematoma, contusion, intraventricular hemorrhage (IVH), and SAH were evaluated for information from the cranial region. In addition, the degree of midline shift and obliteration of the basal cistern were estimated by two neurosurgeons.

Using the King's Outcome Scale for Childhood Head Injury (KOSCHI) classification, the functional outcome in the present study was assessed at hospital discharge and 6-month follow-up [15]. In detail, KOSCHI was categorized into favorable (good recovery and moderate disability) and unfavorable outcomes (severe disability, vegetative state, and death) for binary classifier proposes [3].

### Statistical Analysis

Clinical characteristics and imaging findings were calculated from descriptive statistics and reported as percentages for categorical data and mean  $\pm$  standard deviation (SD) for continuous variables. Predictors were estimated using binary logistic regression analysis for predictive model development. The candidate predictors were identified at a  $P < 0.10$ . Thus, the candidate variables were entered into multivariable analysis for the final model based on the backward elimination method. Any  $P$ -values  $< 0.05$  were considered statistically significant, and the Akaike information criterion (AIC) with clinical relevance was used for model selection [16,17].

Assessment of the predictive model's performance consisted of two domains, calibration and discrimination. For calibration, the Hosmer-Lemeshow goodness-of-fit (GOF) test and the calibration plot were performed, and a GOF test  $P$ -value  $\geq 0.05$  indicated good calibration of the model [18]. Discrimination of the model refers to the predictability of a model

to differentiate between binary classifiers. The concordance statistic index (c-index) or AUC was measured to indicate discriminatory ability [18,19]. Consequently, internal validation was performed to observe the overfitting problems of the model. Resampling techniques were used for both 1,000 bootstrapping and five cross-validations in the present study. The results of internal validation were reported as the optimism-corrected c-index for both techniques [19-21]. Finally, the predictive model exhibition was utilized following model performances and internal validation as a two-dimensional nomogram. The statistical analysis was performed using R version 4.4.0 software (R Foundation, Vienna, Austria).

## RESULTS

### Clinical Characteristics and Imaging Findings

Demographic information is listed in Table 1. The mean age of the patients was 141.8 months (SD, 48.0 months); 20.4% of the present cohort were children <5 years of age. More than two-thirds (64.1%) were male, and motorcycle accident was the most common mechanism of injury. In addition, road traffic injury was the major cause of TBI, comprising 84.5% of all cases. Common findings from the physical examination were scalp injury, loss of consciousness, and amnesia, and 9.7% of cases experienced hypotension episodes at the emergency department. Furthermore, early posttraumatic seizure occurred in 5.8% of the present study cohort. Lower extremity injury was the most common associated injury in the present cohort, and isolated TBI was observed in 75.7% of cases. In addition, hypotension was not significantly associated with multiple organ injuries (chi-square test,  $P=0.74$ )

Imaging findings after cranial computed tomography are shown in Table 2. All cases of SDH were acute, and hematomas were commonly located in the frontal area, tentorium cerebelli/falx cerebri, and temporal region. The common co-existing injuries were cerebral contusion (37.9%), calvaria skull fracture (33.0%), and SAH (30.1%). Furthermore, obliteration of the basal cistern and midline shift  $\geq 5$  mm were observed in 10.7% and 6.8% of cases, respectively. In the present study, surgical treatment was performed in 14.6% of subjects. Decompressive craniectomy was performed in 7.8% of subjects and intracranial monitoring in 1.9% of all cases. One child underwent burr hole due to bilateral chronic SDH. The mean length of hospital stay in the present cohort was 10.4 days (SD, 7.4 days), and the mortality rate at hospital discharge was 8.7%. Based on the KOSCHI at hospital discharge, good recovery, moderate

