Development of a nomogram to predict the outcome of moderate or severe pediatric traumatic brain injury

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Abstract:

OBJECTIVES: Traumatic brain injury (TBI) in children has become the major cause of mortality and morbidity in Thailand that has had an impact with economic consequences. This study aimed to develop and internally validate a nomogram for a 6-month follow-up outcome prediction in moderate or severe pediatric TBI.

METHODS: This retrospective cohort study involved 104 children with moderate or severe TBI. Various clinical variables were reviewed. The functional outcome was assessed at the hospital discharge and at a 6-month follow-up based on the King’s Outcome Scale for Childhood Head Injury classification. Predictors associated with the 6-month follow-up outcome were developed from the predictive model using multivariable binary logistic regression to estimate the performance and internal validation. A nomogram was developed and presented as a predictive model.

RESULTS: The mean age of the samples was 99.75 months (standard deviation 59.65). Road traffic accidents were the highest injury mechanism at 84.6%. The predictive model comprised Glasgow Coma Scale of 3–8 (odds ratio [OR]: 16.07; 95% confidence interval [CI]: 1.27–202.42), pupillary response in one eye (OR 7.74; 95% CI 1.26–47.29), pupillary nonresponse in both eyes (OR: 57.74; 95% CI: 2.28–145.81), hypotension (OR: 19.54; 95% CI 3.23–117.96), and subarachnoid hemorrhage (OR: 9.01, 95% CI: 1.33–60.80). The concordance statistic index (C-index) of the model's discrimination was 0.931, while the C-index following the bootstrapping and 5-cross validation were 0.920 and 0.924, respectively.

CONCLUSIONS: The performance of a clinical nomogram for predicting 6-month follow-up outcomes in pediatric TBI patients was assessed at an excellent level. However, further external validation would be required for the confirmation of the tool's performance.

Keywords: Brain injury, clinical prediction rules, nomogram, Traumatic brain injury

Introduction

Traumatic brain injury (TBI) is a serious public health problem, which in Thailand, TBI causes death, and incapacity in the population, particularly for children. Fulkerson et al. studied the outcome of TBI children who recorded a Glasgow Coma Scale (GCS) score of 3 or 4. They found that the mortality of children with a GCS of 3 and 4 was 61.4% and 43.5%, respectively, with a good recovery found in only 4.6%–8.7%. The predictors for survival included pupillary response, abuse mechanism, hypotension, hypothermia, and midline shift. Long-term sequelae of TBI patients would also be related to future productivity loss.
Nevertheless, in Thailand, preventive campaigns to reduce pediatric TBI have not dramatically decreased the number of road accidents involving children.[3] Thus, prediction of the functional outcome in pediatric patients following TBI is an important procedure for allocating resources and developing future health strategies. Hence, a nomogram is a clinical prediction tool that has been well documented in the literature.[6] Previous studies used a nomogram to predict both clinical outcomes and prognosis; such as neuro-oncology,[7] TBI,[8,9] stroke,[10] and posttraumatic seizure.[11] Tunthanathip and Udomwithayaphiban studied TBI patients with penetrating injury and used a nomogram to predict the mortality. For the results, the nomogram had a sensitivity of 0.800, specificity of 0.926, positive predictive value of 0.727, negative predictive value of 0.950, and an area under the receiver operating characteristic curve (AUC) of 0.860.[8]

However, the predictive performance of a nomogram to determine the functional outcomes of pediatric TBI patients has never been assessed. To fill this knowledge gap, this present study developed and internally validated a nomogram for a 6-month follow-up outcome prediction in pediatric TBI.

Methods

Study design and setting
This historical cohort study reviewed the medical records of patients with TBI who were younger than 15 years and admitted at a trauma center located in Southern Thailand between January 2009 and January 2020.

Study population
All TBI patients who had a postresuscitation GCS of 3–12 were included in the study. Exclusion criteria were patients who had died before arrival, died within the first 24 h following TBI, and those who did not undergo a computed tomography (CT) scan of the brain.

Sample size estimation
The authors used the formula in the “statistics and sample size pro” application for calculating the sample size for the diagnostic tests.[12] By providing the input from the previous study[10] (prevalence: 32.3; sensitivity: 0.8), the sample size should include at least 62 patients.

