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Research Paper

Complicated Mild Traumatic Brain Injury at a Level I Pediatric Trauma Center: Burden of Care and Imaging Findings

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ABSTRACT

OBJECTIVE: The aims of this study were: (1) to characterize mild traumatic brain injury (mTBI), mTBI with skull fracture, and complicated mTBI in school-aged children seen at a Level I pediatric trauma center and (2) to examine the nature of imaging findings seen in children with mTBI with skull fracture and those with complicated mTBI.
METHODS: A total of 1777 pediatric patients (male: 1193 or 67.1%; age = 11.1 ± 3.5 years) sustaining mTBI who presented to the Emergency Department or directly to the trauma service in the years 2010 to 2013 were identified and classified into mTBI (n = 1,319 or 74.2%), mTBI with skull fracture (n = 127 or 7.2%), and complicated mTBI (n = 331 or 18.6%). Patient characteristics and imaging findings were analyzed using descriptive statistics, Pearson's χ^2 test, Fisher's exact test, and logistic regression analysis.
RESULTS: In children with complicated mTBI, subdural hematoma (36.9%) was the most common finding. Of the 331 children with complicated mTBI, 241 (72.8%) had multiple findings compared with one (0.8%) of 127 children having mTBI with skull fracture (Fisher's exact $P < 0.001$), with logistic regression analysis revealing younger age as a potential risk factor ($P < 0.01$). Children sustaining a depressed or complex skull fracture were nearly twice as likely as those with simple, linear skull fracture to have intracranial abnormality.
CONCLUSIONS: Multiple radiographic findings in children sustaining mTBI with skull fracture or complicated mTBI are prevalent (72.8%), with younger age as a potential risk factor.

Introduction

Traumatic brain injury (TBI) can be classified based on its severity from mild to severe. TBI is defined as mild TBI (mTBI), if the Glasgow Coma Scale (GCS) within 24 hours of injury is 13 to 15, the duration of loss of consciousness (LOC) is less than 30 minutes, and the duration of post-traumatic amnesia (PTA) is less than 24 hours.[1] mTBI is often further characterized as complicated mTBI by researchers if there is radiographic evidence of abnormality, such as a depressed skull fracture or other trauma-related intracranial abnormality (e.g., hemorrhage, contusion, and edema).[2,3] Other researchers have omitted skull fracture as a criterion in designating an injury as complicated or uncomplicated.[2] According to a recent report from the Centers for Disease Control (CDC),[4] the incidence of complicated mTBI in pediatric cohorts presenting to Emergency Departments (ED) or other acute care settings is estimated to be approximately 7.5%.

Although research on mTBI has received increased attention in recent years there have been no recent reports describing the potential burden of complicated

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mTBI that are presenting to Level I pediatric trauma centers. The primary objective of this study was to report on epidemiology of mTBI, mTBI with skull fracture, and complicated mTBI in school-aged children seen at a Level I pediatric trauma center over a 4-year period. The secondary objective was to examine the nature of imaging findings seen in children with mTBI with skull fracture and those with complicated mTBI.

Methods

The governing institution's Institutional Review Board (IRB) approved all study procedures described herein. We included patients with all forms of mTBI who presented to the ED or directly to the trauma service in the years 2010 to 2013. Subjects were identified via two methods. First, they were searched using a trauma registry. Enrollment into the trauma registry occurs when a child is admitted to the hospital with any blunt, penetrating, or burn injury, or is transferred by Emergency Medical Services from another hospital to our institution for traumatic injuries, even if subsequently discharged from the ED. Search criteria from this registry included: age five to 18 years at the time of injury, any head injury diagnosis code (ICD-9), and arrival GCS of 13 to 15. Second, additional subjects were identified who presented to the ED but were not admitted to the trauma service. Search criteria from this group included: age five to 18 years at the time of injury, any concussion diagnosis code (ICD-9 850.x), and were not admitted to the trauma service.

Once these two cohorts were identified, basic demographic variables were retrieved, and chart reviews were carried out to identify if CT or MRI brain imaging studies were obtained, followed by a detailed categorization of relevant findings, if any, on such studies. The actual images were not reviewed, but rather the imaging reports were examined by trained pediatric neuroradiologists. If imaging reports noted hemorrhagic contusion but without a size noted, author CH, who has several years of experience reviewing imaging studies of TBI patients, personally viewed the study to make a size determination. Based on this information, subjects were classified into one of three categories: (1) mTBI, (2) mTBI with skull fracture only, and (3) complicated mTBI.