**Table 1.** Characteristics of children with traumatic subdural hematoma (n=103)

Factor	6-Month follow-up outcome		Total
	Unfavorable outcome	Favorable outcome	
Age group (yr)			
<5	7 (38.9)	14 (16.5)	21 (20.4)
$\geq 5$	11 (61.1)	71 (83.5)	82 (79.6)
Age (mo)	98.83 $\pm$ 64.6	120.5 $\pm$ 52.3	116.7 $\pm$ 54.9
Sex			
Male	11 (61.1)	55 (64.7)	66 (64.1)
Female	7 (38.9)	30 (35.3)	37 (35.9)
Mechanism			
Motorcycle crash	11 (61.1)	52 (61.2)	63 (61.2)
Ground-level fall	1 (5.6)	11 (12.9)	12 (11.7)
Pedestrian injury	3 (16.7)	9 (10.6)	12 (11.7)
Car crash	2 (11.1)	6 (7.1)	8 (7.8)
Head struck by an object	1 (5.6)	3 (3.5)	4 (3.9)
Fall from height	0	2 (2.4)	2 (1.9)
Bicycle accident	0	2 (2.4)	2 (1.9)
Sign and symptom			
Scalp injury	13 (72.2)	54 (63.5)	67 (65.0)
Loss of consciousness	11 (61.1)	48 (56.5)	59 (57.3)
Amnesia	10 (55.6)	29 (34.1)	39 (37.9)
Vomiting	0	19 (22.4)	19 (18.4)
Bleeding per nose/ear	2 (11.1)	8 (9.4)	10 (9.7)
Hypotension	11 (61.1)	82 (96.5)	10 (9.7)
Weakness	2 (11.1)	6 (7.1)	8 (7.8)
Seizure	1 (5.6)	5 (5.9)	6 (5.8)
Hypoxia	1 (5.6)	0	1 (1.0)
Associated organ injury (n=25)			
Lower extremity	2 (11.1)	11 (12.9)	13 (12.6)
Upper extremity	1 (5.6)	3 (3.5)	4 (3.9)
Maxillofacial bone	0	3 (3.5)	3 (2.9)
Orbit	0	2 (2.4)	2 (1.9)
Spine	0	1 (1.2)	1 (1.0)
Liver	0	1 (1.2)	1 (1.0)
Bowel	0	1 (1.2)	1 (1.0)
Glasgow coma scale score			
13-15	1 (5.6)	57 (67.1)	58 (56.3)
9-12	1 (5.6)	15 (17.6)	16 (15.5)
3-8	16 (88.9)	13 (15.3)	29 (28.2)
Pupillary light reflex			
React both eyes	3 (16.7)	78 (91.8)	81 (78.6)
Fixed one eye	6 (33.3)	4 (4.7)	10 (9.7)
Fixed both eyes	9 (50.0)	3 (3.5)	12 (11.7)

Values are presented as number (%) or mean $\pm$ standard deviation.

