Journal of Pediatric Surgery 55 (2020) 1238–1244

Contents lists available at ScienceDirect

Journal of Pediatric Surgery

journal homepage: www.elsevier.com/locate/jpedsurg

Ability of the PILOT score to predict 6-month functional outcome in pediatric patients with moderate–severe traumatic brain injury☆,☆☆,★

Brian F. Flaherty [a,*], Margaret L. Jackson [b], Charles S. Cox Jr [c], Amy Clark [a], Linda Ewing-Cobbs [d], Richard Holubkov [a], Kevin R. Moore [e], Rajan P. Patel [f], Heather T. Keenan [a]

[a] Division of Critical Care, Department of Pediatrics, University of Utah School of Medicine, Salt Lake City, UT
[b] Department of Surgery, University of Texas McGovern Medical School, Houston, TX
[c] Department of Pediatric Surgery, University of Texas McGovern Medical School, Houston, TX
[d] Department of Pediatrics and Children's Learning Institute, University of Texas McGovern Medical School, Houston, TX
[e] Department of Medical Imaging, Primary Children's Hospital, Salt Lake City, UT
[f] Division of Neuroradiology, Department of Diagnostic and Interventional Radiology, University of Texas McGovern Medical School, Houston, TX

ARTICLE INFO

Article history:
Received 28 March 2019
Received in revised form 18 June 2019
Accepted 28 June 2019

Key words:
Pediatrics
Traumatic brain injury
Prognosis
Intracranial pressure

ABSTRACT

Purpose: To assess the Pediatric Intensity Level of Therapy (PILOT) score alone and in combination with Emergency Department (ED) GCS and Rotterdam score of initial head CT to predict functional outcomes in children with traumatic brain injury (TBI).
Methods: Children (n = 108) aged 31 months–15 years with moderate to severe TBI were prospectively enrolled at two sites. The ability of PILOT, ED GCS, and Rotterdam scores to predict the 6-month Pediatric Injury Functional Outcome Scale (PIFOS) was evaluated using multivariable regression models with enrollment site, age, and sex as covariates.
Results: PILOT total (sum) score was more predictive of PIFOS ($R^2 = 0.23$) compared to mean ($R^2 = 0.20$) or peak daily PILOT scores ($R^2 = 0.11$). PILOT total score predicted PIFOS better than ED GCS ($R^2 = 0.01$) or Rotterdam score ($R^2 = 0.06$) and was similar to PILOT, ED GCS, and Rotterdam score combined. PILOT total score performed better in patients with intracranial pressure monitors (n = 30, $R^2 = 0.28$, slope = 0.30) than without (n = 78, $R^2 = 0.09$, slope = 0.36).
Conclusions: The PILOT score correlated moderately with functional outcome following TBI and outperformed other common predictors. PILOT may be a useful predictor or moderator of functional outcomes.
Level of evidence: Prognosis study, Level II.

Traumatic brain injury (TBI) is a leading cause of pediatric mortality and may result in substantial morbidity among survivors [1–3]. Estimating the prognosis for children with serious TBI early in their intensive care unit (ICU) course is challenging, but important. An ability to predict morbidity has the potential to impact acute and rehabilitation care, improve counseling of families on expected outcomes, and allow improved risk stratification for subgroup analysis in research. Multiple methods to estimate prognosis have been explored including physiologic measures, injury severity scores, imaging measures, and biomarkers [4]. While some of these measures discriminate mortality, they are limited in their ability to predict morbidity [4–17]. Studies examining morbidity have largely used a dichotomized version of the Glasgow Outcome Scale (GOS) score that may not adequately identify patients with residual neurologic deficits [18]. A variety of current measures used to predict outcomes, including the Glasgow Coma Scale (GCS) score and the Rotterdam CT score, relies on presenting signs and symptoms, but does not take into account potentially disease-modifying therapies or the disease trajectory [19,20]. With increasing research showing that compliance with guidelines around optimizing intracranial pressure and cerebral perfusion pressure is associated with improved outcomes, a measure of the intensity of such therapies may have a role in prognosis [21–23].

☆ Funding: This work was supported with funding provided by the Centers for Disease Control under Cooperative Agreement U01/CE002188. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention. This work was also supported by the National Institutes of Health/*Eunice Kennedy Shriver* National Institute of Child Health and Human Development K24HD072984. Neither the CDC nor the NICHD played a role in the design or conduct of the study; collection, management, analysis and interpretation of the data; preparation, review or approval of the manuscript; and decision to submit the manuscript for publication.
☆☆ Declaration of interests: The authors have no competing interests to report.
★ Study Performed at Primary Children's Hospital, Salt Lake City, UTChildren's Memorial Hermann Hospital, Houston TX
* Corresponding author at: Department of Pediatrics, Division of Pediatric Critical Care, PO Box 581289, Salt Lake City, UT 84158.
E-mail address: Brian.flaherty@hsc.utah.edu (B.F. Flaherty).

https://doi.org/10.1016/j.jpedsurg.2019.06.022
0022-3468/

The Pediatric Intensity Level of Therapy (PILOT) scale was developed as a measure of the intensity of intracranial pressure (ICP) management therapies in pediatric patients with severe TBI undergoing ICP monitoring [24]. As part of its development, the prognostic ability of the mean PILOT score was examined and showed an association with 6-month GOS score. The PILOT score is listed as a National Institute of Neurologic Diseases and Stroke (NINDS) common data element for studies of pediatric TBI, making it an easily available data point [25].Thus, the PILOT score may serve as a good candidate for further investigation as a prognostic marker. How to best use the PILOT score as a prognostic marker is unknown. It is unknown whether the mean score is most predictive of outcome, whether the addition of the PILOT score to clinical variables creates improved prognostic models, and whether the PILOT score, as a measure of therapeutic intensity, may be predictive of outcome among patients with TBI receiving ICP directed therapies who do not have an ICP monitor in place.

