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Pediatric head trauma: the evidence regarding indications for emergent neuroimaging

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Abstract Traumatic brain injury (TBI) is a leading cause of childhood death and disability worldwide. In the United States, childhood head trauma results in approximately 3,000 deaths, 50,000 hospitalizations, and 650,000 emergency department (ED) visits annually. Children presenting to the ED with seemingly minor head trauma account for approximately one-half of children with documented TBIs. Despite the frequency and importance of childhood minor head trauma, there exists no highly accurate, reliable and validated clinical scoring system or prediction rule for assessing risk of TBI among those with minor head trauma. At the same time, use of CT scanning in these children in recent years has increased substantially. The major benefit of CT scanning is early identification (and treatment) of TBIs that might otherwise be missed and result in increased risk of morbidity and mortality. Unnecessary CT imaging, however, exposes the child needlessly to the risk of radiation-induced malignancies. What constitutes appropriate criteria for obtaining CT scans in children after minor blunt head trauma remains controversial. Current evidence to guide clinicians in this regard is limited; however, large studies performed in multi-center research networks have recently been conducted. These studies should provide the foundation of evidence to guide CT decisions by clinicians, help identify TBIs in a timely fashion, and reduce unnecessary radiation exposure.

Keywords Traumatic brain injury · Blunt head trauma · Pediatric trauma · Radiation exposure

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Introduction

Trauma is a leading cause of death in children older than 1 year, and traumatic brain injury (TBI) is the leading cause of death and disability due to trauma, accounting for more than 70% of fatal childhood injuries. Each year in the United States, blunt head trauma in children results in approximately 3,000 deaths, 50,000 hospitalizations, and 650,000 emergency department (ED) visits [1, 2]. Approximately one-half of these visits involve CT imaging of the head [1], and the frequency of use of CT has increased substantially in the last decade [1, 3]. For those children who present to the ED with overt signs of injury caused by blunt head trauma, such as a Glasgow coma scale (GCS) score of less than 14, there is little controversy regarding care: an emergent head CT scan should be included in the evaluation in order to assess for an intracranial injury, particularly one requiring operative intervention. Most children with blunt head trauma evaluated in the ED, however, present with few or subtle signs of TBI, and diagnostic and treatment approaches to this cohort of patients are controversial.

Variation in care

There is substantial variation in the care provided to children with minor head trauma [4, 5], and data to be used as evidence for clinical decision-making in evaluating children with minor blunt head trauma are limited. For example, studies have shown that approximately 90% of all children evaluated in the ED for blunt head trauma have few or subtle neurological signs (i.e. GCS 14 or 15), including approximately 75% of patients evaluated with CT scans [6–11]. Furthermore, of those children who have findings of TBI documented on the CT, nearly one-half have a GCS of 14 or 15; thus a normal GCS of 15 does not exclude the possibility of an acute brain injury. Among children with a GCS of 15 after head trauma, however, the prevalence of brain injury on CT is low (5% or less) and surgical intervention is required in less than 1% of these patients [6–9, 11, 12].

The controversy over CT use

Given the limited evidence to guide acute management of children with minor head trauma, much controversy remains over use of CT scanning. It has been argued that CT scans should be used liberally in the evaluation of these children. For example, pre-verbal children with blunt head trauma are often difficult to evaluate and clinical findings of brain injury can be subtle or overlooked [9, 10]. In addition, one could argue that in children of any age, liberal use of CT scanning could prevent morbidity and mortality caused by unrecognized TBIs. More limited use of CT scans, however, seems prudent when considering that of all the children who undergo CT scans for head trauma each year in the United States, visible TBIs are found in less than 10%. Furthermore, risks of CT might be of consequence, and include the need to transport the patient outside the close observation of the ED, risks associated with pharmacological sedation for CT, and, most important, the theoretical risk of lethal malignancy from CT. Current estimates of this risk from one head CT scan in a child is in the range of 1:2,000–1:5,000, depending on the age of the child [13–15].