Subjects were assigned to the mTBI group, if they had no imaging study done, or if an imaging study was done and found to be negative for any traumatic injuries. The mTBI with skull fracture only group had any combination of a linear non-depressed skull fracture, depressed skull fracture, or a skull fracture described as complex or comminuted. In addition, subjects in this group could not have any described intracranial abnormalities. Lastly, subjects in the complicated mTBI group had any combination of the following: hemorrhagic contusion, hemorrhagic shear or axonal injury, traumatic subarachnoid hemorrhage, subdural hematoma, epidural hematoma, extra-axial hematoma, or cerebral edema. If a subject had skull fracture plus any of the aforementioned intracranial findings, he/she was classified as complicated mTBI. Additional characterization of these respective intracranial findings was made, including relative number, size, and distribution of such findings.

Descriptive statistics were calculated for patient demographics as well as the characteristics for concussion diagnosis. Pearson's χ^2 test and a one-way analysis of variance (ANOVA) were performed to compare patient characteristics by mTBI classification. Furthermore, Pearson's χ^2 test and Fisher's exact test were used to examine subcategories of imaging findings in children with mTBI with skull fracture and those with complicated mTBI, including proportion of children with a simple linear nondepressed skull fracture versus proportion of children with either a depressed skull fragment or more complex or comminuted fracture fragments, and hemorrhagic contusion by location and size. A logistic regression analysis with the calculations of an odds ratio (OR) and its 95% confidence interval (CI) was conducted to examine the association of age and gender on the presence of multiple findings in radiographic studies among these two mTBI groups. Lastly, the relationship between type of skull fracture (skull fracture linear or nondepressed vs. skull fracture depressed or skull fracture complex/comminuted nondepressed) and mTBI diagnosis was analyzed using Pearson's χ^2 test with a calculation of an OR and its 95% CI.

Results

A total of 1777 subjects were identified and analyzed for this study (male: 1193 or 67.1%; age = 11.1 ± 3.5 years). Imaging was completed for 1268 of 1777 cases (71.4%). Of those with imaging done, three had a CT originally after the trauma, followed by an additional, follow-up MRI, nine had an MRI only without a prior CT, and the rest (1256 patients) had a CT scan only. Table 1 summarizes demographic variables by mTBI group. Of all the subjects, 1319 (74.2%) were classified as mTBI, 127 (7.2%) as mTBI with skull fracture, and 331 (18.6%) as complicated mTBI. There was no significant association between gender and mTBI classification ($\chi^2 = 2.33$, $P = 0.312$). On the other hand, age was significantly different among the mTBI groups ($F = 23.16$, $P < 0.001$). The *post hoc* tests with the Bonferroni correction revealed that the mTBI group (11.5 ± 3.5 years) was significantly older than the mTBI with skull fracture group (9.8 ± 3.0 years, $P < 0.001$) and the complicated mTBI group (10.4 ± 3.4 years, $P < 0.001$).

Of the children sustaining mTBI with skull fracture ($n = 127$), 74.0% had a simple linear skull fracture, 11.8% had a depressed skull fracture, and 14.2% had a complex or comminuted skull fracture which was nondepressed (Fig 1). The proportion of children with a simple linear skull fracture was significantly greater than that of children with a depressed skull or a complex or comminuted skull fracture ($\chi^2 = 96.69$, $P < 0.001$).

TABLE 1.
Demographics of Children With Mild Traumatic Brain Injury

Variable		mTBI Classification ($N = 1,777$) mTBI 1,319 (74.2)	 mTBI with Skull Fracture 127 (7.2)	 Complicated mTBI 331 (18.6)	p
Gender	Male	878 (66.6)	93 (73.2)	222 (67.1)	0.312[a]
	Female	441 (34.3)	34 (26.8)	109 (32.9)	
Age [mean (SD)]		11.5 (3.5)	9.8 (3.0)	10.4 (3.4)	< 0.001[b]

Abbreviation: mTBI: mild traumatic brain injury.
Values are frequency (%) unless specified otherwise.
[a] From Pearson's χ^2 test.
[b] From one-way analysis of variance.