**Table 2.** Imaging finding of children with traumatic SDH (n=103)

Factor	6-Month follow-up outcome		Total
	Unfavorable outcome	Favorable outcome	
Skull fracture	9 (50.0)	25 (22.4)	34 (33.0)
Linear	5 (27.8)	14 (16.5)	19 (18.4)
Simple depressed	3 (16.7)	4 (4.7)	7 (6.8)
Compound depressed	1 (5.6)	1 (1.2)	2 (1.9)
Diastatic	0	6 (7.1)	6 (5.8)
Basilar skull fracture	4 (22.2)	12 (14.1)	16 (15.5)
Acute SDH	18 (17.5)	85 (82.5)	103 (100)
Thickness of SDH (mm)	5.3±3.9	4.0±3.2	116.7± 54.9
Co-existing intracranial injury			
Epidural hematoma	6 (33.3)	14 (16.5)	20 (19.4)
Thickness of epidural hematoma (mm)	15.5±11.2	7.9±5.4	4.6 ± 3.3
Contusion	10 (55.6)	29 (34.1)	39 (37.9)
Volume of contusion (ml)	24.6±32.2	20.5±23.4	21.4±25.8
Subarachnoid hemorrhage	10 (55.6)	21 (24.7)	31 (30.1)
Intraventricular hemorrhage	5 (27.8)	6 (7.1)	11 (10.7)
Brainstem contusion	0	1 (1.2)	1 (1.0)
Location of SDH			
Frontal	6 (33.3)	23 (27.1)	29 (28.2)
Tentorium cerebelli/falx cerebri	3 (16.7)	23 (27.1)	26 (25.2)
Temporal	5 (37.8)	18 (21.2)	23 (22.3)
Parietal	2 (11.1)	12 (14.1)	14 (13.6)
Occipital	2 (11.1)	7 (8.2)	9 (8.7)
Cerebellum	0	2 (2.4)	2 (1.9)
Lateralization of SDH			
Left	4 (22.2)	25 (29.4)	29 (28.2)
Right	4 (22.2)	31 (36.5)	35 (34.0)
Midline	5 (27.8)	22 (25.9)	27 (26.2)
Bilateral	5 (27.8)	7 (8.2)	12 (11.7)
Basal cistern obliteration	9 (50.0)	2 (2.4)	11 (10.7)
Midline shift			
<5 mm	13 (72.2)	83 (97.6)	96 (93.2)
≥5 mm	5 (27.8)	2 (2.4)	7 (6.8)

Values are presented as number (%) or mean±standard deviation. SDH: subdural hematoma.

disability, and severe disability were found in 76.7%, 5.8%, and 7.8%, respectively, of patients. When the 6-month follow-up KOSCHI was administered, good recovery, moderate disability, severe disability, and death were found in 77.7%, 4.9%, 8.7%, and 8.7% of subjects, respectively. Therefore, 17.5% of the present study cohort had an unfavorable outcome at hospital discharge, as shown in [Table 3](#).

**Table 3.** Treatment and outcome of children with traumatic subdural hematoma (n=103)

Factor	No (%)
Surgical treatment	15 (14.6)
Decompressive craniectomy	8 (7.8)
Craniotomy	4 (3.9)
Intracranial pressure monitoring	2 (1.9)
Burr hole with irrigation	1 (1.0)
Hospital-discharge KOSCHI	
Death	9 (8.7)
Vegetative stage	1 (1.0)
Severe disability	8 (7.8)
Moderate disability	6 (5.8)
Good recovery	79 (76.7)
6-Month follow-up KOSCHI	
Death	9 (8.7)
Vegetative stage	0
Severe disability	9 (8.7)
Moderate disability	5 (4.9)
Good recovery	80 (77.7)
6-Month follow-up outcome	
Unfavorable outcome	18 (17.5)
Favorable outcome	85 (82.5)

KOSCHI: King's Outcome Scale for Childhood Head Injury.

### Model Development

Clinical variables were analyzed using univariate logistic regression as shown in [Table 4](#). The following 12 variables were candidate predictors: age group, hypotension, amnesia, GCS score, pupillary light reflex, IVH, SAH, thickness of epidural hematoma, lateralization of SDH, obliteration of basal cistern, midline shift, and treatment. Therefore, candidate predictors were analyzed using multivariable analysis. Following the backward elimination procedure, the final model with the lowest AIC consisted of hypotension (odds ratio [OR], 9.4; 95% confidence interval [CI], 2.0–42.9), GCS score of 3–8 (OR, 8.2; 95% CI, 1.7–38.9), a fixed pupil in one eye (OR, 4.8; 95% CI, 2.6–8.8), and fixed pupils in both eyes (OR, 3.5; 95% CI, 1.6–7.1). In addition, a midline shift ≥ 5 mm (OR, 1.1; 95% CI, 0.62–10.73) and co-existing IVH (OR, 6.5; 95% CI, 0.003–26.1) were also included in the final model, as shown in [Figure 1](#).