Methods and measurements
The demographics, neuroimaging, and treatment on admission were reviewed for analysis. Because hypotension causes a misinterpretation of the GCS score from poor cerebral perfusion, the GCS score collected in the present study was the patient’s GCS score with the stable vital signs following resuscitation at the emergency department.[9] Moreover, the GCS score after resuscitation was categorized into moderate TBI (GCS score of 9–12) and severe TBI (GCS score of 3–8),[11] while hypotension and bradycardia were defined based on the age of the patient.[8] The findings from the CT of the brain, type of intracranial injuries, midline shift, and obliteration of the basal cistern were reviewed by two neurosurgeons. Based on Vieira et al., diffuse axonal injury (DAI) was defined where patients had signs of DAI from a CT scan or magnetic resonance imaging.[13]

Outcomes
According to the King’s Outcome Scale for Childhood Head Injury (KOSCHI) classification, the functional outcome of this study was assessed at the hospital discharge and at a 6-month follow-up visit.[4] The authors evaluated the outcomes by telephone for patients who did not attend the follow-up. The study was approved by the Human Research Ethics Committee of the Faculty of Medicine, Prince of Songkla University (REC.63-373-10-1, Date: 29.09.2020).

Statistical analysis
The demographic data, neuroimaging findings, treatment, and the KOSCHI classification were calculated from descriptive statistics. These were reported as percentages for the categorical data and mean ± standard deviation (SD) for continuous variables. The KOSCHI classification was dichotomized into favorable outcomes and unfavorable outcomes for binary purposes. In detail, death, a vegetative state, and severe disability were categorized into an unfavorable group, whereas good recovery and moderate disability were categorized as favorable outcomes.[3,4]

For the development of the model, the predictors were recognized using binary logistic regression analysis. In detail, the candidate variables were identified with their P < 0.10 and entered into the multivariable analysis.
to build the final model. All $P < 0.05$ were observed as statistically significant. Furthermore, the variance inflation factor (VIF) was analyzed in the final model for the detection of multicollinearity with a VIF value of 10 or more referring to multicollinearity.

The evaluation of the model’s performance comprised two domains in terms of calibration and discrimination. For calibration, the Hosmer-Lemeshow goodness-of-fit (GOF) test and the calibration plot were performed. A GOF test at a $P = 0.05$ or more indicated good calibration of the model. Discrimination of the model was related to the predictability to differentiate between the binary classifiers. The concordance statistic index (C-index) or AUC were measured to indicate the discriminatory ability, while an internal validation was conducted to detect the overfitting problems of the model. Resampling techniques were used as both 1000 bootstrapping and 5-cross validation. Finally, the model was built as a nomogram. Statistical analyses were performed using the R version 3.6.2 software (R Foundation, Vienna, Austria).

## Results

### Clinical and neuroimaging characteristics

A total of 104 pediatric patients diagnosed with moderate and severe TBI were included in the cohort. The mean patient age was 99.75 months (SD 59.65). There were 67 males and 37 females. Children injured as a result of road traffic accidents made up 84.6% of the cohort. A total of 48.1% of the cases were moderate TBI, whereas the GCS of 3–8 was observed in 51.9% of the cohort. The clinical characteristics are summarized in Table 1.

Neuroimaging detected skull fracture and basilar skull fracture in 30.8% and 18.3% of the samples, respectively. In

