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General

Predictors of skull fracture and intracerebral pathology after pediatric traumatic brain injury

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Objective

The objective of this study is to demographically identify and describe the local pediatric population that presented to the Emergency Department for TBI and their associated outcomes.

Methods

This was an observational cohort study of consecutive Emergency Department patients aged 0-4 years diagnosed as having a TBI as one of their discharge diagnoses, in a level 1 trauma center in Southeastern United States. Main outcome measures included predictors of abnormal head CT scan and hospital admission. Additionally, demographic characteristics, injury patterns and mechanisms of injury are described.

Results

Predictors of abnormal head CT in this pediatric population include younger age, lower pediatric Glasgow Coma Scale (PGCS), mechanism of traffic accident, and the presence of vomiting. Hospital admission was predicted by the presence of an abnormal CT finding or loss of consciousness in this population. In this single center study, younger children (0-2) were less likely to be symptomatic but more likely to have significant abnormal CT findings.

Conclusion

This paper highlights the burden of TBI in infants and toddlers presenting to the emergency department and highlights the differences in presentation of this common complaint. Better understanding of this population will help to form better strategies or to amend current management practices in order to provide more effective treatment to such patients, especially in hospitals lacking the sophisticated pediatric emergency departments.

INTRODUCTION

Traumatic brain injury (TBI) is a significant cause of morbidity and mortality in the pediatric population, with an estimated annual incidence of 1850 per 100,000 in the 0-4 year old age group.[1] This young population is at particular risk for clinically important traumatic brain injury due to their more vulnerable anatomy, as their still developing brain place them at risk for longer-term sequelae. These detrimental side effects can be particularly more pronounced in children and can include working memory, behavioral inhibition and problem solving.[2] A 2025 parental survey reports on decreased grades after mild TBI.[3] Longitudinal studies have shown that lower IQ scores, delayed adaptive abilities and slower processing speeds are also associated with childhood TBI.[4,5]

Clinically, evaluation of this age group, and particularly below the age of two, presents several challenges. They are often unable to fully communicate or even recall the exact mechanism of injury or to fully describe their symptoms, and the physician must rely on the parent's or chaperone's description of events. Beyond this, pediatric patients cannot simply be evaluated as small adults as their still developing anatomy can lead to distinctive types of injuries not seen in adults.[6] For young children, one study has reported that up to 11% of skull fractures and 8% of intracranial injuries presented without signs of external trauma.[7]

While clinically significant intracranial injuries, such as those that require surgical intervention are rare, they can have significant morbidity and mortality if missed and can be asymptomatic in infants.[8,9] Due to this, and the inherent challenge of evaluating this population, the use of head CT in evaluation of pediatric TBI patients has become increasingly more common; a 2024 systematic review and meta-analysis reports on the over-utilization of brain CTs for TBI overall.[9] Despite its utility, this diagnostic modality must be weighed against the risk of radiation exposure in such a vulnerable population.[10] Several studies have emerged to provide clinical decision rules to help reduce the use of CT scans in context of low-likelihood patients.[11-13]

With pediatric TBI placing a substantial global burden,[14] and the challenge of treating this young and vulnerable population outside of a pediatric emergency department it is important to gain a better understanding who these patients are and how they present in order to better treat and help to prevent TBI.[15,16] The objective of this study is therefore to demographically identify and describe the local pediatric population that presented to the Emergency Department for TBI and their associated outcomes.

MATERIALS AND METHODS

Methodology and other study details are reported in accordance with STROBE guidelines.[17] The study was conducted in the Emergency Department (ED) of a level one trauma center in the southeastern United States. Our pediatric ED sees over 24,000 visits per year, and is home to emergency medicine, pediatrics, and pediatric surgery residency programs. This study was approved by our institution's IRB as an expedited study with a HIPAA waiver.

