Minor head injury in children

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Purpose of review
This review will examine mild closed head injury (CHI) and the current evidence on head computed tomography (CT) imaging risks in children, prediction rules to guide decisions on CT scan use, and issues of concussion after initial evaluation.

Recent findings
The current literature offers preliminary evidence on the risks of radiation exposure from CT scans in children. A recent study introduces a validated prediction rule for use in mild CHI, to limit the number of CT scans performed. Concurrent with this progress, fast (or short sequence) MRI represents an emerging technology that may prove to be a viable alternative to CT scan use in certain cases of mild CHI where imaging is desired. The initial emergency department evaluation for mild CHI is the start point for a sequence of follow-up to assure that postconcussive symptoms fully resolve. The literature on sports-related concussion offers some information that may be used for patients with non-sports-related concussion.

Summary
It is clear that CT scan use should be as safe and limited in scope as possible for children. Common decisions on the use of CT imaging for mild head injury can now be guided by a prediction rule for clinically important traumatic brain injury. Parameters for the follow-up care of patients with mild CHI after emergency department discharge are needed in the future to assure that postconcussive symptoms are adequately screened for full resolution.

Keywords
mild traumatic brain injury, minor head injury, pediatrics

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Introduction

Closed head injury (CHI) is a common occurrence in children and is estimated to result in 650 000 to 1 million emergency department (ED) visits annually [1,2]. Many cases of closed head injury are owing to apparently mild trauma mechanisms. Fewer than 10% of mild CHI patients have traumatic brain injury (TBI) on computed tomography (CT) scan imaging and even fewer require an intervention [3••]. Despite this fact, the widespread availability of CT imaging has promoted a surge in its use for the evaluation of pediatric CHI. A vast number of head CT scans (estimated at over 2.5 million per annum) are conducted in the United States for the evaluation of children with CHI in the ED [2]. The time, costs, and risks of radiation exposure have thus far done little to slow the trend in head CT scan use for pediatric CHI. Indeed, the clinical assurance that a normal head CT study can offer to clinician, patient, and parent cannot be underestimated and can overshadow the inherent risks of this imaging modality. Past evidence sustained the notion that patients with a normal head CT scan and neurological examination could be safely discharged from the ED following CHI [2]. Limited information was available to guide the ED management of CHI without CT scan results. Yet, as further information on CT scan risks in children has emerged in the scientific and popular literature, it has become essential to seek options to make CT scan safer, to limit its use, and to explore alternatives to CT scan imaging for CHI in children. Cases of mild CHI and/or mild TBI are a key target for progress in the use of CT scans in the ED.

It is now recognized that many patients who are evaluated for CHI in the ED also have subsequent postconcussive symptoms that can last for several months or longer and can complicate their post-ED care [4]. Concussion is the most common form of CHI, which is estimated to constitute 80–90% of all TBI. The terms concussion and mild TBI have been used interchangeably, and will be used similarly here [5••]. Although there is currently no universal definition of concussion, a pragmatic description offered in a recent review is 'a trauma-induced alteration in mental status that may or may not involve loss of consciousness (LOC)' [6••]. A wide range of injury mechanisms can result in a concussion, including many apparently mild CHI events. Issues of concussion are thus an integral part of the ED evaluation of mild CHI and can have a significant impact on imaging and disposition decisions.

The current literature offers important progress in the evaluation of children with apparently mild head injury and decisions on head CT scan use. It also provides insight into the signs, symptoms, and issues in the management of concussion following initial evaluation in the ED. This review will examine mild CHI and the current evidence on: head CT imaging risks in children, prediction rules to guide decisions on CT scan use, and issues of concussion after initial evaluation.

Closed head injury and imaging risks in children

CT remains the gold standard for the detection of acute traumatic intracranial pathology following closed head injury. In fact, CT scans are obtained in up to half of the pediatric patients who are evaluated for head trauma in North American emergency departments [1]. Among the many factors that can influence the decision to obtain a head CT scan in a child, such as the possible need for sedation, time outside the department, cost, and resource utilization, perhaps the most significant consideration is the risk incurred by radiation exposure when this imaging modality is used. The radiation exposure associated with CT imaging has always been known in theory. In the last decade, the literature has offered more specific evidence of the increased lifetime risks of leukemia and solid organ tumors in pediatric patients who undergo CT imaging studies. These risks are particularly striking when compared with far lower estimates for adult patients. Although the current evidence on CT-related radiation risks is retrospectively derived from data on survivors of nuclear disasters and/or calculated via ‘phantoms’ exposed to CT, it provides a compelling reason to limit the use of head CT imaging in children [7–9].

