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Pediatric Traumatic Brain Injury and Radiation Risks: A Clinical Decision Analysis

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Objective To determine the optimal imaging strategy for young children with minor head injury considering health-related quality of life and radiation risk. In children with minor head trauma, the risk of missing a clinically important traumatic brain injury (ciTBI) must be weighed against the risk of radiation-induced malignancy from computed tomography (CT) to assess impact on public health.

Study design We included children <2 years old with minor blunt head trauma defined by a Glasgow Coma Scale score of 14-15. We used decision analysis to model a CT-all versus no-CT strategy and assigned values to clinical outcomes based on a validated health-related quality of life scale: (1) baseline health; (2) non-ciTBI; (3) ciTBI without neurosurgery, death, or intubation; and (4) ciTBI with neurosurgery, death, or intubation >24 hours with probabilities from a prospective study of 10 000 children. Sensitivity analysis determined the optimal management strategy over a range of ciTBI risk.

Results The no-CT strategy resulted in less risk with the expected probability of a ciTBI of 0.9%. Sensitivity analysis for the probability of ciTBI identified 4.8% as the threshold above which CT all becomes the preferred strategy and shows that the threshold decreases with less radiation. The CT all strategy represents the preferred approach for children identified as high-risk.

Conclusion Among children <2 years old with minor head trauma, the no-CT strategy is preferable for those at low risk, reserving CT for children at higher risk. *(J Pediatr 2013;162:392-7)*.

Head trauma results in >600 000 emergency department (ED) visits, 60 000 hospitalizations, and 7400 deaths annually in children in the US.[1,2] Although the vast majority of children with blunt head trauma experience mild injuries, some have a clinically important traumatic brain injury (ciTBI).[3] Given the potential for rare but devastating outcomes from missed injuries, clinicians must rapidly identify children with ciTBI at the time of ED evaluation. Very young children represent the most challenging group to evaluate given the difficulties in assessment and the potentially higher risk for occult injuries.[4-7]

Cranial computed tomography (CT) represents the gold standard for the diagnosis of acute traumatic brain injury (TBI). CT imaging rates after minor blunt head trauma more than doubled between 1995 and 2005.[3,8,9] However, <10% of CT scans in children with blunt head trauma show TBI, and only a small fraction of these require intervention.[6,7,10-12] The increasing use of CT raises concerns about the exposure from ionizing radiation, which increases the baseline risk of long-term malignancy, particularly due to the increased sensitivity of developing tissues to radiation and the longer lifetime to manifest a radiation-induced malignancy.[10,11,13] For a 1-year-old child, studies estimate the risk of developing a lethal malignancy from a single CT of the brain of up to 1:1500 compared with 1:5000 for a 10-year-old child.[10,13-16]

Although previous studies evaluated clinical decision rules to identify TBI,[3,5,12,17-29] the risk tradeoff associated with the risk of radiation to young children remains an issue. We sought to assess health outcomes, including the impact of radiation-associated risks, associated with the ED management of children younger than 2 years of age presenting with blunt head trauma and Glasgow Coma Scale scores (GCS) of 14-15, a group that accounts for approximately half of all TBIs in this age group and poses the greatest diagnostic challenge.[5] Data from multiple studies suggest rates of head CT in children with head trauma greatly varies, with rates from 15% to 58%.[8,9,30-32] This may reflect differences in clinician or institutional preference, different assessments of the probabilities of ciTBI, and/or lack of standardization. We sought to identify the optimal strategy for CT imaging of children younger than age 2 with GCS scores of 14-15, identifying the risk threshold at which CT imaging becomes the preferred strategy, considering health-related quality of life and risk of radiation

AIS	Abbreviated Injury Scale
ciTBI	Clinically important traumatic brain injury
CT	Computed tomography
ED	Emergency department
GCS	Glasgow Coma Scale
p(ciTBI)	Probability of clinically important traumatic brain injury
PECARN	Pediatric Emergency Care Applied Research Network
TBI	Traumatic brain injury

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from CT use over time. We also evaluated the imaging implications for higher-risk children within this population based on an existing algorithm.[3] We recognize that no institution or clinician would uniformly apply a single strategy for every case and the role of clinical judgment is essential, but we seek to identify the optimal threshold for CT imaging of children with differing hypothetical risks of TBI from the perspective of patient health utility.

