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ORIGINAL RESEARCH

Incidence of traumatic brain injuries in head-injured children with seizures

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Abstract

Objective: Incidence and short-term outcomes of clinically important traumatic brain injury (ciTBI) in head-injured children presenting to ED with post-traumatic seizure (PTS) is not described in current literature.

Methods: Planned secondary analysis of a prospective observational study undertaken in 10 Australasian Paediatric Research in Emergency Department International Collaborative (PREDICT) network EDs between 2011 and 2014 of head-injured children <18 years with and without PTS. Clinical predictors and outcomes were analysed by attributable risk (AR), risk ratios (RR) and 95% confidence interval (CI), including the association with Glasgow Coma Scale (GCS) scores.

Results: Of 20 137 head injuries, 336 (1.7%) had PTS with median age of 4.8 years. Initial GCS was 15 in 268/336 (79.8%, AR −16.1 [95% CI −20.4 to −11.8]), 14 in 24/336 (7.1%, AR 4.4 [95% CI 1.6–7.2]) and ≤13 in 44/336 (13.1%, AR 11.7 [95% CI 8.1–15.3]) in comparison with those without PTS, respectively. The ciTBI rate was 34 (10.1%) with PTS *versus* 219 (1.1%) without PTS (AR 9.0 [95% CI 5.8–12.2]) with 5/268 (1.9%), 6/24 (25.0%) and 23/44 (52.3%) with GCS 15, 14 and ≤13, respectively. In PTS, rates of admission ≥2 nights (34 [10.1%] AR 9.0 [95% CI 5.8–12.3]), intubation >24 h (9 [2.7%] AR 2.5 [95% CI 0.8–4.2]) and neurosurgery (8 [2.4%] AR 2.0 [95% CI 0.4–

Key findings

- In a large prospective cohort we demonstrated that reduced GCS on ED arrival in head-injured children with PTS increases the risk of ciTBI.
- In head-injured children with PTS and GCS 15 on arrival the need for neurosurgical intervention is minimal and support for observation over immediate CT scanning.

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3.7]), were higher than those without PTS. Children with PTS and GCS 15 or 14 had no neurosurgery, intubations or death, with two deaths in children with PTS and GCS ≤13.

Conclusions: PTS was uncommon in head-injured children presenting to the ED but associated with an increased risk of ciTBI in those with reduced GCS on arrival.

Key words: *acute brain injury, child, head injuries, seizures.*

Introduction

Head injury is a common cause of ED presentation in children. Only a minority of children with any severity of head injury (0.6–4%) experience post-traumatic seizures (PTS).[1–3] However, head-injured children with PTS have an increased risk of traumatic brain injury on computed tomography scan (TBI-on-CT) and need for neurosurgical intervention.[1,4,5] Current guidelines[6,7] strongly recommend that all head-injured patients who experience PTS should receive a CT scan, regardless of the child's presenting Glasgow Coma Scale (GCS) or presenting symptomology, because of the association with TBI-on-CT.[1,7,8] However, it is not clear if the recommendation for CT scanning is applicable to all children with PTS irrespective of their clinical condition after assessment in ED.

In their sub-analysis of the Paediatric Emergency Care Applied Research Network (PECARN) head injury rule derivation data,[1] 87% of children with PTS underwent CT scanning with TBI-on-CT demonstrated in 15.5%. Yet among those with TBI-on-CT, 4.2% of those patients were determined to be suitable for discharge from ED, reflecting that not all children with PTS require CT scanning and not all children with TBI-on-CT require intervention or admission.

A recent systematic review and metanalysis has further confirmed, in a pooled dataset of over 65 000 children from seven studies, that children with a GCS of 15 had an immediate PTS rate of 0.9%, underwent imaging in 87% with a frequency of any TBI of 13.0% and requiring neurosurgical intervention in 2.3%.[9] Of importance, none of the studies included in the systematic review correlated with the more clinically relevant outcomes defined by the PECARN group as clinically important TBI (ciTBI), incorporating need for prolonged hospital admission, ICU interventions and death (Table S1).

The primary objective of the present study was to assess and compare the incidence and outcomes of both TBI-on-CT and ciTBI in a large prospective cohort of head-injured children of all severities who presented with and without PTS in a health setting with a low baseline CT rate. Additionally, in children with PTS, we aimed to determine the association between initial GCS at ED assessment with ED disposition and outcome. Our hypothesis for this planned secondary analysis was that the occurrence of PTS in head-injured children presenting with GCS 15 with no other risk factors, in comparison with patients without PTS is not associated with an increased risk of ciTBI.