Data were abstracted from the electronic medical record using an a priori designed data abstraction form. Persons entering the data were blinded to the study aim and outcomes. Data were entered into our Clinical and Translational Science Institute's REDCap database. REDCap (Research Electronic Data Capture) is a secure, Web-based application designed to support traditional case report form data capture. Statistical analyses were performed using JMP 18 for Windows. Normally distributed variables are summarized using means and standard deviations while skewed variables are reported using medians and interquartile ranges (IQR). Missing data were recorded as unknown.

Subjects were considered eligible if they were between the ages of 0 to 4, and sustained a head injury, as determined by having a corresponding International Classification of Disease (ICD) code amongst one of their discharge diagnoses. The codes used were 800.0-801.9, 803.0-804.9, 850.0-854.1, 950.1-950.3, 959.01 and 995.55 based on the Centers for Disease Control (CDC) guidelines.[18] The codes were purposely broad in order to capture all head injuries. If on review a record was determined not be a head injury, then the record was reviewed by a second member of the research team. If there was agreement by both researchers that the subject did not experience a head injury upon review, they were excluded after documenting the reason. Where there was disagreement, the primary author resolved the issue via consensus.

Severity of head injury was classified using the Pediatric Glasgow Coma scale (PGCS) and Pediatric Coma scale,[19-21] with PGCS 13-15 considered mild, PGCS 9-12 moderate, and a score less than 8 classified as severe. Post-injury symptomatology collected included the occurrence of loss of consciousness (LOC), the duration of LOC, seizure, and vomiting.

RESULTS

DEMOGRAPHICS

The cohort consisted of 562 patients. Their median age was 1 year, with an IQR of 0-3 years. 73.7% were age two or younger, with 32% of under the age of 1. Fifty-six percent were boys. 71% were walk-in, 25% arrived by ambulance, and 4% were transported by helicopter. Sixty-five percent of our cohort was Caucasian, twenty-four percent were African-American, five percent were Hispanic, and six percent were other.

INJURY CHARACTERISTICS

Twenty-three percent reported vomiting associated with their head injury; 10% reported a loss of consciousness, with four patients reporting a LOC of greater than 30 minutes (table 1).

Post-injury seizure activity was reported in 16 patients (2.8%). Both vomiting (30.4% vs. 20.8%, p= 0.0174) and loss of consciousness (15.7% vs. 9.2%, p=0.036) were significantly more common in the 3-4 year old age group than the 0-2 year old age group, while the frequency of seizure was also higher in 3-4 year old age group (4.7% vs. 2.2%). The majority of children (96.8%) suffered a mild head injury [PGCS 13-15]. Only 0.9% had a moderate head injury [PGCS 9-12], and 2.3% suffered a severe head injury [PGCS ⩽8]. The frequency of head injury severities between the two age groups was almost identical (table 2).

Eighty-eight percent of the children in our cohort presented to the ED within 12 hours of injury, five percent arrived within 12-24 hours, and seven percent presented over 24 hours after injury. The majority of those who presented after twelve hours were two years or younger. Of those who presented after 24 hours, 36% had fractures reported in their CT findings and 7% had bleeds.

MECHANISM OF INJURY

The majority (63%) of injuries occurred in association with a fall, while 22% were struck in the head, 7% injured in the use of a recreational vehicle and 6% were injured in a traffic accident. One percent had been assaulted and 1% were injured in a sport. Sixty-four percent of the 33 children involved in traffic accidents were backseat passengers. Seatbelt usage was able to be determined in 82% of 33 children involved in traffic accidents, 66% of those reported seatbelt usage. Fifteen children were injured while on a recreational vehicle: 7 on a bike, 5 on an all terrain vehicle (ATV), and 3 were listed as other (horse, scooter, etc.). Three quarters (75%) of those whose injury involved a recreational vehicle denied helmet use.