To explore the PILOT score as a prognostic marker in children with TBI, we evaluated whether the peak, mean, or total PILOT score was the strongest predictor of outcome at six months following injury using the Pediatric Injury Functional Outcome Scale (PIFOS) [26] a validated measure assessing multiple domains important to child functioning after TBI. Further, we hypothesized that the PILOT score, in combination with presenting GCS score and Rotterdam CT score, would provide better prognosis of functional outcome compared to the PILOT, GCS, or Rotterdam CT score alone among patients with and without ICP monitors.

1. Materials and methods

These analyses use data collected for the Children's Development after Trauma study (CDAT) [27]. The CDAT study is a 5 year longitudinal, observational cohort study of children's developmental outcomes after traumatic brain injury. CDAT recruited patients from two American College of Surgeons verified level 1 pediatric trauma centers, Primary Children's Hospital (PCH) in Salt Lake City, UT and Children's Memorial Hermann Hospital/University of Texas Health Science Center at Houston (UTHealth), between January 20th, 2013 and September 30th, 2015. Patients aged 0–15 years and their caregiver were approached for study enrollment either in the ED or hospital (PCH and UTHealth) or were contacted via telephone after review of ED admission logs (UTHealth). As part of the original study design, children were sequentially enrolled according to age and TBI severity to ensure representation of all age and severity groups. IRB approval was obtained from both the University of Utah and UTHealth.

1.1. Inclusion criteria

Patients aged 31 months to 15 years old at the time of injury who sustained a moderate to severe TBI (defined as a GCS score of 12 or less), were admitted to the pediatric ICU (PICU), and completed a 6-month outcome assessment were included. Thirty-one months of age was chosen as the lower age limit for inclusion to ensure all patients were at least 36 months of age at the 6-month evaluation and eligible for the outcome measure. Moderate and severe TBIs were included to ensure that all patients with ICP monitors were included and to include subjects with less severe TBI who did not have ICP monitors but who may have received ICP lowering therapies. Prior work has shown variability in the use of ICP monitors in severe and moderate TBI and that patients with moderate–severe TBI do receive ICP lowering therapies without ICP monitors in place [21,22,28–30].

1.2. Exclusion criteria

Patients with severe development delay or psychiatric disorder, defined by the need for a self-contained educational program prior to injury were excluded owing to the difficulty in assessing outcomes, as were patients who did not survive to discharge. Parents/guardians who did not speak either English or Spanish were excluded.

1.3. Data source

Clinical data including demographics, mechanism of injury, and presenting clinical symptoms were abstracted from the medical record using a standardized data abstraction form. Outcome assessments were at 3- and 6-months post injury. English speaking families completed follow-up assessments via telephone or online. Spanish speaking families completed assessments via telephone interview with a Spanish speaking study coordinator.

1.4. Measures

1.4.1. PILOT score

The PILOT score is derived from a 12 item instrument designed to assess the therapeutic intensity of ICP management therapies [24]. The score was developed and validated with a cohort of 113 patients including 27 with severe TBI and ICP monitors in place, non-severe TBI, non-TBI traumatic injury, and PICU patients without traumatic injury under 18 years of age. The score collects data related to therapies including: temperature and blood pressure control; use of sedatives and paralytics; use of hyperosmolar agents, CSF drainage, and surgical interventions. Scores range from 0 to 38, with higher scores indicating more intense therapy in a given 24-h period after ICU admission. The variables and associated point totals used to calculate the PILOT score are summarized in Supplemental Table 1. Medical records were retrospectively reviewed to obtain the PILOT score elements. The PILOT score was calculated by summing the point totals for each 24-h block that the subject was in the PICU up to 7 days. It is summarized as peak (maximum 24-h score), mean (total divided by number of PICU days) or total (sum) over the PICU stay.

1.4.2. Rotterdam score

The Rotterdam score is a grading system developed to predict the risk of mortality from traumatic intracranial injury based on head CT findings (range 1–6, with higher scores indicating higher risk of mortality) [20]. Rotterdam scores have previously been associated with outcomes in pediatric TBI [31,32]. A pediatric neuroradiologist at each site assigned the Rotterdam score. To insure consistency in Rotterdam scores across the two centers, both radiologists assigned the Rotterdam score on 9 cases. Of the 36 elements scored, they differed on 3 elements (17%). The radiologists then discussed their differences and calibrated scoring prior to scoring the entire cohort.

1.4.3. Glasgow Coma Score

The lowest presenting GCS score, as adapted for children, was abstracted from the medical record [33]. The GCS scores include motor (1–6), eye opening (1–4) and verbal response (1–5) with the lowest possible score = 3. If multiple scores were available in the medical record, the attending trauma surgeon's score was preferentially used, followed by the attending ED physician's score, then the score from the surgical fellow and ED fellow.

1.4.4. Outcome

PIFOS is a multidomain measure that assesses postinjury changes in areas of motor, self-care, communication, social–emotional, cognitive, physical, and academic domains. PIFOS is designed for children aged 3 years and older and was initially validated using a cohort of subjects with TBI ranging from mild to severe. The PIFOS has been used in several studies of pediatric TBI as an injury-specific outcome measure [26,34,35] that reflects important areas of disability for TBI beyond the five broad domains of death to normal function provided by the GOS [18]. PIFOS has excellent interrater reliability ($\alpha = 0.90$) and internal consistency at 3 ($\alpha = 0.90$) and 12 ($\alpha = 0.93$) months postinjury.