Methods

Study design, setting and patients

We performed a secondary analysis of a prospective, multi-centre, observational study which enrolled children presenting with head injury of any severity to 10 paediatric EDs in Australia and New Zealand between April 2011 and November 2014.[10] All EDs are members of the Paediatric Research in Emergency Departments International Collaborative (PREDICT) research network.[11]

In the primary study, we collected and analysed rule-specific predictor and outcome variables to validate three international head injury clinical decision rules (CDR) in children aged <18 years.[2,3,8] Exclusion criteria were trivial facial injury only, patient/family refusal to participate, referral directly from ED triage to an external provider, did not wait to be seen or neuroimaging done prior to transfer to a study site.

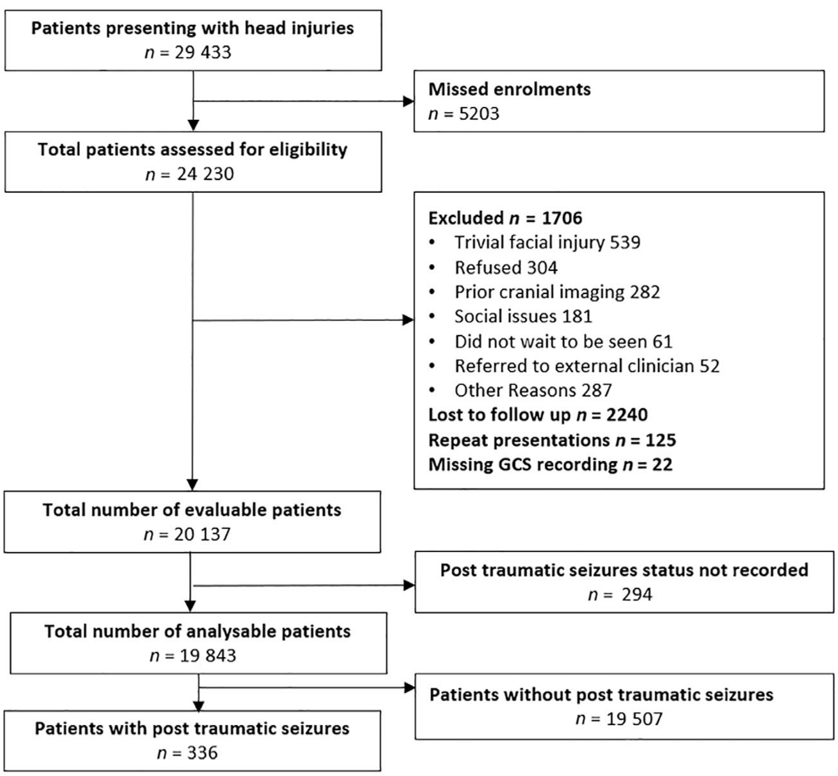

Figure 1. *Patient flowchart.*

TABLE 1. *Comparison of head-injured children with and without post-traumatic seizures* (n = *19 843*)