Table 1. Symptoms associated with head injury

	0-2 years (n=414)	3-4 years (n=148)	P-value
Vomiting	86 (20.8%)	45 (30.4%)	0.0174
Seizures	9 (2.2%)	7 (4.7%)	NS
Loss of Consciousness	35 (8.5%)	22 (14.9%)	0.0361

Table 2. PGCS severity across age groups

	Mild (PGCS 13-15)	Moderate (PGCS 9-12)	Severe (PGCS 3-8)
0-2 years (n=414)	402 (97.1%)	3 (0.7%)	9 (2.2%)
3-4 years (n=148)	142 (96%)	2 (1.3%)	4 (2.7%)

Table 3. Predictors of hospital admission

Abnormal head CT	P<0.0001
Loss of Consciousness	P<0.0001
Age group (0-2 vs. 3-4)	NS
Presentation after 24 hrs	NS

INJURY OUTCOMES

In our cohort, 16% of the patients were admitted to the hospital, with approximately equal distributions between the 0-2 and 3-4 age groups. Thirty-eight percent of admissions were to the ICU, with a median length of stay of 1 day (IQR 1-4, range 1-21). Predictors of hospital admission are listed in table 3.

There were 4 in-hospital deaths in our cohort. Neurosurgical intervention was required in 1.6% of the patient cohort: four for open calvarial fractures, four for subdural hematomas, and one for an extradural hematoma. In this group, vomiting was only reported in one patient. Three of the nine patients lost consciousness, with two of those for more than thirty minutes. Three injuries were reported as a fall, four being struck in the head, one occurring in an ATV accident and one in traffic accidents. The injury occurring in the traffic accident was recorded as not wearing a seatbelt.

Close to 3% returned to the ED within 72 hours of their first visit, and 1.8% were readmitted within 30 days of their initial visit. Of those that returned within 72 hours, 27% had fractures and 13% had bleeds. Table 4 shows the breakdown between age groups 0-2 and 3-4 by all outcomes- there were no statistically significant differences.

IMAGING

Head CT scans were performed in 57.8% of our cohort (table 5), and 25.8% were abnormal. Of these abnormal scans, 19% had brain bleeds, 53.6% had fractures and 27.4% had both a fracture and a bleed (table 6). Table 7 details the specific findings on CT; table 8 categorizes head injury severity within the cohort of abnormal CTs, and finally table 9 highlights the factors associated with having an abnormal CT scan.

DISCUSSION

This study reflects the demographic patterns of TBI in our infant and toddler (0-4 yrs) population. The majority of patients who presented were found to have mild head injuries, findings that are consistent with previously published studies.[22] With over 80% of patients presenting to the ED within twelve hours of injury, this could reflect the concern that parents have regarding head injury in their young children, and perhaps an understanding of the vulnerability to severe outcomes in this population. However, this early presentation was also seen in previously published adult cohorts.[23] A third of those that did present beyond 24 hours had fractures reported, most of which were two or younger. This finding, along with other common symptoms of TBI (such as vomiting and seizure) occurring significantly more in the older section of our cohort, reinforces the concept that TBI in infants can present as grossly asymptomatic.

The common mechanisms of injury in this population are mostly preventable. As a child grows older they are more likely to be injured during play, but proper parent education on importance of keeping their infant out of areas where the risk of fall is high is important, as is taking the proper precautions in "baby-proofing" the residence and supervision of a newly mobile child. While motor vehicle accidents were not a major cause of injury in our population, they do carry great risk for severe injury. The majority of children were back seat passengers, which is known to be a safer location for children than the front seat, but edu-

Table 4. Hospital outcomes after head injury by age group

	0-2 years (n=414)	3-4 years (n=148)
Admitted to hospital	67 (16.2%)	23 (15.5%)
Admitted to ICU	25 (6%)	10 (6.8%)
Hospital length of stay in days (mean)	2.67	3
ICU length of stay in days (mean)	3.16	3.6
Surgical intervention	7 (1.7%)	2 (1.3%)
Return to ED in 72 hours	14 (3.4%)	1 (0.7%)
Readmitted to hospital within 30 days	9 (2.2%)	1 (0.7%)
In- hospital death	3 (0.7%)	1 (0.7%)