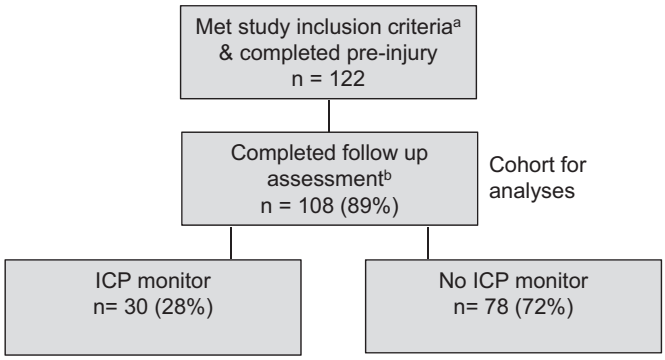

Fig. 1. Flow diagram of patient inclusion. [a]Includes all those aged 31 months to 15 years with moderate to severe TBI and admitted to the pediatric ICU. [b]Outcome assessments were completed at 6 month follow up with the exception of 2 subjects with intracranial pressure (ICP) monitoring who had 3 but not 6 month follow up.

Concurrent validity was established with existing cognitive, psychological health, and functional outcome measures including the GOS [36]. PIFOS items were modified slightly for online presentation in the current study; the total score ranged from 24 to 96 with higher scores indicating increasing limitations of daily activities and need for increasing support. Parents completed the PIFOS at 3 and 6 months postinjury.

1.5. Statistical analysis

The primary outcome is the PIFOS at 6-month follow up. For two individuals with ICP monitors and missing 6 month outcome data, the 3 month assessment was carried forward. We described child, injury and clinical characteristics for the overall cohort including summary statistics for the daily, peak, total, and mean PILOT score and the PIFOS outcome. Multiple linear regression was used to evaluate and compare models of interest. All models included the covariates of enrollment site, sex, and age, specified a priori.

We examined three different values of the PILOT score for correlation with the PIFOS: peak, mean, and total scores [24]. Specifically, it was unknown whether one day of high therapeutic intensity reflected by the peak score would be more predictive of outcome than lower therapeutic intensity for multiple days (sum), versus the mean score as reported by Shore and colleagues [24]. Thus, we examined the peak, mean, and total PILOT score in three separate models to evaluate which measure was the best predictor of the outcome. Models were compared using Akaike's Information Criterion (AIC), an information theory-based measure of model fit relative to other models (smaller is better), R^2, the proportion of variability in outcome that is explained by the model (larger is better), and predicted residual error sum of squares (PRESS), a cross-validation-based measure of the predictive stability of the model (smaller is better). AIC differences of 2 or greater are considered to represent meaningful improvement in model fit [37]. After selecting the "best" PILOT score summary measure, we fit a series of models evaluating the PILOT score, ED GCS, and Rotterdam CT score separately and in combination. We again utilized AIC, R^2, and PRESS, to compare models. Because R^2 will always increase as variables are added to the model, we also considered adjusted R^2 which increases only if the model improves more than would be expected by chance.

Because the PILOT score was created for intensity of therapy associated with ICP use, the comparison of peak, mean, and total PILOT score was repeated on the subsets of participants with and without ICP monitors. Because models with different subjects cannot be directly compared using AIC or PRESS, comparison of the model overall and for those with and without ICP monitors was performed by examining the R^2 and the slope of the regression line.

2. Results

2.1. Patient population

A total of 108 children were included in analyses: 30 with an ICP monitor and 78 with no ICP monitor (Fig. 1). Table 1 summarizes the demographics, imaging, and clinical data. Briefly, 55% of the cohort were from the Utah site, motor vehicle crashes were the most frequent mechanism of injury (64%), and 87 (81%) of the cohort had severe TBI. Twenty-eight (32%) of the patients with severe TBI and 2 (10%) of the patients with moderate TBI had an ICP monitor.

Table 1
Patient characteristics.

	Overall (N = 108)		Overall (N = 108)
Demographics and Injury		**Initial Clinical Data**	
Enrollment site: PCH	59 (55%)	**ED GCS Motor:** median (IQR)	3 (1, 5)
Child sex: Female	39 (36%)	**ED GCS Total:** median (IQR)	5 (3, 7)
Age (years) at injury: mean (SD)	9.0 (4.2)	**Sedated at time of GCS**	80 (74%)
Injury severity		**Muscle relaxed at time of GCS**	71 (66%)
Moderate TBI	20 (19%)	**Intubated prehospital or ED**	93 (86%)
Severe TBI	88 (81%)	**Seizures prehospital or ED**	15 (14%)
Injury mechanism		**Head & neck AIS:** median (IQR)	4 (3, 4)
Assault	1 (1%)	**Max AIS excluding head:** median (IQR)	2 (1, 3)
Pedestrian or bicycle	15 (14%)	**Injury Severity Score:** median (IQR)	21 (12, 29)
Motorized vehicle	69 (64%)	**Hypoxia in ED (SaO_2 < 90)**	8 (7%)
Fall	15 (14%)	**Hypotension in ED**	10 (9%)
Struck by or against	5 (5%)		
Organized sport	1 (1%)	**Inpatient Data**	
Other	2 (2%)	**Seizures**	7 (6%)
Loss of consciousness	99 (92%)	**Vasoactive medications (first 7 days)**	16 (15%)
		ICP monitor	30 (28%)
Imaging		**Duration (days)**: median (IQR)	5 (3, 9)
Any injury seen on brain imaging	99 (92%)	**Mechanical ventilation**	94 (87%)
Skull fracture	68 (63%)	**Duration (days):** median (IQR)	2 (1, 5)
Cortical contusion	21 (19%)	**GCS Motor 24 h:** median (IQR)	6 (4, 6)
Intracranial hemorrhage	79 (73%)	**GCS Total 24 h:** median (IQR)	12 (7, 15)
Rotterdam CT Score: mean (SD)	2.8 (0.9)	**PICU LOS (days):** median (IQR)	2 (1, 5)
		Hospital LOS (days): median (IQR)	9 (4, 16)