	Head-injured children with PTS (n = 336) n (%)	Head-injured children without PTS (n = 19 507) n (%)	AR (95% CI)	RR (95% CI)
All ages (years)				
<1	30 (8.9)	2278 (11.7)	−2.8 (−5.8 to 0.3)	(Ref)
1 to 2	55 (16.4)	2925 (15.0)	1.4 (−2.6 to 5.4)	1.2 (0.98–1.4)
>2	251 (74.7)	14 304 (73.3)	1.4 (−3.3 to 6.1)	1.0 (0.99–1.1)
Median (IQR)	4.80 (10.3)	4.19 (7.1)		
Sex				
Male	212 (63.1)	12 437 (63.8)	−0.7 (−5.9 to 4.5)	0.99 (0.9–1.1)
GCS				
15	268 (79.8)	18 698 (95.9)	−16.1 (−20.4 to −11.8)	(Ref)
14	24 (7.1)	534 (2.7)	4.4 (1.6 to 7.2)	3.00 (2.0–4.4)
≤13	44 (13.1)	275 (1.4)	11.7 (8.0 to 15.3)	9.7 (7.2–13.1)
Mechanism				
Falls				
Fall from height <1 m	149 (46.4)	9613 (51.0)	−4.9 (−10.3 to 0.4)	1.1 (1.04–1.2)
Fall from height 1–1.5 m	80 (24.9)	2577 (13.7)	10.6 (6.0 to 15.2)	1.8 (1.6–2.1)
Fall from height 1.5–3 m	33 (10.3)	1066 (5.7)	4.4 (1.2 to 7.6)	2.2 (1.7–3.0)
Fall from height >3 m	2 (0.6)	151 (0.8)	−0.2 (−1.0 to 0.7)	1.3 (0.3–4.9)
Fall downstairs (>5 stairs)	7 (2.2)	247 (1.3)	0.9 (−0.7 to 2.5)	1.7 (0.8–3.5)
Traffic incident				
Pedestrian struck by moving vehicle	7 (2.1)	229 (1.2)	0.9 (−0.6 to 2.5)	1.8 (0.8–3.7)
Bike rider struck by automobile without a helmet	1 (0.3)	26 (0.1)	0.2 (−0.4 to 0.8)	2.2 (0.3–16.3)
Fall from bicycle without a helmet	8 (2.4)	368 (1.9)	0.5 (−1.3 to 2.1)	1.3 (0.6–2.5)
Motor vehicle related (include quad bike, motor bike)	18 (5.4)	808 (4.2)	1.2 (−1.2 to 3.7)	1.3 (0.8–2.0)
Sports	52 (15.5)	3433 (17.6)	−2.1 (−6.0 to 1.8)	0.9 (0.7–1.1)
Miscellaneous				
High impact object struck head	12 (3.6)	1013 (5.3)	−1.7 (−3.8 to 0.4)	0.7 (0.4–1.2)
Non-accidental head injury	10 (3.0)	92 (0.5)	2.6 (0.7 to 4.4)	6.40 (3.4–12.2)

AR, attributable risk; CI, confidence interval; GCS, Glasgow Coma Scale; IQR, interquartile range; PTS, post-traumatic seizure; RR, risk ratio.

Study procedures

Details of the primary study protocol and results are described in detail elsewhere.[10,12] In brief, patients were enrolled by the treating ED clinician, who collected clinical data including GCS scores[13] on their initial clinician assessment, or if not available, GCS scores at triage. A research assistant recorded ED and hospital management data after the visit and conducted telephone follow up for the patients who had not undergone neuroimaging. Demographic, epidemiological, neuroimaging, admission, and neurosurgery information were also collected.

In the present study, we identified children with PTS among our total population by searching the data recorded in the study database. We defined PTS as any seizure occurring after a head injury, including seizures that occurred in the community or in the ED. The occurrence of PTS was determined at first assessment of the child by the medical practitioner and therefore preceded any imaging (if done) or decision to admit. PTS was determined by direct interrogation of witnesses to the seizure (including paramedics, parents, or lay observers at the scene, with variable understanding of seizure activity) or by medical and nursing staff (if the seizure occurred at the time of ED arrival). We excluded children who firstly had a seizure which then resulted in the head injury. In addition, because of varying definitions of PTS in the literature,[14] we limited inclusion to those without a known history of epilepsy.[1,9]

Apart from these pre-defined exclusions, all children with head injury, including those who were

TABLE 2. *Patients with post-traumatic seizures meeting PECARN CDR exclusion criteria (*n = 336*)*

	n (%)	95% CI
Number of patients meeting PECARN exclusion	121 (36.0)	30.9–41.4
Presenting after 24 h	17 (5.1)	3.0–8.0
Trivial mechanisms of injury†	0 (0.0)	0.0–1.1
Suspicion of penetrating trauma	27 (8.0)	5.4–11.5
Known brain tumours	2 (0.6)	0.1–2.1
Pre-existing neurological disorders complicating assessment	38 (11.3)	8.1–15.2
Neuroimaging at an outside hospital before transfer	2 (0.6)	0.1–2.1
Ventricular shunts	2 (0.6)	0.1–2.1
Bleeding disorders	4 (1.2)	0.3–3.0
GCS <14	44 (13.1)	9.7–17.2

†Trivial mechanism of injury defined as falls from standings height, walking or running into stationary objects, no signs or symptoms of head trauma other than scalp abrasions and lacerations. CDR, clinical decision rule; GCS, Glasgow Coma Scale; PECARN, Paediatric Emergency Care and Research Network.