Table 5. Frequency of head CT performed, and whether abnormal across age groups

	0-2 years (n=414)	3-4 years (n=148)	p-value
Head CT done	247 (59.7%)	78 (52.7%)	NS
Abnormal head CT	73 (29.5%)	11 (14.1%)	0.0006
Normal head CT	174 (70.5%)	67 (85.9%)	

Table 6. Breakdown of bleeds and fractures by abnormal brain CT per age group

Age group	Fracture	Bleed	Both fracture and bleed
0-2 yrs	40 (54.8%)	14 (19.2%)	19 (26%)
3-4 yrs	5(45.5%)	2 (18.2%)	4 (36.3%)

Table 7. Frequency of abnormal head CT findings

CT finding	Frequency
Fracture of skull +/- through foramen magnum	69 (12.3%)
Herniation	6 (1.1%)
Epidural hematoma	13 (2.3%)
Subdural hematoma	16 (2.8%)
Subarachnoid hemorrhage	5 (0.9%)
Intraventricular hemorrhage	1 (0.2%)
Parenchymal or Hemorrhagic contusion	12 (2.1%)

Table 8. Abnormal head CT by GCS score between age groups.

	Mild(GCS 13-15)	Moderate (GCS 9-12)	Severe (GCS 3-8)	p-value
0-2 years (n=73)	65 (89%)	2 (2.8%)	6 (8.2%)	NS
3-4 years (n=11)	8 (72.7%)	2 (18.2%)	1 (9.1%)	

cation about this and proper age-appropriate restraint use could further mitigate the risk for TBI.[24,25]

CT usage in the pediatric population is an increasingly important topic, in both clinical and public circles. A 2013 study showed that 46.8% of parents presenting at a pediatric emergency department knew of the increased risk for malignancy from a CT scan before speaking to a clinician.[26] Despite being a definitive way to look for injury in a symptomatic or pre-verbal child, a group with significantly more abnormal findings, CT use must continue to be weighed against potential harm and increasing parental preference.

Table 9. Predictors of abnormal head CT

Younger age (0-2yrs)	**P = 0.006**
Lower GCS	P=0.023
Mechanism of traffic accident	P=0.003
Vomiting after head injury	P= 0.0005

Judicious use could significantly reduce the amount of unnecessary radiation exposure.

STRENGTHS OF LIMITATIONS

The biggest strength of the current study is the detailed emergency department patient level data, such as injury characteristics. Other strengths include the consecutive nature of the cohort, which helps to minimize bias, and cohort size. The current study also has some important limitations: 1) the cohort was assembled using billing codes as a starting point; 2) data were abstracted from medical record review and therefore certain pieces of data were missing for some subjects; 3) these data pertain to only a single medical center, albeit the only dedicated pediatric emergency department and level one trauma center in our area.

CONCLUSIONS

This paper highlights the burden of TBI in infants and toddlers presenting to the emergency department and highlights the differences in presentation of this common complaint. Better understanding of this population will help to form better strategies or to amend current management practices in order to provide more effective treatment to such patients, especially in hospitals lacking the sophisticated pediatric emergency departments.

AUTHOR CONTRIBUTIONS

PA, LG drafted the initial manuscript. BCJ and HS edited and critically revised the manuscript. LG supervised the project. All authors read and approved the final manuscript.

Abbreviations

CT	**Computed Tomography**
TBI	Traumatic Brain Injury
PGCS	Pediatric Glasgow Coma score
GCS	Glasgow Coma score
ED	Emergency Department
LOC	Loss of Consciousness

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INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted in accordance with the Declaration of Helsinki. The Orlando College of Osteopathic Medicine's Research Committee determined this study to be exempt. (study #2025-01).

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author(s).

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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