Clinical evaluation in the ED: patient history

There is particular controversy surrounding certain elements of the patient's history that are used by clinicians to justify the need for a head CT in a child after blunt head trauma. Perhaps the most controversial of these is the reported history of loss of consciousness (LOC). A history of LOC is commonly reported by parents and families of children evaluated in the ED for blunt head trauma (about 15–30% of patients), yet the reliability of this report is not clear. For example, some children who are reported to be "out for 5 min" are later found to be quite playful and interactive in the ED. The controversy, then, both relates to the reliability of the reporting of duration of LOC, as well as whether LOC is an important historical factor after adjusting for mental status and other findings on physical examination. Indeed, in several multi-variable analyses, LOC has not been found to be an independent predictor of TBI [8, 11, 12, 16]. In a study conducted by our group, an isolated history of LOC without any associated clinical findings (i.e. no abnormal mental status, focal neurological deficit, headache, vomiting, seizure or skull fracture) was associated with positive findings on CT scan in none of 122 cases [17].

Other controversial patient historical factors that have been studied with variable results include complaints of headache and/or vomiting. Although frequently reported at the time of evaluation for blunt head trauma, these symptoms have been of variable reliability as predictors of brain injury visualized on CT. Several recent studies using headache and vomiting as criteria for obtaining head CTs, however, missed no "important" brain injuries [11, 12, 18, 19], although large multi-center studies are needed to confirm these results.

Clinical evaluation in the ED: physical examination findings

The most important physical examination finding in the evaluation for TBI is the patient's mental status as assessed by the GCS score. The GCS score has been found to be an important predictor in several multivariate analyses [8, 11, 12, 18, 19]. In aggregate, these studies suggest that the risk of brain injury visible on CT in patients evaluated in the ED after blunt head trauma and with a normal GCS score of 15 is approximately 2–3%; with a GCS score of 14 the risk is approximately 7–8%; and with a GCS score of 13 the risk of injury is approximately 25%. Therefore, based on these data, any patient with a GSC of 13 or lower after blunt head trauma would unquestionably require emergent CT scanning, and clinicians should have a very low threshold for scanning those with GCS scores of 14. For children with GCS scores of 14–15 after blunt head trauma, however, large, reliable and valid decision rules could play an important role in determining the need for emergent neuroimaging. Most studies on this topic have been relatively small, with different methodologies and different outcome definitions. Sufficiently large multi-center studies are needed to determine highly accurate point estimates of risk and to apply the results with confidence. Currently, the necessary narrow confidence intervals around the risk of TBI given different combinations of historical and physical examination findings after blunt head trauma are lacking.

Pre-verbal children

Unique features of both the history and physical examination must be considered in pre-verbal children with minor head trauma [9, 10]. As with older children, the most important predictor of TBI in this age group is level of consciousness as measured by the Pediatric GCS. Another important predictor in this age range, however, is the presence of a scalp hematoma [9–11]. Evidence also suggests that the younger the child, the greater the risk of brain injury, such that a 1-month-old infant is at greater risk of TBI than a 3-month-old, who is at greater risk than a 12-month-old [9, 10]. Furthermore, an all-too-frequent phenomenon of TBI in pre-verbal children is that of inflicted injury [20–23]. It has been reported that approximately 25% of children hospitalized for head trauma in this age range are victims of child abuse [22, 23]. In addition, if a history elicited from the parents reveals no clear cause of injuries found on examination, or when the mechanism described is inconsistent with physical findings, inflicted injury should be more highly considered [23]. Recent studies have also identified new bio markers that can be useful in identifying children with inflicted TBI [24].

As described above, one of the most important findings on physical examination of the pre-verbal child with blunt head trauma is a scalp hematoma, and this might be the sole finding to suggest underlying brain injury in many head-injured infants [9, 10]. Previous research suggests that nearly 50% of children younger than 2 years with TBI are asymptomatic; however, scalp hematomas are present in more than 90% of otherwise asymptomatic infants with TBIs and in 95% of infants with skull fractures [9, 10, 25]. The risk of TBI in children younger than 2 years with scalp hematomas and underlying skull fractures is approximately 30%, versus less than 1% if no underlying skull fracture is found [9]. Finally, large scalp hematomas and those in non-frontal locations of the scalp have been found to be associated with a higher risk of TBIs [26].

Developing decision rules for use of CT scans in blunt head trauma

When developing decision rules to guide clinical practice in the identification of children at risk for TBI after blunt head trauma, two important issues must be considered: one is that the rule must be highly accurate and supported by evidence, and the second is that it must be simple to apply in practice. If a decision rule is too complex, it will not be easily remembered and applied in the clinical setting. Several prospective studies have been conducted in the last several years to develop decision rules for the use of CT scans in children with blunt head trauma. These studies suggest that criteria exist that might be used in the derivation of an accurate decision rule. None of these rules, however, has been sufficiently large and accurate nor adequately validated for ideal application in the clinical setting.