PCH = Primary Children's Hospital, Salt Lake City, Utah; TBI = traumatic brain injury; ED = Emergency Department; GCS = Glasgow Coma Scale; AIS = Abbreviate Injury Scale; ICP = intracranial pressure; LOS = length of stay; SD = standard deviation; IQR = interquartile range.

Table 2
PILOT scores and functional outcome.

	Min, Max	Mean (SD)	Median (IQR)
PILOT scores: daily			
Day 1 (n = 108)	0, 24	5.2 (5.2)	4.0 (2.0, 7.0)
Day 2 (n = 100)	0, 17	2.7 (3.4)	1.0 (0.0, 4.0)
Day 3 (n = 75)	0, 15	2.9 (3.9)	1.0 (0.0, 5.0)
Day 4 (n = 52)	0, 16	3.9 (4.3)	3.0 (0.0, 6.0)
Day 5 (n = 37)	0, 15	4.7 (4.6)	4.0 (1.0, 8.0)
Day 6 (n = 34)	0, 12	4.4 (3.9)	4.0 (1.0, 7.0)
Day 7 (n = 26)	0, 16	5.2 (4.3)	3.5 (2.0, 8.0)
PILOT scores: summary			
Peak PILOT Score	0, 24	5.7 (5.4)	4.0 (2.0, 8.0)
Mean PILOT Score	0, 13.4	2.9 (3.0)	2.0 (1.0, 3.5)
Total PILOT Score	0, 94	15.9 (22.1)	6.0 (2.0, 18.0)
Functional outcomes			
PIFOS total	24–82	34.2 (11.8)	31.0 (26.0, 39.0)

PILOT = Pediatric Intensity Level of Therapy; PIFOS = Pediatric Injury Functional Outcome Scale; SD = standard deviation; IQR = interquartile range.

2.2. PILOT and PIFOS outcome scores

Table 2 displays summary statistics for the PILOT and PIFOS scores. As shown, 26 children (24%) were still receiving ICP directed therapies on day 7 of their PICU stay. PIFOS scores ranged from 24 (indicating no change from preinjury functioning) to 82 (indicating significant reduction in functioning in multiple areas).

2.3. Prediction models

The comparison of the modeled results for the peak, mean, and total PILOT scores among all participants, and in the subsets of those with and without an ICP monitor is displayed in Table 3. Of the three PILOT summary measures, the PILOT total score was the superior predictor of PIFOS by all three of the criteria for evaluation, indicating a best-fitting model by AIC, strongest explanatory ability per R^2, and highest predictive stability per PRESS for the total cohort, ICP monitor subgroup, and No ICP monitor subgroup.

As shown in Table 4, the PILOT total score performed better than the ED GCS or Rotterdam scores alone for the total cohort, ICP monitor subgroup, and No ICP monitor subgroup. When comparing models with combinations of the PILOT total score, ED GCS, and Rotterdam score for the total cohort, the model with PILOT total score alone had similar performance to the model with PILOT total score and Rotterdam, and the model with all three; thus, the PILOT total score alone was preferred for its simplicity. In the ICP monitor group, the PILOT total score alone was better than other models and, in the No ICP monitor group, the model with the PILOT total score and ED GCS performed the best.

Fig. 2a–c shows the relationship between the PILOT total score and the PIFOS in the total cohort and for those with and without ICP monitors from the model adjusting for average values of site, sex, and age. Those with no ICP monitor ($R^2 = 0.09$) had notably more variation in outcome than those with an ICP monitor ($R^2 = 0.28$). However, the slopes of the fitted lines were similar in the two groups (0.36 and 0.30). In comparison to patients with ICP monitors, patients without ICP monitors tended to be less injured with lower PILOT scores and improved outcomes (Supplemental Table 2). In the ICP monitor group, three outliers had higher than expected PIFOS scores. These outliers had high injury severity scores (ISS) of 75, 29, and 43 and head/neck abbreviated injury scale (AIS) scores of 6, 4, and 5, respectively. The high ISS in the patients with an AIS of 4 and 5 suggests that there was other significant bodily injury.

Table 3
Linear models of correlation of peak, mean, and total PILOT score with PIFOS[a] (total cohort: N = 108).

Model	AIC	R^2	PRESS
PILOT score			
Peak score	529.8	0.11	14,758
Mean score	518.8	0.20	13,527
Total score	513.6	0.23	12,964
ICP monitor subgroup (N = 30)			
Model	**AIC**	**R^2**	**PRESS**
PILOT score			
Peak score	174.8	0.07	10,430
Mean score	167.9	0.26	8524
Total score	167.4	0.28	8370
No ICP monitor subgroup (N = 78)			
Model	**AIC**	**R^2**	**PRESS**
PILOT score			
Peak score	336.0	0.05	5864
Mean score	337.1	0.03	5920
Total score	332.3	0.09	5599

PILOT = Pediatric Intensity Level of Therapy; PIFOS = Pediatric Injury Functional Outcome Scale; AIC = Akaike's Information Criterion; PRESS = predicted residual error sum of squares; ICP = intracranial pressure.
[a] All models additionally controlled for enrollment site, sex, and age.