Brenner *et al.* estimate that the lifetime ‘attributable’ risk of mortality from leukemia or solid organ malignancy from a single pediatric head CT ranges from approximately 1 : 2000 for infants to 1 : 5000 for older children. When additional CT imaging studies requiring a longer period of radiation exposure are also needed, such as chest or abdomen/pelvis CT, the overall ‘attributable’ risk figures can increase by several magnitudes [8]. As pediatric patients may account for up to 16% of all CT scans performed in the United States, the Society for Pediatric Radiology has lobbied for measures to limit radiation exposure, including: standardized lowering of radiation doses used during imaging of children; and implementation of newer, faster equipment with automatic radiation adjustment controls based on standards [9]. In 2007, the Alliance for Radiation Safety in Pediatric Imaging launched a campaign, aptly named ‘Image Gently’, to disseminate information to radiologists and pediatricians [10]. The campaign effectively provided a databank of information for the reduction of radiation doses for CT scans in children to levels that are ‘as low as radiographically achievable’ (ALARA) [9]; however, uniform ALARA standards for CT radiation dosing in pediatric patients have not been universally adopted and are essentially unregulated. Hospitals and imaging facilities that have protocols for CT scanning in children may utilize ALARA principles, but can also base radiation dosing on the experience of the radiologist and technicians, or on automated equipment settings. Uniform application of specific ALARA radiation dose protocols in CT imaging of pediatric patients remains a key challenge for the future.

A recent study by King *et al.* demonstrates a significant difference in the mean effective doses (mED) of radiation utilized for pediatric head CT scans at a regional children’s hospital versus at a trauma center; this was compared for age-based cohorts utilizing measurement in milli-Sieverts (mSv) [11•]. The unit of mSv reflects the likelihood of biological risk owing to radiation exposure and incorporates the sensitivities of various organs. The highest mED was noted for patients aged 0–3 years who were imaged at the trauma center. Yet the greatest difference in mEDs between the centers was noted in the 10–14-year age cohort, with 2.23 mSv at the trauma center and 1.71 mSv at the regional children’s hospital (95% CI 0.37–0.66, *P* 0.001). When viewed overall, the study demonstrates an age-adjusted mED of 0.44 mSv lower at the regional children’s hospital than at the trauma center. The study thus provides evidence of both the differences in practice protocols for CT radiation dosing in children and the comparative reduction in radiation exposure that is achieved at a pediatric center.

Longitudinal prospective data on the biologic sequelae of CT scans in children is greatly needed but presently unavailable. Current evidence mandates a judicious approach to the use of head CT scans in children along with careful and standardized adjustment of radiation doses when CT scans must be performed. Data from pediatric centers highlights the importance of an ongoing collaboration between the emergency and radiology departments to assure that appropriate techniques and radiation dose protocols are utilized to assure that CT imaging of children is as safe as possible.

Clinical prediction rules for closed head injury

TBI is a significant cause of morbidity and mortality in children. As noted above, fewer than 10% of CT scans in children with more minor head trauma demonstrate a

TBI and neurosurgical intervention is rarely needed [1]. Identification of children who are at low risk of TBI is therefore a key factor in the reduction of CT scan use for the evaluation of CHI. Clinical prediction rules derived through prospective studies have emerged as viable tools to identify the subset of children at low risk of TBI through historical and clinical variables [2,12,13]. It is estimated that the CT scan rates for pediatric CHI could be reduced to as low as 13% (from the current level of 50%) if clinical prediction rules were consistently utilized [1].

Direct comparison of the clinical prediction rules for CHI reported to date remains problematic, given that significant heterogeneity exists in the populations studied as well as the outcomes tested. Meta-analysis of this research is further confounded by variations in the definition of head injury severity and/or mechanisms of injury that have been examined [14••]. Outcomes that have been used for clinically important TBI (ciTBI) have included death, neurosurgical intervention, intubation for over 24 h, need for hospitalization over 48 h or anti-epileptic treatment for more than 7 days.

A study by Maguire *et al.* [14••] compared eight published clinical prediction rules via systematic review. Resultant data on combined performance from these studies was limited owing to the heterogeneity of variables between the different prediction rules. The overall frequency of CT scans predicted for three different groups of children varied widely: those with any severity of head injury, 14–86%; those with minor head injury, 13–77%; and children below 3 years old, 35–95%. The overall sensitivity of these prediction rules was lowest for children less than 3 years old (lower limit of 95% confidence interval = 0.72–0.87), likely because this population was least represented in the studies [7]. The authors note the greatest degree of prediction rule evidence in two of the eight studies that were compared.