| Factor                        | Unfavorable outcome ($n=22$) | Favorable outcome ($n=82$) | Total, $n$ (%) |
|-------------------------------|------------------------------|----------------------------|----------------|
| Gender                        |                              |                            |                |
| Male                          | 13 (59.1)                    | 54 (65.9)                  | 67 (64.4)      |
| Female                        | 9 (40.9)                     | 28 (34.1)                  | 37 (35.6)      |
| Age group (years)             |                              |                            |                |
| $\leq 2$                      | 2 (9.1)                      | 6 (7.3)                    | 8 (7.7)        |
| $>2$                          | 20 (90.9)                    | 76 (92.7)                  | 96 (92.3)      |
| $\leq 5$                      | 11 (50.0)                    | 25 (30.5)                  | 36 (34.6)      |
| $>5$                          | 11 (50.0)                    | 57 (69.5)                  | 68 (65.4)      |
| Mean age-month±SD             | 92.85±64.22                  | 101.52±58.73               | 99.75±59.65    |
| GCS score                     |                              |                            |                |
| 9-12                          | 1 (4.5)                      | 49 (59.8)                  | 50 (48.1)      |
| 3-8                           | 21 (95.5)                    | 33 (40.2)                  | 54 (51.9)      |
| Injured mechanism             |                              |                            |                |
| Motorcycle crash              | 10 (45.5)                    | 48 (58.5)                  | 58 (55.8)      |
| Vehicle crash                 | 2 (9.1)                      | 13 (15.9)                  | 15 (14.4)      |
| Pedestrians injured in a traffic accident | 4 (18.2)                  | 11 (13.4)                  | 15 (14.4)      |
| Fall from a height            | 1 (4.5)                      | 5 (6.1)                    | 6 (5.8)        |
| Bicycle accident              | 3 (13.6)                     | 3 (3.6)                    | 6 (5.8)        |
| Object striking the head      | 2 (9.1)                      | 2 (2.4)                    | 4 (3.8)        |
| Loss of consciousness         | 8 (36.4)                     | 43 (52.4)                  | 51 (49.0)      |
| Vomiting                      | 2 (9.1)                      | 4 (4.9)                    | 6 (5.8)        |
| Hemiparesis                   | 3 (13.6)                     | 11 (13.4)                  | 14 (13.5)      |
| Scalp hematoma/laceration     | 13 (59.1)                    | 45 (54.9)                  | 58 (55.8)      |
| Bleeding per nose/ear         | 4 (18.2)                     | 5 (6.1)                    | 9 (8.7)        |
| Hypotension                   | 15 (68.2)                    | 9 (11.0)                   | 24 (23.1)      |
| Bradycardia                   | 3 (13.6)                     | 1 (1.2)                    | 4 (3.8)        |
| Seizure                       | 2 (9.1)                      | 9 (11.0)                   | 11 (10.6)      |
| Pupillary light reflex        |                              |                            |                |
| Fixed BE                      | 15 (68.2)                    | 8 (9.8)                    | 23 (22.1)      |
| React one eye                 | 3 (13.6)                     | 4 (4.9)                    | 7 (6.7)        |
| React both eyes               | 4 (18.2)                     | 70 (85.4)                  | 74 (71.2)      |
| Surgery ($n=20$)              |                              |                            |                |
| Decompressive craniectomy     | 3 (13.6)                     | 7 (8.5)                    | 10 (9.6)       |
| Craniotomy with clot removal  | 1 (4.5)                      | 7 (8.5)                    | 8 (7.7)        |
| ICP monitoring                | 1 (4.5)                      | 1 (1.2)                    | 2 (1.9)        |

ICP: Intracranial pressure, SD: Standard deviation, GCS: Glasgow Coma Scale
addition, epidural hematoma and subdural hematoma (SDH) were common intracranial injuries. The neuroimaging findings are summarized in Table 2. A total of 19.2% of cases underwent surgery. Table 3 provides a summary of the treatment and outcome. Decompressive craniectomy was performed on ten patients, while eight children received craniotomy with clot removal operations, and an intracranial monitoring procedure was performed for two children. According to the KOSCHI categories at the hospital discharge, the mortality rate was 16.3%. A vegetative state, severe disability, moderate disability, and good recovery were 1.9%, 5.8%, 10.6%, and 65.4%, respectively. When a 6-month follow-up was performed, no further deaths were recorded. Hence, the dichotomized KOSCHI groups were composed of favorable and unfavorable subgroups as 78.8% and 21.2%, respectively, at the 6-month follow-up.

Model development
Initially, ten variables (GCS score, road traffic accident, hypotension, bradycardia, pupillary light reflex, SDH, subarachnoid hemorrhage (SAH), DAI, midline shift, and basal cistern obliteration) were selected as candidates for multivariable analysis [Table 4]. After the backward elimination procedure, the VIF of the GCS of 3–8, hypotension, pupillary light reflex, and SAH were 1.059, 1.088, 1.224, and 1.248, respectively.

Model performance and internal validation
Using the Hosmer-Lemeshow GOF test, the result of the model’s calibration gave a $P = 0.89$ that indicated good calibration [Figure 1]. The domain of the model’s discrimination had a C-index value of 0.931. The overfitting of the model was considered by 1000