### Model Performance and Internal Validation

The domain of the model discrimination was estimated using the Hosmer-Lemeshow GOF test with a P-value of 0.99 and a c-index of 0.971, indicating good calibration. The domain of the model calibration was evaluated based on the calibration

**Table 4.** Binary logistic regression analysis for unfavorable outcome

Factor	Crude odds ratio (95% CI)	P-value
Age group (yr)		
<5	Ref	
≥5	0.31 (0.10–0.93)	0.03
Sex		
Male	Ref	
Female	1.16 (0.41–3.32)	0.77
Road traffic mechanism		
No	Ref	
Yes	0.46 (0.09–2.21)	0.33
Sign and symptom		
Loss of consciousness	0.93 (0.32–2.72)	0.90
Weakness	1.96 (0.33–11.72)	0.45
Scalp injury	1.64 (0.52–5.16)	0.39
Bleeding per nose/ear	1.07 (0.20–5.66)	0.93
Hypotension	17.39 (3.19–77.3)	<0.001
Seizure	0.92 (0.09–8.84)	0.94
Amnesia	2.73 (0.94–7.93)	0.06
Associated injury		
Isolated traumatic brain injury	Ref	
Associated organ injury	1.74 (0.46–6.61)	0.41
Glasgow coma scale score		
13–15	Ref	
9–12	3.80 (0.22–64.36)	0.35
3–8	70.15 (8.52–57.75)	<0.001
Pupillary light reflex		
React both eyes	Ref	
Fixed one eye	56.66 (8.68–31.94)	<0.001
Fixed both eyes	79.0 (13.83–45.12)	<0.001
Imaging finding		
Skull fracture	2.19 (0.76–6.31)	0.14
Basilar skull fracture	1.62 (0.44–5.96)	0.46
Epidural hematoma	2.54 (0.78–8.23)	0.11
Contusion	1.82 (0.64–5.29)	0.25
Subarachnoid hemorrhage	3.81 (1.33–10.91)	0.01
Intraventricular hemorrhage	5.06 (1.34–19.03)	0.01
Thickness of epidural hematoma	1.18 (0.97–1.45)	0.09
Thickness of SDH	1.09 (0.96–1.24)	0.17
SDH at tentorial cerebri/falx cerebri		
No	Ref	
Yes	0.47 (0.12–1.80)	0.27
SDH at frontal lobe		
No	Ref	
Yes	1.26 (0.41–3.85)	0.68
Lateralization of SDH		
Left	Ref	
Right	0.78 (0.17–3.56)	0.75
Midline	1.12 (0.26–4.84)	0.87
Bilateral	3.75 (0.75–18.70)	0.10
Basal cistern obliteration		
No	Ref	
Yes	41.5 (7.73–22.25)	<0.001

Factor	Crude odds ratio (95% CI)	P-value
Midline shift-mm		
<5	Ref	
≥5	15.96 (2.79–91.02)	<0.01
Treatment		
Conservative treatment	Ref	
Decompressive craniectomy	7.51 (1.47–38.29)	0.01
Craniotomy	11.27 (0.93–135.23)	0.06
Intracranial pressure monitoring	5.63 (0.32–96.95)	0.18

CI: confidence interval; SDH: subdural hematoma.

plot, which was the logistic calibration (intercept,  $-3.790$ ; slope,  $7.286$ ), as shown in [Figure 2](#). For internal validation, the overfitting performance of the model was evaluated using 1,000 bootstrapping and five cross-validations. The c-index values of bootstrapping and cross-validation were 0.971 and 0.971, respectively.