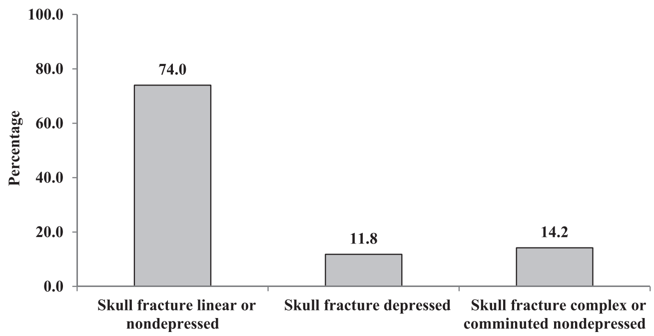

FIGURE 1.
Imaging summary of children sustaining mild traumatic brain injury with skull fracture ($n = 127$).

For the complicated mTBI cohort, the pattern and relative distribution of imaging findings are summarized in Table 2. The single most common radiographic finding was subdural hematoma at 36.9%. Hemorrhagic contusion (single focus = 23.0%, multiple foci = 13.9%), extra-axial hematoma (21.1%), epidural hematoma (19.3%), and traumatic subarachnoid hemorrhage (18.7%) were relatively common findings, while cerebral edema (5.1%) and hemorrhagic shear or axonal injury (3.0%) were uncommon. Among children with a single contusion ($n = 76$), the most common location was the frontal lobe (51.3%), followed by the temporal lobe (28.9%), the parietal lobe (13.2%), and the occipital lobe (1.3%). Of all single hemorrhagic contusions, 57.9% and 42.1% were greater than 5 mm and less than or equal to 5 mm, respectively. There was no significant association between size and location with respect to single hemorrhagic contusion (Fisher's exact $P = 0.326$, Fig 2). Findings of hemorrhagic contusion in more than one location (i.e., hemorrhagic contusion: multiple) occurred in 13.9% of all complicated mTBI (Table 2). These findings were most commonly located in the frontal lobe (73.9%), followed by the temporal lobe (58.7%), the parietal lobe (17.4%), and the occipital lobe (2.2%). The majority of these injuries (87.0 to 100.0% depending on the location) did not specify a size of hemorrhagic contusion. Traumatic subarachnoid hemorrhage occurred in nearly 20% of all children with complicated mTBI. This was confined to the cortical surface in 51.6% of these patients, deeper in the cortical sulci 32.3% of the time, and in the cisterns 8.1% of the time. Location of traumatic SAH was not clearly identified in 16% of subjects.

TABLE 2.
Imaging Summary of Children With Complicated Mild Traumatic Brain Injury ($n = 331$)

Finding	Frequency	%
Hemorrhagic contusion: single	76	23.0
Frontal	39	51.3[a]
Temporal	22	28.9[a]
Parietal	10	13.2[a]
Occipital	1	1.3[a]
Other	4	5.3[a]
Hemorrhagic contusion: multiple	46	13.9
Frontal	34	73.9[b]
Temporal	27	58.7[b]
Parietal	8	17.4[b]
Occipital	1	2.2[b]
Other	1	2.2[b]
Hemorrhagic shear or axonal injury	10	3.0
Traumatic subarachnoid hemorrhage	62	18.7
Subdural hematoma	122	36.9
Epidural hematoma	64	19.3
Extra-axial hematoma	70	21.1
Cerebral edema	17	5.1

Percentage (%) is out of a total number of subjects with complicated mTBI ($n = 331$) unless specified otherwise.
[a] Out of a total number of subjects with hemorrhagic contusion: single ($n = 76$).
[b] Out of a total number of subjects with hemorrhagic contusion: multiple ($n = 46$).