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### Table 2: Imaging findings of the present cohort ($n=104$)

| Factor                     | Unfavorable outcome ($n=22$) | Favorable outcome ($n=82$) | Total, $n$ (%) |
|----------------------------|-------------------------------|----------------------------|----------------|
| Skull fracture             | 7 (31.8)                      | 25 (30.5)                  | 32 (30.8)      |
| Basilar skull fracture     | 6 (27.3)                      | 13 (15.9)                  | 19 (18.3)      |
| Epidural hematoma          | 5 (22.7)                      | 23 (28.0)                  | 28 (26.9)      |
| SDH                        | 12 (54.5)                     | 25 (30.5)                  | 37 (35.6)      |
| Contusion                  | 8 (36.4)                      | 21 (25.6)                  | 29 (27.9)      |
| Brainstem contusion        | 1 (4.5)                       | 3 (3.7)                    | 4 (3.8)        |
| SAH                        | 9 (40.9)                      | 14 (17.1)                  | 23 (22.1)      |
| Intraventricular hemorrhage| 5 (22.7)                      | 7 (8.5)                    | 12 (11.5)      |
| DAI                        | 8 (36.4)                      | 16 (19.5)                  | 24 (23.1)      |
| Midline shift (cm)         |                               |                            |                |
| <0.5                       | 16 (72.7)                     | 76 (92.7)                  | 92 (88.5)      |
| ≥0.5                       | 6 (27.3)                      | 6 (7.3)                    | 12 (11.5)      |
| Mean of midline shift (cm) | 0.23±0.34                     | 0.06±1.6                   | 0.098±0.22     |
| Basal cistern obliteration | 10 (45.5)                     | 11 (13.4)                  | 21 (20.2)      |

SD: Standard deviation, SAH: Subarachnoid hemorrhage, SDH: Subdural hematoma, DAI: Diffuse axonal injury

### Table 3: Outcome of the present cohort ($n=104$)

| Factor                     | Unfavorable outcome ($n=22$) | Favorable outcome ($n=82$) | Total, $n$ (%) |
|----------------------------|-------------------------------|----------------------------|----------------|
| Hospital discharge KOSCHI  |                               |                            |                |
| Death                      | 17 (77.3)                     | 0                          | 17 (16.3)      |
| Vegetative state           | 2 (9.1)                       | 0                          | 2 (1.9)        |
| Severe disability          | 3 (13.6)                      | 3 (3.7)                    | 6 (5.8)        |
| Moderate disability        | 0                             | 11 (13.4)                  | 11 (10.6)      |
| Good recovery              | 0                             | 68 (82.9)                  | 68 (65.4)      |
| 6 months follow-up KOSCHI  |                               |                            |                |
| Death                      | 17 (77.3)                     | 0                          | 17 (16.4)      |
| Vegetative state           | 2 (9.1)                       | 0                          | 2 (1.9)        |
| Severe disability          | 3 (13.6)                      | 0                          | 3 (2.9)        |
| Moderate disability        | 0                             | 13 (15.9)                  | 13 (12.5)      |
| Good recovery              | 0                             | 69 (84.1)                  | 69 (66.3)      |

KOSCHI: King’s Outcome Scale for Childhood Head Injury
bootsparng and 5-cross validation techniques, while the C-index values of bootstrapping and cross-validation were 0.920 and 0.924, respectively.

Model presentation
After validation, the model was presented as the final process to provide a valid prediction for new patients and then presented as a nomogram [Figure 2].

Discussion
The severity of TBI was significantly associated with the functional outcome in the cohort. The results of this study were in concordance with previous studies.[17,18] Bedry and Tadele investigated 315 children with TBI and reported that severe TBI was associated with mortality or disability compared with moderate

Table 4: Binary logistic regression for the 6-month follow-up unfavorable outcome