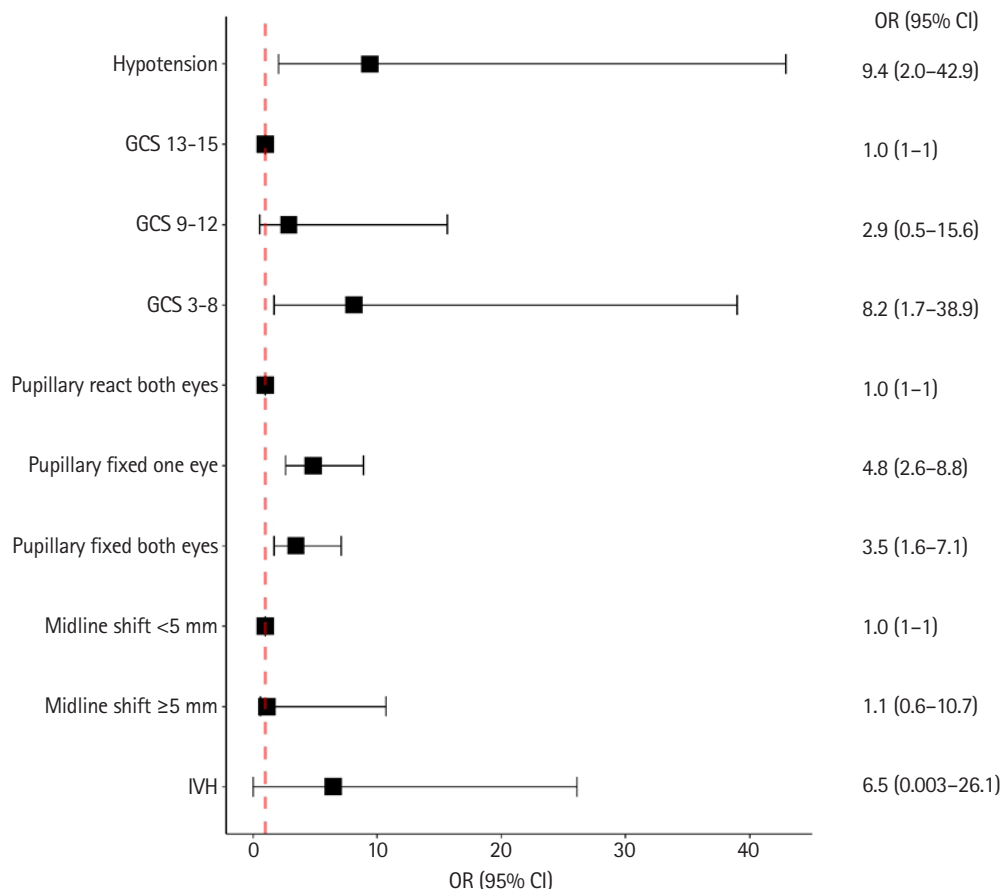
### Model Presentation

The c-index of the predictive model was outstanding without overfitting. Therefore, the final predictive model was finalized into a nomogram for predicting the unfavorable outcomes of new patients at the 6-month follow-up, as shown in [Figure 3](#).