One study evaluated 175 children between the ages of 5 and 17 years with nontrivial head trauma [18]. All patients had a GCS of 15 and normal neurological examinations. CT scans were obtained in all these children in an effort to validate previously published criteria by the same author for identifying adults at risk for TBI. Although all 14 children with TBIs on CT were identified by the rule, 120 other children without TBI on CT met at least one of the rule criteria. Therefore, although the decision rule was sensitive, it was not highly specific. Furthermore, because of the small size of the study, the confidence intervals of the point estimates of the accuracy of the rule are wide.

Another head CT decision rule was developed in a multi-center prospective study of more than 13,000 adults and children with blunt head trauma of all severities; CT scans were performed in all study patients [27]. Through binary recursive partitioning analysis, the authors were able to identify eight important clinical predictors, found on either history or physical examination, of “significant intracranial injuries” on CT scan. In a sub-analysis of the 1,666 pediatric patients enrolled in this study, 1,434 demonstrated 1 or more of the rule predictors for significant intracranial injuries, and 136 of these patients had a “significant TBI” on the scan [12]. The authors concluded that use of the decision rule criteria would have reduced the number of CT scans by approximately 14%. The limitations of that study include the lack of inclusion of all TBIs on CT, limited patient follow-up to assess for delayed presentations of injury, and the lack of validation of the results.

In another multi-center prospective study of 22,772 children in the United Kingdom with blunt head trauma of all severities, the investigators sought to predict the requirement for neurosurgery or “marked abnormalities” on CT [19]. Only 3% of the children enrolled had a CT scan performed, however, making the results applicable mainly to countries and centers in which CT scans are used much more sparingly. Although the authors report high sensitivity and specificity for “clinically significant injuries,” direct patient follow-up was not performed, and the resulting decision rule is complicated, employing 14 variables. The complexity of the rule limits its ease of use in the acute care setting.

Our group conducted a study of more than 2,000 children younger than 18 years of age with non-trivial head trauma, in whom CTs were performed at the discretion of the treating physician [11]. Of the 2,043 enrolled patients, 98 had TBIs visualized on CT. Clinical data were recorded before the CT was obtained (if obtained), and 2 physicians evaluated 5% of the patients to establish inter-rater reliability of the assessment of clinical variables. To address an important limitation of other studies, patients discharged to home had telephone follow-up to assess for missed injuries, and the medical records of admitted patients were reviewed to assess TBI outcomes. In this study, we derived and cross-validated decision rules for two TBI outcomes: TBI visible on CT, and TBI requiring acute intervention (defined by neurosurgery, hospitalization for 2 or more nights for the head injury, use of anti-convulsant medications for more than 7 days, or persistent neurological deficits at discharge). Although separate decision rules were initially created for the two TBI outcomes, the two rules were combined into a single rule with five variables: altered mental status, clinical signs of skull fracture, vomiting, headache, and scalp hematoma (for patients 2 years and younger) [11]. The combined rule demonstrated a negative predictive value of 99.7% and sensitivity of 99% for TBI on CT. All injuries requiring acute intervention were also identified by the rule. The study was limited, however, by its performance at only a single institution, relatively small sample size, and lack of external validation.

Fortunately, two prospective multi-center studies with the goal of creating highly accurate and reliable prediction rules for TBI among children with blunt head trauma have recently been conducted by the Pediatric Emergency Research of Canada (PERC) network [28] and the Pediatric Emergency Care Applied Research Network (PECARN) [29]. These studies should result in the generation of more accurate, reliable and validated decision rules in order to limit the use of CT scan to only those children with blunt head trauma at non-negligible risk for TBI.

Conclusion

Determining the appropriate evaluation of children with blunt head trauma is important, and controversy exists over the use of CT scans. The greatest controversy concerns the use of CT in children with seemingly minor head trauma who have few or no apparent signs and symptoms of TBI. The major benefit of CT scan use is the early identification of TBIs, while a major drawback is the potential risk of radiation-induced malignancies. Current evidence regarding indications for CT use in children after blunt head trauma is limited, and large, multi-center research networks are needed to create definitive, accurate, and validated decision rules that can be easily applied in clinical practice. Two such studies in two multi-center research networks have recently been performed and when published, should provide the foundation of evidence not only to guide CT decisions by clinicians, but also to help parents participate in the decision-making process.

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