TABLE 3. *Outcome for head-injured children with and without post-traumatic seizures (*n = 19 843*)*

	Head-injured children with PTS (*n* = 336) *n* (%)	Head-injured children without PTS (*n* = 19 507) *n* (%)	AR (95% CI)	RR (95% CI)
CT scan	131 (39.0)	1895 (9.7)	29.3 (24.0 to 34.5)	4.0 (3.5–4.6)
Abnormal CT	52 (15.5)	529 (2.7)	11.5 (2.9 to 20.2)	1.4 (1.1–1.8)
TBI-on-CT	42 (12.5)	332 (1.7)	10.8 (7.3 to 14.3)	7.3 (5.4–9.9)
Admission (any length)	198 (58.9)	4232 (21.7)	37.2 (31.9 to 42.5)	2.7 (2.5–3.00)
ciTBI	34 (10.1)	219 (1.1)	9.0 (5.8 to 12.2)	9.0 (6.4–12.7)
Admission ≥2 nights with TBI on CT	34 (10.1)	212 (1.1)	9.0 (5.8 to 12.3)	9.3 (6.6–13.2)
ETT >24 h	9 (2.7)	33 (0.2)	2.5 (0.8 to 4.2)	15.8 (7.6–32.8)
Neurosurgery	8 (2.4)	66 (0.3)	2.0 (0.4 to 3.7)	7.0 (3.4–14.5)
Death from TBI	2 (0.6)	12 (0.1)	0.5 (−0.3 to 1.4)	9.7 (2.2–43.1)

AR, attributable risk; CI, confidence interval; ciTBI, clinically important traumatic brain injury; CT, computed tomography; ETT, endotracheal tube; PTS, post-traumatic seizure; RR, risk ratio; TBI, traumatic brain injury.

TABLE 4. *Comparison of computed tomography findings and outcomes of head-injured children with post-traumatic seizures (n = 336)*

	GCS 15 (*n* = 268) *n* (%)	GCS 14 (*n* = 24) *n* (%)	AR (95% CI)	RR (95% CI)	GCS ≤13 (*n* = 44) *n* (%)	AR (95% CI)	RR (95% CI)
CT scan	70 (26.1)	19 (79.2)	53.1 (36.0–70.1)	3.0 (2.3–4.0)	42 (95.5)	69.3 (61.2 to 77.4)	3.7 (3.0–4.5)
TBI-on-CT	11 (4.1)	7 (29.2)	25.1 (6.7–43.4)	7.1 (3.0–16.6)	24 (54.5)	50.4 (35.5 to 65.3)	13.3 (7.0–25.2)
Outcomes							
Admission (any length)	138 (51.5)	18 (75.0)	23.5 (5.2–41.8)	1.5 (1.1–1.9)	42 (95.5)	44.0 (35.4 to 52.6)	1.9 (1.6–2.1)
ciTBI	5 (1.9)	6 (25.0)	23.1 (5.7–40.5)	13.4 (4.4–40.7)	23 (52.3)	50.4 (35.6 to 65.3)	28.0 (11.2–69.8)
Admission ≥2 days with TBI on CT	5 (1.9)	6 (25.0)	40.3 (1.0–79.5)	1.9 (0.9–3.9)	23 (52.3)	50.4 (19.9 to 80.9)	2.1 (1.1–4.1)
Neurosurgery	0 (0.0)	0 (0.0)			8 (18.2)	18.2 (6.8 to 29.6)	
ETT >24 h	0 (0.0)	0 (0.0)			9 (20.5)	22.5 (9.6 to 35.4)	
Death	0 (0.0)	0 (0.0)			2 (4.5)	4.6 (−1.6 to 10.7)	

NB. Patients could meet more than one criterion for ciTBI or have more than one TBI-on-CT. AR, attributable risk (compared to GCS 15); CI, confidence interval; ciTBI, clinically important traumatic brain injury; CT, computed tomography; ETT, endotracheal intubation; GCS, Glasgow Coma Scale; RR, relative risk (compared to GCS 15); TBI, traumatic brain injury.

excluded from both the PECARN study[8] and the PECARN sub-analysis of PTS, were eligible.[1] Specifically, children excluded in our primary study, were included in this secondary evaluation with; previous history of head injury; penetrating trauma; known brain tumours; pre-existing neurological disorders not associated with epilepsy; neuroimaging at an outside hospital before transfer; presence of a ventricular shunt; known bleeding disorders; any GCS score; and those presenting ≥24 h after the head injury. Abnormal CT, TBI-on-CT, neurosurgical interventions, ciTBI and injury mechanism severity were defined as per the PECARN CDR (Table S1).[8]

Patient and public involvement

No patients/public were involved in the development of the primary study.