Palchak *et al.* prospectively examined 2043 head-injured patients aged 0–18 years, and reported four variables that predicted TBI requiring acute intervention with high sensitivity (1.00, 95% CI 0.97–1.00) and high negative predictive value (1.00, 95% CI 0.997–1.00): abnormal mental status, signs of skull fracture, scalp hematoma if age 2 years or less, or history of vomiting [12]. A large prospective multicenter study by Dunning *et al.* [13] in England included 22 772 head-injured patients aged 0–16 years and reported a broad array of variables that predicted ciTBI with high sensitivity (0.98, 95% CI 0.96–1.00) and negative predictive value (0.999, 95% CI 0.999–1.00). The variables predictive of ciTBI were reported as loss of consciousness over 5 min, amnesia over 5 min, abnormal drowsiness, vomiting at least three times, suspicion of nonaccidental injury, Glasgow Coma Score (GCS) less than 14 (or GCS<15 if age <1 year), penetrating or depressed skull injury or tense fontanel, signs of basilar skull fracture, focal neurologic findings, presence of bruise, swelling or laceration more than 5 cm if under 1 year old, high-speed road traffic collision (occupant, cyclist, or pedestrian > 40 mph, or high-speed injury from a projectile object). The outcome measures for this study were quite different, with ciTBI defined by outcomes of death, neurosurgical intervention, or clinically significant intracranial injury on CT scan. This is in contrast to the Palchak *et al.* study, which used TBI requiring acute intervention as the main outcome measure. Both studies yield clinically relevant data but cannot be reliably combined into a clear pathway for prediction of ciTBI.

A recent multicenter prospective study by Kuppermann *et al.* [1] in the United States has added much needed clarity to the clinical prediction of ciTBI. The study includes data on 42 412 patients aged 0–18 years with nontrivial, nonpenetrating head injuries and GCS at least 14 from 25 institutions in Pediatric Emergency Care Applied Research Network (PECARN). There were two phases to the study, one in which clinical prediction rules were derived (79.7% of study population) and a second in which the prediction rules were validated (20.3% of study population). The data set was further divided between patients under 2 years old and those 2–18 years old, to adjust for limited verbal communication in younger patients. Overall 35% (14 969) patients in the study had a head CT scan performed based on individual clinician decision. Outcomes for ciTBI were defined as death from TBI, intubation over 24 h for TBI, or hospital admission of at least 2 nights for TBI on CT scan. A total of 780 patients had traumatic brain injuries on head CT scan, which was 5.2% of all CT scans performed in the study. However, only 376 patients with a positive head CT scan finding had ciTBI by the study criteria, which was 0.9% of the total study population. The prediction rules derived for both patient groups had extremely low risks of missed ciTBI and stratified the use of head CT scan: high-risk patients should receive a CT, intermediate-risk patients may be observed or scanned based on clinical factors, and low-risk patients should not receive CT. High-risk patients included those with GCS < 14 or other signs of altered mental status, palpable skull fracture (under 2 years), or signs of basilar skull fracture (2–18 years). Intermediate-risk patients under 2 years included those with scalp hematomas (occipital, parietal, or temporal), history of loss of consciousness at least 5 s, severe mechanism of injury, or not acting normally per the parents; 2–18 years included those with history of loss of consciousness or vomiting, severe mechanism of injury, or severe headache. Low-risk patients were those who did not have any of the criteria above for the high or intermediate-risk patients. Approximately half of the study patients qualified for the low-risk categories in both age groups. Of these patients, those under 2 years had a 0.02% risk of ciTBI and those 2–18 years had a 0.05% risk of ciTBI. This strikingly low missed ciTBI rate demonstrates the strength of the derived prediction rules, in addition to the high sensitivity and negative predictive values of the rules in both the derivation and validation phases of the study. Neither rule missed any ciTBI for which neurosurgical intervention would be indicated in the validation population. The algorithmic approach proposed in the study is likely to gain wide acceptance for management of head-injured children given its scientific rigor and ease of use. Within the study population alone, low-risk criteria were met and CT scans could have been avoided for 25% of patients below 2 years and 20% of patients 2–18 years old. A caveat to the prediction rules is that clinical judgment of variations in mechanism of injury and unique patient characteristics must prevail. Nonetheless, the rules provide a critical framework for important clinical decisions on the use of head CT scans and reduction in unnecessary CT radiation exposure for pediatric patients.