| Factor                        | Univariate analysis | Multivariable analysis |
|-------------------------------|---------------------|------------------------|
|                               | OR (95% CI)        | P          | OR (95% CI)        | P          |
| Age group (years)             |                     |            |                     |            |
| ≤2                            | Reference           |            | Reference           |            |
| >2                            | 0.89 (0.16-4.73)    | 0.89       | 0.89 (0.16-4.73)    | 0.89       |
| ≤5                            | Reference           |            | Reference           |            |
| >5                            | 0.53 (0.21-1.36)    | 0.19       | 0.53 (0.21-1.36)    | 0.19       |
| Loss of consciousness*        | 0.84 (0.33-2.11)    | 0.72       | 0.84 (0.33-2.11)    | 0.72       |
| Vomiting*                     | 1.72 (0.29-10.06)   | 0.54       | 1.72 (0.29-10.06)   | 0.54       |
| Hemiparesis*                  | 0.89 (0.22-3.51)    | 0.87       | 0.89 (0.22-3.51)    | 0.87       |
| Scalp injury*                 | 1.43 (0.56-3.65)    | 0.45       | 1.43 (0.56-3.65)    | 0.45       |
| Bleeding per nose/ear*        | 1.76 (0.40-7.64)    | 0.45       | 1.76 (0.40-7.64)    | 0.45       |
| Seizure*                      | 0.71 (0.14-3.57)    | 0.68       | 0.71 (0.14-3.57)    | 0.68       |
| GCS score                     |                     |            |                     |            |
| 9-12                          | Reference           |            | Reference           |            |
| 3-8                           | 36.35 (4.67-282.97) | 0.001      | 16.07 (1.27-202.42) | 0.03       |
| Road traffic accident         |                     |            |                     |            |
| No                            | Reference           |            | Reference           |            |
| Yes                           | 3.24 (1.05-9.96)    | 0.03       | 3.24 (1.05-9.96)    | 0.03       |
| Hypotension                   | 18.00 (5.87-55.153) | <0.001     | 19.54 (3.23-117.96) | 0.001      |
| Bradycardia                   | 11.28 (1.11-114.12) | 0.04       | 11.28 (1.11-114.12) | 0.04       |
| Pupillary light reflex        |                     |            |                     |            |
| React both eyes               | Reference           |            | Reference           |            |
| React one eye                 | 18.40 (3.19-105.95) | 0.001      | 18.40 (3.19-105.95) | 0.001      |
| Fixed both eyes               | 25.87 (7.40-90.23)  | <0.001     | 25.87 (7.40-90.23)  | <0.001     |
| Skull fracture*               | 1.48 (0.57-3.87)    | 0.41       | 1.48 (0.57-3.87)    | 0.41       |
| Basilar skull fracture*       | 1.71 (0.57-5.15)    | 0.33       | 1.71 (0.57-5.15)    | 0.33       |
| EDH*                          | 1.15 (0.42-3.18)    | 0.77       | 1.15 (0.42-3.18)    | 0.77       |
| SDH*                          | 2.20 (0.86-5.57)    | 0.09       | 2.20 (0.86-5.57)    | 0.09       |
| Contusion*                    | 1.08 (0.39-2.97)    | 0.87       | 1.08 (0.39-2.97)    | 0.87       |
| Brainstem contusion*          | 3.54 (0.47-26.62)   | 0.21       | 3.54 (0.47-26.62)   | 0.21       |
| IVH*                          | 2.74 (0.78-9.61)    | 0.11       | 2.74 (0.78-9.61)    | 0.11       |
| SAH*                          | 6.27 (2.25-17.43)   | <0.001     | 6.27 (2.25-17.43)   | <0.001     |
| DAI*                          | 3.36 (1.24-9.11)    | 0.01       | 3.36 (1.24-9.11)    | 0.01       |
| Midline shift                 |                     |            |                     |            |
| <0.5                          | Reference           |            | Reference           |            |
| ≥0.5                          | 6.17 (1.74-21.83)   | 0.005      | 6.17 (1.74-21.83)   | 0.005      |
| Basal cistern                 |                     |            |                     |            |
| Patent                        | Reference           |            | Reference           |            |
| Obliteration                  | 6.32 (2.20-18.13)   | 0.001      | 6.32 (2.20-18.13)   | 0.001      |
| Operation                     |                     |            |                     |            |
| No surgery                    | Reference           |            | Reference           |            |
| DC                            | 1.68 (0.39-7.22)    | 0.48       | 1.68 (0.39-7.22)    | 0.48       |
| Craniotomy                    | 2.36 (0.51-10.88)   | 0.26       | 2.36 (0.51-10.88)   | 0.26       |
| ICP monitoring                | 3.94 (0.23-66.28)   | 0.34       | 3.94 (0.23-66.28)   | 0.34       |

*Data showed only the “yes group,” while reference groups (no group) were hidden. DAI: Diffuse axonal injury, DC: Decompressive craniectomy, EDH: Epidural hematoma, GCS: Glasgow Coma Scale, ICP: Intracranial pressure, IVH: Intraventricular hemorrhage, SAH: Subarachnoid hemorrhage, SDH: Subdural hematoma, CI: Confidence interval, OR: Odds ratio
and mild TBI (odds ratio [OR]: 2.55; 95% CI: 1.96–4.52). Similarly, Kan et al. demonstrated that a low GCS score was significantly associated with poor outcomes in TBI children aged 2–16 years. This was potentially explained by the high-energy force impacting on the head, leading to more damage of the brain parenchyma that caused a poor GCS score.