Statistical analysis

Data were entered into Epidata (The Epidata Association, Odense, Denmark), and later REDCap[15] hosted at Murdoch Children's Research Institute, and analysed using Stata 13 (StataCorp, College Station, TX, USA). Descriptive statistics were calculated for key variables with 95% confidence intervals (CI) where relevant. Comparisons of demographic and injury characteristics between those presenting with and without PTS were undertaken. Associations between clinical predictors and outcomes of those presenting to the ED with and without a PTS were analysed by attributable risk (AR), risk ratios (RR) and 95% CI, including the association of PTS with an initial GCS score of ≤13, 14 and 15.

The study was approved by the institutional ethics committee at each participating site. We obtained informed verbal consent from parents/guardians; for life-threatening or fatal injuries, the participating ethics committees granted a waiver of consent. The study was registered with the Australian New Zealand Clinical Trials Registry (ANZCTR) ACTRN12614000463673.

Results

We identified 336 head-injured children with PTS (1.7% of the original cohort of 20 137 children) (Fig. 1). Of these, the majority were aged >2 years (74.7%) and the median age was 4.8 years. Males were frequent in both the PTS positive and PTS negative groups (63.1% and 63.8%, respectively) (Table 1). There were 121 patients included in this analysis who met PECARN exclusion criteria, including those presenting to the ED ≥24 h after injury, suspected penetrating trauma, known brain tumours, ventricular shunts and bleeding disorders (Table 2).

In comparison with children without PTS, head-injured children with PTS more frequently presented to the ED with an initial GCS <15 with PTS recorded in 1.4%, 4.3% and 2.3% of those with GCS 15, 14 and ≤13, respectively (Table 1).

Mechanism of injury was similar in both those with or without PTS; falls from any height were the most frequent cause of head injury, followed by sports related head injury. Importantly, suspicion of non-accidental injury (as determined by the clinician managing the patient and recorded on the case report form) was more frequent in children with PTS (Table 1).

Head-injured children with PTS underwent a CT scan in 39.0% of cases (26.1%, 79.2% and 95.5% with GCS 15, 14 and ≤13, respectively). There was an overall positivity rate for any abnormality of 32.1%. In addition, 15 children underwent magnetic resonance imaging during their admission.

Head-injured children with PTS had a ciTBI incidence of 10.1% overall with the incidence of 1.9%, 25.0% and 52.3% in GCS 15, 14 and ≤13, respectively (Tables 3 and 4). Children with PTS had a lesser rate of GCS 15 (AR −16.1) when compared to children without PTS and TBI/ciTBI rates were 4.1% and 1.9%, respectively. Death from TBI occurred in two children, both with GCS ≤13 (Table 3).

In head-injured children with PTS and a GCS 15 or 14, admissions of any duration occurred in 51.5% and 75.0%, respectively, with no neurosurgery, intubations or death in these children. Among children with GCS ≤13, 95% were admitted with 52.3% having a ciTBI, including neurosurgery (18.2%) and ETT >24 h (22.5%) (Table 4). In the 131 head-injured children with PTS who underwent CT scan, the most common findings were intracranial haemorrhage or contusion (37/336 [11%]) and skull fractures (31/336 [9.2%]), irrespective of GCS score (Table S2).

Discussion

In this planned evaluation of a large, prospective multicentre cohort study of over 20 000 head-injured children[10] the incidence of PTS was low. In patients with PTS, the key finding is that an abnormal GCS score at initial ED clinician assessment is the most significant determinant of ciTBI. Although the overall incidence of ciTBI in head-injured children was higher in those with PTS than without, head-injured children with PTS and GCS 15 had only a modest increased rate of ciTBI of 1.9% in comparison with those without PTS, whereas children with GCS 14 and GCS ≤13 had rates 13 and 28 times higher, respectively.

These results were similar to the Badawy study[1] where 466 patients presented with GCS 15, of whom 332 (71.2%) underwent a CT scan in ED. There were 20 (6.0%) TBIs detected but only one child, with multiple other PECARN CDR criteria present, including altered mental status, required neurosurgery for an epidural hematoma. In our study none of the children with PTS who presented with GCS 14 or 15 died, were intubated or underwent neurosurgery.

Although our findings are consistent with several prospective observational cohort studies[1,16–18] with reported incidences of PTS in head-injured children between 1.3% and 3.1%, these studies all have significantly higher CT rates of 86.9% to 98% than our cohort. These studies were undertaken in the USA with a higher baseline CT rate (35.3%)[8] in head injury assessment than in the Australian and New Zealand setting (10.1%).[12] In our cohort, the CT scanning rate of 39% for patients with PTS, whereas significantly higher than the overall CT rate in our parent study, was much lower in comparison with North American data.[1] These findings demonstrate the minimal need for neurosurgical intervention in children presenting with PTS and GCS 15 at ED assessment and provides support for observation, rather than immediate CT scanning, after consideration of any other risk factors.