Concussion

Longitudinal outcomes for young children with mild CHI are generally uncomplicated when compared with those with more significant CHI, and they have the lowest likelihood of any functional impairment at 2 years after injury [15]. However, postconcussive symptoms can occur in a wide range of pediatric patients with mild CHI and can persist for weeks to months post trauma. Two recent reviews of sports-related concussion detail an array of signs and symptoms reported following concussion, and one distinguishes simple (resolves in 7–10 days) from complex concussion (symptoms persist, multiple concussions, prolonged cognitive impairment) [5••,6••]. Common symptoms of concussion include headache, dizziness, and nausea or vomiting; these key symptoms are addressed in the PECARN study decision rules for use of head CT scans discussed above.

Evidence is lacking to guide the clinical management of children with mild CHI after ED discharge because there are specific parameters for follow-up. Return-to-play decisions for athletes now hinge on the full resolution of postconcussive symptoms at rest and during exercise, with a gradual, step-wise increase in level of activity [6••]. Younger athletes with concussion are recognized as needing longer recovery times, and the return-to-play process is likewise prolonged. A step-wise approach for return to activity would seem prudent for patients with non-sports-related concussion; however, there are no recommendations available in the literature at this time. Although neuropsychological testing is encouraged as ‘one of the cornerstones of concussion evaluation,’ there are also no recommendations available to guide its use [6••]. Some centers now offer clinics for follow-up of patients after CHI through pediatric trauma and neurology services and this is likely to become more widely available as further data emerges on concussion in children (http://www.mgh.harvard.edu/children/specialtiesandservices/trauma/follow_up_clinic.aspx). These centers will provide ongoing concussion screening and neuropsychological testing to assure that all symptoms have resolved following CHI, and also provide further specialty intervention for persistent symptoms. Prompt follow-up of all children with CHI after acute ED care is a vital first step to assure screening for the full resolution of any post-concussive symptoms, and should be conducted through the primary care provider. Information links (via electronic medical records and follow-up notification systems) between the ED and primary care settings are critical to the success of this follow-up for mild CHI. Ultimately the safety of pediatric patients after mild CHI hinges on a reliable and ongoing plan for follow-up, regardless of whether CT scan images are obtained or not during initial ED care.

Future directions

The management of mild CHI in children is at a critical juncture in the future direction of clinical practice in the ED. Based on the PECARN study, the use of head CT scans to evaluate mild head injury can and should be limited; however, the specific definition of mild CHI, or minor injury mechanism, will continue to be debated as many variations can present in clinical practice. Concern over medico-legal risk incurred by more restricted use of head CT scans will dangle in a challenging balance with potential risk incurred from radiation exposure when head CT scans are used. MRI may prove to be more sensitive in detecting injuries from CHI [16]. The use of short sequence or fast MRI (a limited study that takes 10–15 min to perform) is a promising alternative to CT scan for the evaluation of cases of mild CHI in which imaging is desired; however, it is not available in many centers and has not yet been reported in the literature for use in CHI (http://www2.massgeneral.org/radiology/index.asp?page=imaging_services&subpage=er). Fast MRI has been successfully used for other imaging needs [17]. Future study is needed to evaluate the viability of fast MRI in the acute evaluation of CHI.

Evidence on the overall course of postconcussive symptoms after mild CHI is lacking to date. Limited data are available for sports-related concussions, which are largely considered to reflect a lower impact than other CHI mechanisms. Data are needed to better define time frames for resolution of symptoms, modalities for follow-up (e.g., primary care versus specialty clinic), and testing options after mild CHI. Neuropsychological testing is clearly a helpful resource for persistent postconcussive symptoms, and guidelines for its use are needed. Functional MRI (fMRI) also has been used to assess postinjury brain activation, and may eventually be available for patients with mild CHI with persistent postconcussive symptoms [5••]. Future research is needed in these areas to guide follow-up decisions after acute ED care for pediatric patients with mild CHI and to assure that the best outcomes possible are achieved.

Conclusion

The current literature offers preliminary evidence on the clear risks of radiation exposure from CT scans in children. It is likewise clear that CT scan use should be as safe and limited in scope as possible. Kupperman *et al.* [1] have established a prediction rule that is validated and clinically sound for decisions on whether to use head CT scan in mild CHI, and can help to limit the number of CT scans performed. Concurrent with this progress, fast (or short sequence) MRI represents an emerging technology that may prove to be a viable alternative to radiation exposure from CT scan in certain cases of mild CHI when imaging is desired. The initial ED evaluation for mild CHI is the start point for a sequence of follow-up to assure that postconcussive symptoms fully resolve. The literature on sports-related concussion offers some information that may be used for patients with non-sports-related concussion. Ultimately, specific parameters for the post-ED care of patients with mild CHI are needed in the future.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:
- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 369).

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