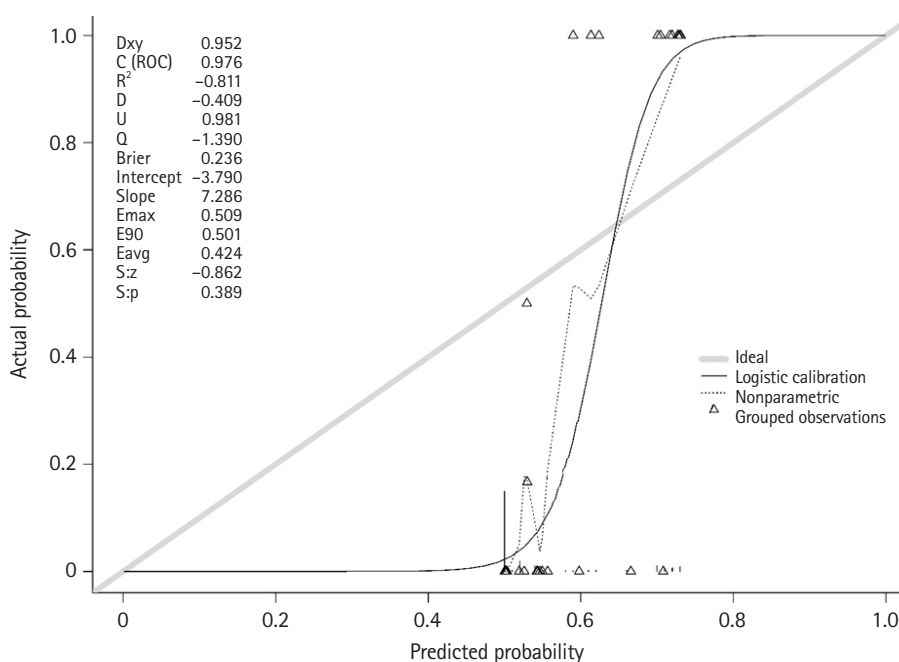
### DISCUSSION

SDH following TBI leads to mortality and disability in patients, especially children. The mortality rate of SDH in children was reported to range from 11% to 20% in prior studies. Taweesomboonyat et al. [2] and Tunthanathip et al. [3] studied 948 children with TBI and found SDH to be significantly associated with unfavorable outcomes. However, studies in which SDH is specifically investigated in a young population are lacking, resulting in increased burden of healthcare cost and poor health-related quality of life. In the present study, a predictive tool to identify children with increased risk of an unfavorable outcome was developed and validated, providing physicians with information for advising parents and making treatment decisions in clinical practice.

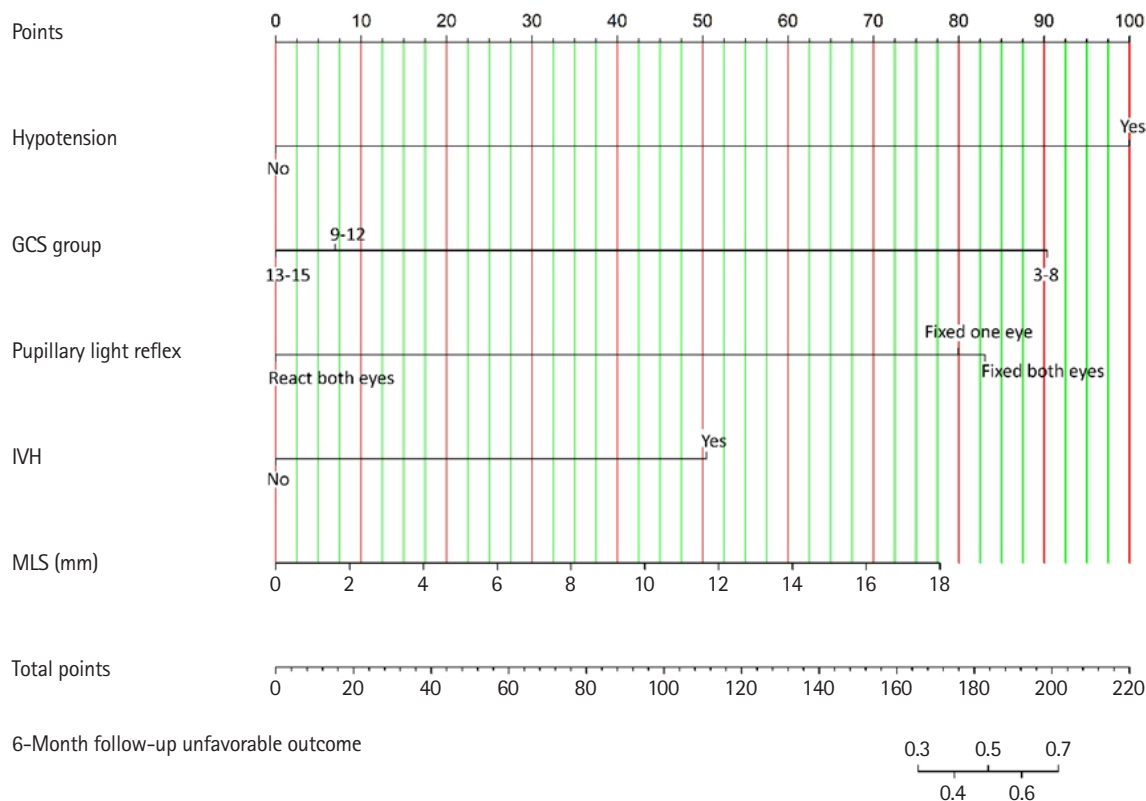
Using multivariable analysis, the predictive model consisted of the following five predictors: hypotension, GCS score, pupillary light reflex, midline shift, and IVH. Hypotension was the strongest predictor, in agreement with previous studies [3,22,23]. In general, systolic blood pressure has been considered significantly associated with mortality in TBI. In prior