Importantly, of the 458 children sustaining mTBI with skull fracture or complicated mTBI, 242 (52.8%) had injuries in which more than one finding was identified on CT scan (Table 3). In particular, 241 of 331 children (72.8%) with complicated mTBI were found to have multiple findings, whereas only one of 127 children (0.8%) sustaining mTBI with skull fracture had multiple findings, with the difference in the proportions being significant (Fisher's exact $P < 0.001$). The logistic regression analysis showed that younger age was significantly associated with multiple findings ($P < 0.01$), after adjusting for gender and mTBI classification. Specifically, a one year decrease in age was associated with an increased odds of having multiple findings by about 11% (OR = 1.11, 95% CI = 1.03 to 1.19). On the other hand, gender was not significantly associated with multiple findings ($P = 0.468$), after adjusting for age and mTBI classification. Lastly, skull fracture depressed or skull fracture complex/comminuted nondepressed was significantly associated with complicated mTBI ($\chi^2 = 7.73$, $P = 0.005$). The odds of being diagnosed with complicated mTBI for children with skull fracture depressed or skull fracture complex/comminuted nondepressed was about 97% higher than the odds for those with linear nondepressed skull fractures (OR = 1.97, 95% CI = 1.22 to 3.17).

Discussion

The findings in this study emphasize that pediatric complicated mTBI is a frequently encountered problem among school aged children at high level trauma centers; in this cohort, it comprised 18.6% of all presenting cases of mild TBI, with an additional 7.2% as mTBI with skull fracture only. While the CDC recently published a report estimating the incidence of complicated mTBI to be 7.5%,[4] the studies from which this report was drawn reflect a wide variability in the incidence of intracranial abnormality on CT scan (excluding isolated skull fracture) among children presenting with mild TBI, from as little as 1% to as much as 33%.[5-17] Iverson et al.[2] summarized the existing literature in primarily adult cohorts and noted a similar varied incidence of complicated mild TBI ranging from 4.7% to 38.9% across 11 different studies. These differences may reflect variability in defining mTBI, differences in inclusion/exclusion criteria by study, false positive CT scan interpretations, CT imaging technology, regional differences in referral patterns, or variability based on level of acuity typically seen in a given hospital

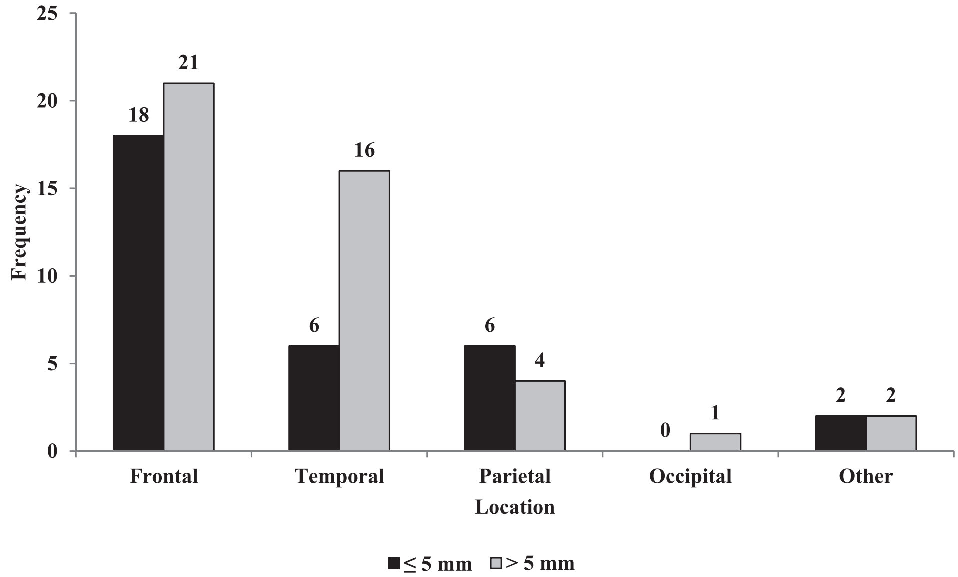

FIGURE 2.
Single hemorrhagic contusion by location and size among children with complicated mild traumatic brain injury ($n = 76$).

(i.e., Level I trauma centers vs. lower level trauma centers). Overall, the incidence of complicated mTBI in this study is within the range of other published studies.

Similar to other reports, there are varied findings seen on CT scan in patients with complicated mTBI, ranging from extra-axial hemorrhages to subarachnoid hemorrhage to parenchymal contusions[5,8,18,19]. Other findings suggestive of injury (cerebral edema and hemorrhagic shear injury) are relatively uncommon in this cohort.