3. Discussion

Therapeutic intensity among children treated for elevated ICP may be an important marker for functional outcome. We examined the prognostic ability of the PILOT score to predict 6-month functional outcome scores in a cohort of patients with moderate–severe TBI. In our full cohort, the PILOT score was moderately predictive of outcome. The PILOT total score performed better than either the mean or peak PILOT scores, possibly because it reflects the need for significant ongoing therapy as well as the intensity of the therapies provided. The PILOT total score outperformed two traditionally used scores, the ED GCS and the

Table 4
Linear models of correlation of PILOT total score, ED GCS, and Rotterdam CT score with PIFOS[a].

Total Cohort (N = 107)[b]				
Model	**AIC**	**R^2**	**Adjusted R^2**	**PRESS**
PILOT total score	509.6	0.23	0.20	12,936
Lowest ED GCS	536.9	0.01	−0.03	16,179
Rotterdam CT score	530.6	0.06	0.03	15,257
PILOT total + ED GCS	511.3	0.23	0.19	13,099
PILOT total + Rotterdam CT	510.0	0.24	0.20	12,891
ED GCS + Rotterdam CT	532.6	0.06	0.02	15,457
PILOT total + ED GCS + Rotterdam CT	511.3	0.25	0.20	12,997
ICP monitor subgroup (N = 30)				
Model	**AIC**	**R^2**	**Adjusted R^2**	**PRESS**
PILOT total score	167.4	0.28	0.16	8370
Lowest ED GCS	174.9	0.07	−0.08	10,572
Rotterdam CT score	175.0	0.06	−0.09	10,956
PILOT total + ED GCS	168.8	0.29	0.14	8500
PILOT total + Rotterdam	169.2	0.28	0.13	9051
ED GCS + Rotterdam	176.7	0.07	−0.12	11,584
PILOT total + ED GCS + Rotterdam	170.7	0.29	0.10	9334
No ICP monitor subgroup (N=77[b])				
Model	**AIC**	**R^2**	**Adjusted R^2**	**PRESS**
PILOT total score	328.4	0.09	0.04	5549
Lowest ED GCS	332.5	0.04	−0.01	5800
Rotterdam CT score	332.8	0.03	−0.02	5806
PILOT total + ED GCS	326.2	0.14	0.08	5381
PILOT total + Rotterdam	330.0	0.09	0.03	5629
ED GCS + Rotterdam	332.6	0.06	−0.00	5782
PILOT total + ED GCS + Rotterdam	327.5	0.14	0.07	5435

PIFOS = Pediatric Injury Functional Outcome Scale; PILOT = Pediatric Intensity Level of Therapy; AIC = Akaike's Information Criterion; PRESS = predicted residual error sum of squares; ED = Emergency Department; GCS = Glasgow Coma Scale; ICP = intracranial pressure.
[a] All models additionally controlled for enrollment site, sex, and age.
[b] One subject that is missing the Rotterdam CT score was omitted to allow direct comparison of models.