Other prognostic factors in this study concurred with previous experiments. Bahloul et al. reported that the prognostic factors were hypotension, bilateral mydriasis, and SAH. Bilaterally, nonreactive pupils was also one of the prognostic factors in the present study that were poor predictors as a result of the low cerebral blood flow, particularly brain stem blood flow (BBF). Brain stem is the vital area of the brain where ischemic processes or infarction develop in this region that cause the dysfunction of pupillary reaction and other vital signs. Ritter et al. studied BBF in severe TBI patients and found that the pupillary reaction depended on the BBF level. In detail, patients with normally reactive pupils had BBF at 30.5 ± 16.8 ml/100 g/min compared with 43.8 ± 18.7 ml/100 g/min in patients with normally reactive pupils. Moreover, the presence of uncal herniation caused a marked decrease in BBF, especially in the upper brainstem, while the presence of systemic hypotension significantly reduced the global cerebral blood flow.

SAH was the one of the predictors in the prognostic model in the present study. From the prior studies, the presence of traumatic SAH in pediatric TBI was associated with the increased severity of the injury, while high levels required care. Hochstader et al. reported the prevalence of SAH in 42% of severe pediatric TBI patients, and this injury was associated with an increased level of care requirement and increased lengths of hospital stay. Dalle Ore et al. studied pediatric TBI patients with traumatic SAH and found that the mortality rate among all TBI children with traumatic SAH was 16.5%.

Nonetheless, it still remains unclear the pathophysiology of SAH that is associated with mortality, as subsequent diffuse cerebral swelling following SAH has been discussed as a cause of a poor outcome.

In this study, surgical treatment was not associated with the 6-month follow-up outcome of TBI. One limitation of a retrospective study design is the occurrence of an inherent bias that is not found in a randomized controlled trial. However, a low prevalence of moderate or severe pediatric TBI was observed in previous studies as 7.5%–29.8% for moderate TBI and 7.9%–13% for severe TBI, respectively. A multicenter study or meta-analysis studies were previously conducted in an attempt to resolve this limitation, while the propensity score approach was also adopted to adjust the selection bias and non-randomized study design.

Limitations
As a result, the C-index values of the nomogram, both the bootstrapping technique and cross-validation, were at an excellent level. However, the overfitting problem should be recognized and resolved by testing the prediction tool with unseen data. Furthermore, the study populations were not large enough to divide the data and use the nomogram to test the performance of the unseen data. In future research, external validation would be the next step to examine the performance of the prediction tool on unseen data from subsequent patients at the same centers at which the nomogram was developed, as temporal validation or patients from centers different from those which contributed in the tool development, as geographic validation.

Therefore, other limitations should be acknowledged. The nomogram was a two-dimensional graphic scoring system, which needed to assign scores to each variable that resulted in being a nonuser-friendly tool in general practice. Therefore, a web-based nomogram or mobile application should be developed and deployed to simplify the tool for the physician’s practice. Moreover, the retrospective study design may lead to bias, so prospective multicenter research should also be performed in the future.

Future research directions
Various prediction tools have been performed in clinical research such as, clinical prediction rules and machine learning. In an era of disruption, a machine learning model could be used as a clinical prediction tool to predict the outcome of various diseases. Amorim et al. used the Naive Bayes (NB) algorithm and other machine learning algorithms to predict the mortality in patients following TBI. The NB algorithm gave an excellent performance with an AUC of 0.906, while the random forest algorithm had an AUC of 0.880. Therefore, further comparative analysis is required in large validation studies.
Conclusions

The clinical nomogram gave excellent performance for predicting the 6-month follow-up outcomes in pediatric TBI patients. However, further external validation is required, as a challenging future study, to compare the performance of real-world implications using other predictive algorithms.

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Author contributions statement

TE: Review and editing (equal), Conceptualization (supporting). TT: Conceptualization (lead); Methodology (lead); writing – original draft (lead); formal analysis (lead).

Ethical approval

All procedures performed in the study that involved studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee or both and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The study was approved by the Human Research Ethics Committee of the Faculty of Medicine, Prince of Songkla University (REC.63-373-10-1, Date: 29.09.2020).

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None.

Conflicts of interest

None Declared.

Transparency Declaration

The study population was TBI patients younger than 15 years old who underwent a CT of the brain between January 2009 and December 2018. In detail, patients diagnosed before were the study population of Tunthanathip and Phuenpathom. The previous study aimed to identify predictors of intracranial injury following CT of the brain, while the present study focused on predicting the functional outcome of KOSCHI classification by nomogram.

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