**Figure 1.** Forest plot of the adjusted odds ratio (OR) of predictors. CI: confidence interval; GCS: Glasgow coma scale; IVH: intraventricular hemorrhage.



**Figure 2.** Calibration plot of the predictive model. Dxy: somers' dxy rank correlation; C (ROC): concordance statistic (area under the receiver operating characteristic curve).



**Figure 3.** Nomogram predicting unfavorable outcomes in children with traumatic subdural hematoma. GCS: Glasgow coma scale; IVH: intraventricular hemorrhage; MLS: midline shift.

studies, blood loss from multiple organ injuries was shown to cause hypotension [13,14]. However, the majority of patients in the present study experienced isolated TBI, and hypotension was not significantly associated with multiple organ injuries. Episodes of hypotension were directly associated with low cerebral perfusion pressure and unfavorable outcomes [24]. In addition, a pupillary light reflex indicated reduced function of the brainstem due to alteration of cerebral perfusion or downward cerebral herniation [25].

In the present study, low GCS score was significantly associated with poor outcomes, in concordance with previous studies. Dent et al. and Petridis et al. reported that low GCS score affected the outcomes in SDH patients [6,7]. Specifically, children with low initial GCS score suffered severe brain tissue damage, lowering the likelihood of brain recovery. Based on the lowest AIC, the final predictive model had two non-significant predictors in multivariable analysis; however, they were reported as prognostic factors with clinical relevance in the literature. In prior studies, the presence of IVH and high midline shift significantly increased the risk of unfavorable outcomes

after treatment [26,27]. However, the limited prevalence of those factors needs to be collected in the future to increase the power of testing the hypothesis. A nomogram from a predictive model was previously developed and estimated and had an excellent c-index level [28]. However, the overfitting performance is a common optimism problem that should be evaluated using internal validation [19-21]. Using five cross-validations and bootstrapping methods, the optimism-corrected c-indices did not decrease the value, which confirmed no overfitting performance in the nomogram [20,21,29].

The present study had several limitations. This was a single-center study with a retrospective design, which might have led to some bias. However, the authors attempted to adjust the confounders using multivariable analysis. In addition, a multicenter study should be conducted in the future for external validation of the nomogram. To the best of our knowledge, this is the first study in which a clinical nomogram for predicting outcomes in children with traumatic SDH was proposed, and the predictability performance was compared between the nomogram and other prediction tools such as machine learning

[30,31].

SDH in pediatric TBI leads to mortality and disability and is associated with poor outcomes that apparently are the consequence of associated injuries and clinical status. The predictability level of the nomogram in the present study was excellent, and external validation should be performed to confirm the predictability of the tool.

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

## ORCID

Anukoon Kaewborisutsakul

<https://orcid.org/0000-0001-9548-3006>

Thara Tunthanathip <https://orcid.org/0000-0002-6303-836X>

## AUTHOR CONTRIBUTIONS

Conceptualization: TT. Data curation: all authors. Formal analysis: TT. Methodology: all authors. Project administration: TT. Visualization: TT. Writing–original draft: all authors. Writing–review & editing: all authors.

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