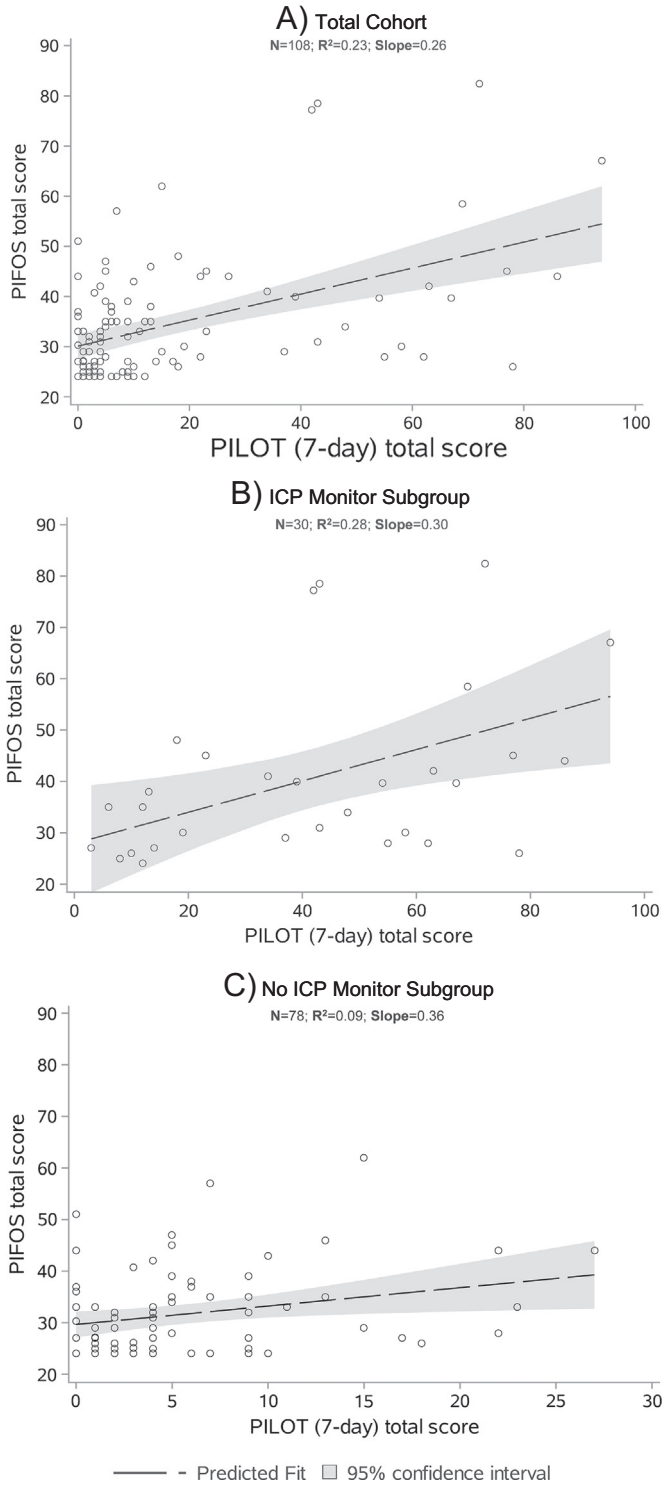

Fig. 2. Scatter plot of Pediatric Injury Functional Outcome Scale (PIFOS) total score vs Pediatric Intensity Level of Therapy (PILOT) total score for the total cohort (A), subgroup with intracranial pressure (ICP) monitors (B), and subgroup with no ICP monitor (C). The X-axis for panel C has been adjusted to allow better visualization of data points. For each panel, the R^2 values and slopes of regression lines are listed.

Rotterdam score, explaining 23% of the variance of the PIFOS. While we hypothesized that the model including the PILOT score, lowest ED GCS, and Rotterdam score would have the highest predictive ability, we found that adding these two predictors to the model with the PILOT total score did not significantly improve model fit. Low GCS and high Rotterdam scores are associated with injuries that lead to more intense ICP directed therapy; thus, the predictive ability seen previously in these scores is accounted for in the PILOT [24].

The PILOT score was developed for children with ICP monitors in situ. Unsurprisingly, the PILOT score performed better in the group with ICP monitors ($R^2 = 0.28$) than in the group without monitors ($R^2 = 0.09$). The three outliers in the ICP group with high ISS suggest that the PILOT score may not perform as well in patients with significant multisystem trauma, potentially owing to other injuries having an effect on functional outcome.

We examined children with and without ICP monitors because ICP therapies are given to children in both groups [21,22,28–30]. While there was a relationship between the PILOT total score and the PIFOS in both groups, the explanatory power of the PILOT total score was poor in the unmonitored group explaining only 9% of the variance (14% when ED GCS was also included in the model). Children who received ICP therapies but no monitor tended to receive less therapy and to have better outcomes than children with ICP monitors, although there was considerable variation, limiting its predictive value.

Prediction of children's outcomes after injury is notoriously difficult. Initial efforts to predict TBI outcomes used readily available clinical measures, such as various cut points of the GCS, the GCS motor score, and the pupillary exam primarily to examine mortality or poor outcome on the GOS or GOS-extended [5–9,11,14,16,39–41]. While the GCS is predictive of poor outcome as defined by a GOS of 3–5 or death, it has been criticized as being overly pessimistic for children with a low presenting GCS [11]. Similarly, consistent with our findings using the PIFOS, prior studies using the GCS explained only a small amount of variance (R^2 of 0.03) in three month Functional Independence Measure (WeeFIM) scores [41,42]. Difficulties in using the GCS score to predict more granular outcomes include its susceptibility to being artificially lowered by sedating medications, seizures, difficulty in assessing an intubated patient, and not accounting for the effect of neuroresuscitation measures both in the ED and ICU [4,11]. Thus, multiple types and severities of intracranial injury may present with a GCS of three. The PILOT score reflects both injury severity and ongoing resuscitative measures over time that are linked to injury severity, which may explain its superior prognostic performance in our cohort.

Imaging has also been examined as a potential prognostic marker for outcome. As most trauma protocols suggest CT imaging for acute injury, CT imaging has been the most studied. Prior pediatric work has noted the association between cerebral swelling and diffuse axonal injury with higher mortality and worse GOS scores [5,6,12,15,39]. Liesemer et al. found the Rotterdam score to have a good ability [AUC of 0.85] to predict mortality in a pediatric cohort with moderate–severe TBI presenting within 24 h of injury [31]. We found that like the GCS, the Rotterdam score poorly predicted the PIFOS. Potential limitations of imaging to predict outcomes include that imaging in the hyperacute period may miss or underestimate the severity of an intracranial bleed or edema [43]. Further, CT may miss subtle findings of diffuse axonal injury [10,44,45] and does not track injury evolution.

Newer promising methods of outcomes prediction, including the use of CSF and serum biomarkers, are being developed. As reviewed by Au et al., brain specific biomarkers that enter the blood through the CSF are being explored for their predictive ability among comatose children [4] and in long-term cognitive outcomes [4,34]. Advantages of biomarkers may include their reflection of injury to neurons, and the ability to follow specific or panels of markers over time. As work in the area of prognostic modeling with clinical, radiographic, and biomarker data evolves, our data show that therapeutic intensity should be considered an important covariate and included in prognostic models that could be used to assist with counseling families and guiding postinjury rehabilitation need.

Our results must be viewed with the following limitations. First, the PIFOS score is valid only for children 3 years and older, limiting our ability to assess PILOT score to predict outcomes in younger patients.