Methods

This study based on literature review was exempt from review by our Institutional Review Board. The authors constructed a decision analysis model for children younger than 2 years with blunt head trauma and a GCS score of 14-15 for 2 strategies: (1) CT all; or (2) no CT (ie, no immediate CT for any children, which is depicted in **Figure 1** as square decision nodes). As shown in the decision tree, following the decision of obtaining a CT or not obtaining a CT, physicians will observe the outcome of chance events (**Figure 1**, *circles*) and end at one of the possible terminal branches (**Figure 1**, *triangles*): baseline health/no TBI, ciTBI, and non-ciTBI. This method determines whether at a given risk of TBI the optimal approach would be CT all or no CT. Through sensitivity analysis, we determine the threshold probability of ciTBI [p(ciTBI)] at which the optimal strategy changes from no CT to CT all. Thus, based on knowing only that a child presents with the same expected p(ciTBI), the analysis provides insights about the expected optimal strategy. Any individual child may differ from the expectation, and thus this analysis should serve to support, but not replace, clinical judgment.

For our model, we used data and definitions from the published, large, prospective multi-center Pediatric Emergency Care Applied Research Network (PECARN) study of a pediatric head injury cohort of 42 412 children (including 10 718 children younger than 2 years old) with blunt head trauma presenting to the ED with GCS scores of 14-15.[3] The study defined ciTBI as head injury resulting in death or requiring neurosurgery, endotracheal intubation for >24 hours for TBI, or hospital admission for ≥2 nights for management of head injury in association with TBI on CT.[3] This study excluded children with trivial mechanisms, such as ground-level falls or walking into stationary objects, as well as patients with penetrating trauma, known brain tumors, preexisting neurologic disorders, ventricular shunts, bleeding disorders, or GCS score other than 14-15.[3] Our model assumes a hypothetical study cohort that met the same criteria. Kuppermann et al provided an algorithm identifying children at higher-risk for ciTBI (GCS of 14 or other signs of altered mental status or palpable skull fracture) and we constructed a decision analysis model for this cohort as well.[3]

We constructed a decision analysis model using TreeAge Pro (TreeAge Software Inc, Williamstown, Massachusetts). We divided ciTBI into: (1) cases resulting in death or requiring neurosurgery or endotracheal intubation for >24 hours for TBI; and (2) cases requiring ≥2 nights of hospitalization according to the PECARN definition.[3] Although death represents a significantly worse outcome than neurosurgery or intubation, we combined these outcomes due to the absence of deaths in the prospective study. We defined non-ciTBIs (or positive CT scans only) as traumatic findings on CT that did not require any of the described acute interventions (eg, a mildly depressed skull fracture or cerebral contusion requiring neither surgical intervention nor hospital admission for >2 nights). In the no-CT strategy, our model also includes children with ciTBI not initially sent for CT but who experience a change in their clinical status that would prompt CT imaging (delayed CT) that could diagnose ciTBI. We used previously published probabilities of 0.9% for ciTBI, 1.7% for non-ciTBI, and 0.2% for neurosurgery, intubation, and death (**Table**).[3] For the high-risk subgroup, we used the probability of 4.4% for ciTBI.[3] Because the rates of non-ciTBI, neurosurgery, intubation, and death were not available for this high-risk group specifically, we calculated probabilities of 15% for non-ciTBI and 1.4% for neurosurgery, intubation, and death based on the available data, by including all patients from the entire cohort (N = 10 718) with these risk factors as in the high-risk group (n = 1490) in our effort to err on the side of overestimating these values (**Table**).

For our model, we assigned values (or utilities) to the health outcomes using a standard scale from 0 (death) to 1 (baseline health, assumed as perfect health for this cohort). Utilities depend on the impact of the particular disease state on an individual and seek to measure quality of life, considering physical function, emotional function, social function, school function, psychosocial function, and cognitive function.[33] We assigned utilities to the CT-all group by mapping each outcome to descriptions from a validated quality-adjusted life expectancy scale created specifically for pediatric head trauma (**Table**).[33] This scale created utility scores using the Abbreviated Injury Scale (AIS)[34] for mild (AIS 2-3), moderate (AIS 4), and severe TBI (AIS 5), which we mapped to non-ciTBI, ciTBI without neurosurgical intervention, and ciTBI with neurosurgical intervention, respectively, with no deaths as noted earlier (**Table**). For example, a closed or comminuted skull fracture would be classified as mild head injury with an AIS score of 2-3, and a subdural hematoma would be classified as moderate head injury with an AIS score of 4.

We further modified the outcomes for ciTBI according to the timing of CT (immediate vs delayed CT). Specifically, we applied a disutility to patients in the no-CT group who later had a CT scan that led to diagnosis of ciTBI, based on the assumption that earlier detection and treatment of the ciTBI might improve patient outcome. Disutilities represent adverse affects on a health outcome, in this case either due to potential harm from radiation or from delay in necessary CT imaging, and thus they subtract from the overall utility and appear as negative numbers in the **Table**. We estimated the value of disutility for delayed CT from a previously well-validated quality-adjusted life expectancy scale that closely matched this state of health, which accounts for