Relative to specific types of injury, a few notable themes emerge from these data. First, extra-axial hemorrhages (combining epidural hemorrhage with subdural hemorrhage and unspecified extra-axial hemorrhage) are present in approximately 75% of children with complicated mTBI. These results are higher than those reported elsewhere.[6,10] Second, hemorrhagic contusions are common overall, with a preponderance of lesions being located in the frontal lobes, followed in order by temporal, parietal, and occipital lesions. This is similar to a previous report.[20] Third, subarachnoid hemorrhage is the next most common finding, and tends to be confined to the cortical surface or sulci, which is also reported elsewhere.[21] Fourth, a significant proportion of patients with complicated mTBI (72.8%) have multiple abnormal findings. The risk of multiple findings is higher with younger ages. The frequency of multiple abnormalities has not been well described elsewhere. Fifth, skull fractures, when in isolation to other types of injury, tend to be simple, linear, and non-depressed fractures. Depressed skull fracture, on the other hand, confers a higher risk of additional intracranial injury.

TABLE 3.
Numbers of Findings by Mild Traumatic Brain Injury With Skull Fracture and Complicated Mild Traumatic Brain Injury

Number of Findings	mTBI With Skull Fracture ($n = 127$)	Complicated mTBI ($n = 331$)
1	126	90
2	1	151
3	0	65
4	0	16
5	0	7
6	0	2

Abbreviation: mTBI: mild traumatic brain injury.

The current study is limited by the fact that it is a retrospective chart review that relied on our interpretations of radiograph reports. Additionally, we used ICD-9 codes to assist in determining the number of children presenting to the ED with concussion. It is possible that there could be some base rate of misdiagnosis. Furthermore, identifying subjects from our trauma database relied on the recorded GCS score of 13 to 15 to categorize them as some form of mTBI. It is possible that some of the subjects may have experienced persistent alteration of consciousness or post traumatic amnesia beyond 24 hours, which would be more appropriately classified as moderate TBI instead of mTBI.

This study was not intended to assess or refine prediction rules for when a clinician should obtain a CT scan. Rather, it is intended to bring attention to this important subgroup of patients with mTBI that are presenting to trauma centers, specifically at Level I trauma centers. According to the American College of Surgeons, there are 55 Level I pediatric trauma centers in the United States.[22] The prevalence of complicated mTBI in our study combined with this number of Level I pediatric trauma centers in the United States implies that complicated mTBI can be a significant burden. On the basis of our clinical experience, these patients are often active children who, upon leaving the hospital, are eager to return to play. While there are multiple guidelines on the safe return to play of children with concussion,[23-25] there is extremely little directed towards this significant demographic of children with complicated mTBI. Experts agree that a decision to return to play after evidence of structural injury should be made cautiously.[26-30] Unfortunately little empiric evidence exists to inform this decision beyond anecdotal experience.

Although studies examining adult patients would suggest that the difference in mTBI and complicated mTBI may be modest or even nonexistent,[31-34] the same notion may not be applicable to pediatric patients. In fact, in many respects, children with complicated mTBI may behave more like those with moderate TBI than those with mTBI. A prospective cohort study of 80 children aged five to 15 showed that children with complicated mTBI, compared with those with mTBI, were more likely to have persistent difficulties at 12 months postinjury in several cognitive domains, including episodic memory, cognitive processing, visuomotor speed, and working memory.[35] Hence, more research focusing on children needs to be conducted to elucidate the characteristics of mTBI in pediatric populations.

In school-aged children with mTBI (GCS 13 to 15 at the time of evaluation) presenting to high-level trauma centers, our study indicates that about 18% of them have complicated mTBI. Radiographic findings in these patients are variable, though extra-axial hemorrhage, hemorrhagic contusion, and subarachnoid hemorrhage are the most common findings. Multiple radiographic findings in children sustaining mTBI with skull fracture or complicated mTBI are prevalent (72.8%), with younger age as a potential risk factor. It is essential for trauma and brain injury programs to track these children's recovery and supervise the appropriateness of their return to academic and physical activities. More prospective studies are needed to help clinicians understand recovery trajectories and outcomes of children with various forms of mTBI.

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