Second, although our group of children with ICP monitors was similar to that used in the initial validation study, it is still relatively small. Third, the PILOT score items were obtained retrospectively from chart review. However, the items needed to calculate the PILOT score are recorded in a standard fashion in the medical record and are likely to be reliable even when collected retrospectively. Other clinical variables impacting TBI outcome, such as hypoxia, multiple trauma, or prearrival arrest, were not included and may have improved model fit. Fourth, as our cohort only included patients who survived to 6 months, our results cannot speak to the ability of the PILOT to predict death. Finally, this study was designed to examine the prognostic ability of the PILOT score and cannot state whether or not more intense therapy affects outcome. These limitations can be addressed with a larger prospective study.

Our study has several strengths also. Our cohort drew from two institutions with different surgical practices for ICP management which increase its generalizability. We prospectively gathered a continuous functional measure of outcome with high granularity to describe function in multiple domains. This may create a more meaningful prediction model compared to global outcomes measure such as the GOS and GOS-extended which have limited ordinal descriptors of outcome and ceiling effects. [46,47] Further, the use of the PIFOS allowed finer calibration of the PILOT score.

4. Conclusion

The PILOT total score has moderate correlation with 6-month PIFOS outcomes among patients with moderate–severe TBI and performs best in patients with ICP monitors. The PILOT total score may be a reasonable marker of outcome for children receiving intracranial pressure directed therapies. The PILOT score is easy to calculate and requires no specialty lab testing or imaging studies, making it easy to deploy in the clinical setting. As a dynamic measure that reflects intensity of therapy over time, the PILOT may be used as either a predictor or moderator of functional outcomes in future research.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpedsurg.2019.06.022.

References

[1] Faul M, Xu L, Wald M, et al. Traumatic brain injury in the United States: emergency department visits, hospitalizations and death 2002–2006. Centers for Disease Control and Prevention, National Center for Injury Prevention and Control: Atlanta (GA); 2010.

[2] Rivara FP, Koepsell TD, Wang J, et al. Disability 3, 12, and 24 months after traumatic brain injury among children and adolescents. Pediatrics 2011;128(5):e1129–38.

[3] Rivara FP, Vavilala MS, Durbin D, et al. Persistence of disability 24 to 36 months after pediatric traumatic brain injury: a cohort study. J Neurotrauma 2012;29(15):2499–504.

[4] Au AK, Clark RSB. Paediatric traumatic brain injury: prognostic insights and outlooks. Curr Opin Neurol 2017;30(6):565–72.

[5] Ong L, Selladurai BM, Dhillon MK, et al. The prognostic value of the Glasgow Coma Scale, hypoxia and computerised tomography in outcome prediction of pediatric head injury. Pediatr Neurosurg 1996;24(6):285–91.

[6] Levin HS, Aldrich EF, Saydjari C, et al. Severe head injury in children: experience of the Traumatic Coma Data Bank. Neurosurgery 1992;31(3):435–43 [discussion 43-4].

[7] Ducrocq SC, Meyer PG, Orliaguet GA, et al. Epidemiology and early predictive factors of mortality and outcome in children with traumatic severe brain injury: experience of a French pediatric trauma center. Pediatr Crit Care Med 2006;7(5):461–7.

[8] Chung CY, Chen CL, Cheng PT, et al. Critical score of Glasgow Coma Scale for pediatric traumatic brain injury. Pediatr Neurol 2006;34(5):379–87.

[9] Fortune PM, Shann F. The motor response to stimulation predicts outcome as well as the full Glasgow Coma Scale in children with severe head injury. Pediatr Crit Care Med 2010;11(3):339–42.

[10] Suskauer SJ, Huisman TA. Neuroimaging in pediatric traumatic brain injury: current and future predictors of functional outcome. Dev Disabil Res Rev 2009;15(2):117–23.

[11] Lieh-Lai MW, Theodorou AA, Sarnaik AP, et al. Limitations of the Glasgow Coma Scale in predicting outcome in children with traumatic brain injury. J Pediatr 1992;120(2 Pt 1):195–9.

[12] Hirsch W, Schobess A, Eichler G, et al. Severe head trauma in children: cranial computer tomography and clinical consequences. Paediatr Anaesth 2002;12(4):337–44.

[13] Young AM, Guilfoyle MR, Fernandes H, et al. The application of adult traumatic brain injury models in a pediatric cohort. J Neurosurg Pediatr 2016;18(5):558–64.

[14] Bahloul M, Ben Hamida C, Chelly H, et al. Severe head injury among children: prognostic factors and outcome. Injury 2009;40(5):535–40.

[15] Claret Teruel G, Palomeque Rico A, Cambra Lasaosa FJ, et al. Severe head injury among children: computed tomography evaluation as a prognostic factor. J Pediatr Surg 2007;42(11):1903–6.

[16] Emami P, Czorlich P, Fritzsche FS, et al. Impact of Glasgow Coma Scale score and pupil parameters on mortality rate and outcome in pediatric and adult severe traumatic brain injury: a retrospective, multicenter cohort study. J Neurosurg 2017;126(3):760–7.

[17] Fulkerson DH, White IK, Rees JM, et al. Analysis of long-term (median 10.5 years) outcomes in children presenting with traumatic brain injury and an initial Glasgow Coma Scale score of 3 or 4. J Neurosurg Pediatr 2015;16(4):410–9.

[18] Jennett B, Bond M. Assessment of outcome after severe brain damage. Lancet 1975;1(7905):480–4.

[19] Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. Lancet 1974;2(7872):81–4.