Furthermore, we have demonstrated a TBI rate lower than a recent systematic review and meta-analysis evaluating the risk of brain injury and neurosurgery in alert (i.e. GCS 15) children after a PTS.[9] In the systematic review combined patient cohort, 533 (0.9%) head-injured patients had GCS 15 associated with immediate PTS, with a background imaging rate of 86% and a 13% TBI rate. Those with an isolated PTS (pre-defined as absence of the PECARN[8] study-specific CDR predictors) had an immediate seizure frequency of 0.1%, a CT scanning rate of 58%, a TBI rate of 7% and a 26.6% admission rate.

The incidence of PTS is increased in head-injured children with a reduced GCS at ED presentation. In a retrospective study, Chiaretti *et al.* demonstrated that the incidence of early PTS was related to GCS on arrival in ED (22.7% in GCS ≤8, 12% in GCS 9–12 and only 2% in GCS 13–15).[19] In a further observational study in children <18 years with moderate to severe TBI, the mean GCS was lower in those who experienced early PTS; however, the difference was not statistically significant.[20] Our study has demonstrated and confirmed that, apart from admission for ≥2 nights because of TBI, the clinically important TBI factors associated with PTS were confined to those with initial GCS ≤13. In those children, the use of early CT scanning and hospital admission is warranted.

It has been reported in earlier studies that children <3 years of age are more at risk of early PTS[19,21] with a further study demonstrating 61% of head-injured children with immediate PTS were <5 years of age.[22] In contrast, in our study, there was no difference in the incidence of PTS in head-injured children by age and as such we did not demonstrate that younger children are more at risk of PTS than older children.

One of the strengths of the present study has been the inclusion of patients that were excluded from the PECARN study including those with delayed presentations, known brain tumours, pre-existing neurological disorders, ventricular shunts and bleeding disorders.[23–25] Although these inclusions increased the heterogeneity of our population, it represents the patient populations presenting every day to the EDs and their inclusion assists on-floor clinicians in their decision making. Even with the inclusion of these subgroups in the database for the present study, we did not demonstrate a higher risk of TBI in our cohort.

Some of the limitations of the present study relate to it being a secondary evaluation of the parent study. These limitations include the inability to report all outcome data for patients who had CT scans, as the original study process was only to follow-up children discharged without CT scan to ensure they did not experience deterioration mandating a later CT scan. As a result of this, we were not able to determine later outcomes in the children who did have CT scans in ED and were then discharged home. For instance, we could not determine any seizure recurrence or return-to-hospital rate in our cohort if they received a CT scan on their initial ED evaluation.

In the parent study, we did not record the time after the head injury that the PTS occurred, nor the duration or characteristic of the actual seizure. These data would assist with differentiating immediate, and early seizures and would assist in determining other factors that may increase the risk of having ciTBI as well as the development of post-traumatic epilepsy following presentation with PTS following a head injury.

Finally, we defined children as having PTS based on history from bystanders at the time of injury, or from clinical observations, if in hospital. There was no capacity to independently confirm the presence or not of the seizure and so some children classified as PTS may not have had a true seizure. However, this reflects real-world clinical practice, and the information available to clinicians in the ED when evaluating head-injured children for risk of ciTBI.

Conclusions

In a large cohort study of over 20 000 children we have correlated GCS with the occurrence of PTS. We demonstrated that, whereas PTS is relatively uncommon in ED presentations of children with head injury, there is an association with increased risk of ciTBI in those with reduced GCS on ED arrival. Children with PTS and GCS 15 at ED presentation had a low rate of ciTBI, and management may be guided by their clinical status, after exclusion of other PECARN risk factors. Those with PTS and a GCS of 14 and ≤13 have higher rates of ciTBI and should be considered for CT scan, as part of their ED evaluation.

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Competing interests

FEB and SRD are section editors for *Emergency Medicine Australasia* and were excluded from the peer-review process and all editorial decisions related to the acceptance and publication of this article. Peer-review was handled independently by members of the Editorial Board to minimise bias. There are no other conflicts of interest relevant to this article to disclose.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting information

Additional supporting information may be found in the online version of this article at the publisher's web site:

Table S1. Definitions.
Table S2. Computed tomography findings in head-injured children with post-traumatic seizures ($n = 336$).