[20] Maas AIR, Hukkelhoven CWPM, Marshall LF, et al. Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. Neurosurgery 2005;57(6):1173–82.

[21] Vavilala MS, Kernic MA, Wang J, et al. Acute care clinical indicators associated with discharge outcomes in children with severe traumatic brain injury. Crit Care Med 2014;42(10):2258–66.

[22] Vavilala MS, Lujan SB, Qiu Q, et al. Intensive care treatments associated with favorable discharge outcomes in Argentine children with severe traumatic brain injury: for the South American Guideline Adherence Group. PLoS One 2017;12(12):e0189296.

[23] Kochanek PM, Carney N, Adelson PD, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents—second edition. Pediatr Crit Care Med 2012;13(Suppl. 1):S1–82.

[24] Shore PM, Hand LL, Roy L, et al. Reliability and validity of the Pediatric Intensity Level of Therapy (PILOT) scale: a measure of the use of intracranial pressure-directed therapies. Crit Care Med 2006;34(7):1981–7.

[25] Adelson PD, Pineda J, Bell MJ, et al. Common data elements for pediatric traumatic brain injury: recommendations from the working group on demographics and clinical assessment. J Neurotrauma 2012;29(4):639–53.

[26] Ewing-Cobbs L, Bloom DR, Prasad MR, et al. Assessing recovery and disability after physical trauma: the Pediatric Injury Functional Outcome Scale. J Pediatr Psychol 2014;39(6):653–65.

[27] Keenan HT, Clark AE, Holubkov R, et al. Psychosocial and executive function recovery trajectories one year after pediatric traumatic brain injury: the influence of age and injury severity. J Neurotrauma 2018;35(2):286–96.

[28] Bennett TD, Riva-Cambrin J, Keenan HT, et al. Variation in intracranial pressure monitoring and outcomes in pediatric traumatic brain injury. Arch Pediatr Adolesc Med 2012;166(7):641–7.

[29] Dixon RR, Nocera M, Zolotor AJ, et al. Intracranial pressure monitoring in infants and young children with traumatic brain injury. Pediatr Crit Care Med 2016;17(11):1064–72.

[30] Bennett TD, Statler KD, Korgenski EK, et al. Osmolar therapy in pediatric traumatic brain injury. Crit Care Med 2012;40(1):208–15.

[31] Liesemer K, Riva-Cambrin J, Bennett KS, et al. Use of Rotterdam CT scores for mortality risk stratification in children with traumatic brain injury. Pediatr Crit Care Med 2014;15(6):554–62.

[32] Haque A, Dhanani Z, Ali A, et al. Outcome of traumatic brain injury in children by using Rotterdam score on computed tomography. J of Ayub Med Col 2018;30(1):140–2.

[33] Reilly PL, Simpson DA, Sprod R, et al. Assessing the conscious level in infants and young children: a paediatric version of the Glasgow Coma Scale. Childs Nerv Syst 1988;4(1):30–3.

[34] Wilkinson AA, Dennis M, Simic N, et al. Brain biomarkers and pre-injury cognition are associated with long-term cognitive outcome in children with traumatic brain injury. BMC Pediatr 2017;17(1):173.

[35] Yeates KO, Beauchamp M, Craig W, et al. Advancing Concussion Assessment in Pediatrics (A-CAP): a prospective, concurrent cohort, longitudinal study of mild traumatic brain injury in children: protocol study. BMJ Open 2017;7(7):e017012.

[36] Jennett B, Teasdale G, Braakman R, et al. Predicting outcome in individual patients after severe head-injury. Lancet 1976;1(7968):1031–4.

[37] Burnham KP, Anderson DR. Model selection and multimodel inference: a practical information-theoretic approach 2nd ed. New York, NY: Springer-Verlag; 2002.

[39] White JR, Farukhi Z, Bull C, et al. Predictors of outcome in severely head-injured children. Crit Care Med 2001;29(3):534–40.

[40] Murphy S, Thomas NJ, Gertz SJ, et al. Tripartite stratification of the Glasgow Coma Scale in children with severe traumatic brain injury and mortality: an analysis from a multicenter comparative effectiveness study. J Neurotrauma 2017;34:2220–9.

[41] Suskauer SJ, Slomine BS, Inscore AB, et al. Injury severity variables as predictors of WeeFIM scores in pediatric TBI: time to follow commands is best. J Pediatr Rehabil Med 2009;2(4):297–307.

[42] Msall ME, DiGaudio K, Duffy LC, et al. WeeFIM. Normative sample of an instrument for tracking functional independence in children. Clin Pediatr 1994;33(7):431–8.

[43] Stein SC, Spettell CM. Delayed and progressive brain injury in children and adolescents with head trauma. Pediatr Neurosurg 1995;23(6):299–304.

[44] Lee B, Newberg A. Neuroimaging in Traumatic Brain Imaging. NeuroRx. 2005, p. 372–83.

[45] Gentry LR, Godersky JC, Thompson B, et al. Prospective comparative study of intermediate-field MR and CT in the evaluation of closed head trauma. AJR Am J Roentgenol 1988;150(3):673–82.

[46] Wilson JTL, Pettigrew LEL, Teasdale GM. Structured interviews for the Glasgow Outcome Scale and the extended Glasgow Outcome Scale: guidelines for their use. J Neurotrauma 1998;15(8):573–85.

[47] Williamson OD, Gabbe BJ, Sutherland AM, et al. Comparing the responsiveness of functional outcome assessment measures for trauma registries. J Trauma 2011;71(1):63–8.