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Identification of Abusive Head Trauma in High-Risk Infants: A Cost-Effectiveness Analysis

Kathleen A. Noorbakhsh, MD[1], Rachel P. Berger, MD, MPH[1], and Kenneth J. Smith, MD, MS[2]

Objectives To evaluate the cost-effectiveness of abusive head trauma detection strategies in emergency department settings with and without rapid magnetic resonance imaging (rMRI) availability.

Study design A Markov decision model estimated outcomes in well-appearing infants with high-risk chief complaints. In an emergency department without rMRI, we considered 3 strategies: clinical judgment, universal head computed tomography (CT) scan, or the Pittsburgh Infant Brain Injury Score (PIBIS) with a CT scan. In an emergency department with rMRI for brain availability, we considered additional strategies: universal rMRI, universal rMRI with a CT scan, PIBIS with rMRI, and PIBIS with rMRI followed by a CT scan. Correct diagnosis eliminated future risk; missed abusive head trauma led to reinjury risk with associated poor outcomes. Cohorts were followed for 1 year from a healthcare perspective. One-way and probabilistic sensitivity analyses were performed. The main outcomes evaluated in this study were abusive head trauma correctly identified and incremental cost per quality-adjusted life-year.

Results Without rMRI availability, PIBIS followed by a CT scan was the most cost-effective strategy. Results were sensitive to variation of CT scan-induced cancer parameters and abusive head trauma prevalence. When rMRI was available, universal rMRI followed by a confirmatory CT scan cost $25 791 to gain 1 additional quality-adjusted life-year compared with PIBIS followed by rMRI with a confirmatory CT scan. In both models, clinical judgement was less effective than alternative strategies.

Conclusions By applying CT scans to a more targeted population, PIBIS decreases radiation exposure and is more effective for the identification of abusive head trauma compared with clinical judgment. When rMRI is available, universal rMRI with a CT scan is more effective than PIBIS and is economically favorable. *(J Pediatr 2020;227:176-83)*.

See editorial, p 15 and related article, p 170

Abusive head trauma is the leading cause of fatal traumatic brain injury in infants.[1,2] One-third of children with abusive head trauma are initially misdiagnosed, contributing to increased morbidity and mortality.[3-6] Diagnosis can be challenging because there often is no reported history of trauma and presenting symptoms are nonspecific.[7,8] The standard criterion for diagnosis is abnormal head computed tomography (CT), an imaging modality associated with significant radiation exposure, particularly for young infants.[9-11] Balancing a desire to have a low threshold to evaluate infants for abusive head trauma with a desire to minimize radiation exposure poses a clinical challenge.

The Pittsburgh Infant Brain Injury Score (PIBIS) is a validated tool to identify infants in the emergency department (ED) at high risk of abusive head trauma and most likely to benefit from a HCT scan.[12] PIBIS offers improved ability to identify at-risk infants and, with this, introduces the potential for increased imaging overall. Rapid magnetic resonance imaging (rMRI) of the brain has emerged as an alternative to a CT scan for the identification of abusive head trauma without the risk of radiation or sedation.[13-15] rMRI has the potential to increase cost and has limited availability. The optimal application of PIBIS and selection of imaging modality to optimize medical costs, radiation exposure, and clinical outcomes is not established.

The decision to incorporate PIBIS into clinical decision making must be weighed against the effectiveness and cost of traditional detection strategies, factoring in differences in effectiveness, cost, availability of imaging modalities, and the risk of radiation-induced cancer. We used decision modeling techniques to address these issues and evaluate the cost effectiveness of different strategies to identify infants with abusive head trauma.

CT	Computed tomography
ED	Emergency department
PIBIS	Pittsburgh Infant Brain Injury Score
rMRI	Rapid magnetic resonance imaging
QALY	Quality-adjusted life-year

From the [1]Department of Pediatrics, and the [2]Department of Medicine, University of Pittsburgh Medical Center, Pittsburgh, PA

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Methods

We performed a cost-utility analysis to compare outcomes, costs, and cost effectiveness of strategies to identify abusive head trauma in a hypothetical cohort of 1000 infants presenting to the ED with high-risk chief complaints. A decision analytic Markov model simulated transitions between health states. The decision model was programmed in TreeAge Pro 2016 (TreeAge Software, Inc, Williamstown, Massachusetts).

Study Setting and Population

We considered 2 scenarios: an ED in which a CT scanner is available and rMRI is not, and an ED having both a CT scanner and rMRI readily available. Our base case was that of a well-appearing 4-month-old infant presenting to the ED with a high-risk chief complaint. High-risk chief complaints included vomiting without diarrhea, fussiness, seizure or spell, brief resolved unexplained event, feeding difficulties, or nonspecific complaint.[4,10,12] Infants were assumed to have no stated history of trauma.

PIBIS Screen

The PIBIS is a validated clinical prediction rule for infants <12 months of age presenting to an ED with a high-risk chief complaint. It is designed to identify infants most likely to benefit from neuroimaging to evaluate for abusive head trauma. abusive head trauma risk is assessed using a 5-point scoring system. Two points are assigned for bruising and 1 point for each of the following: age ≥3 months, head circumference >85th percentile, or hemoglobin <11.2 g/dL.[12]

Model Design

The decision model included 7 health states: (1) well, (2) abusive head trauma diagnosed and treated, (3) missed abusive head trauma, (4) well following missed abusive head trauma, (5) recurrent abusive head trauma, (6) severe neurologic disability, and (7) death. Infants begin the model either with or without abusive head trauma. All infants have a baseline risk of death and disability. Infants diagnosed with abusive head trauma incur the costs of medical treatment and return to a well state. Because the model considers a select population of well-appearing infants, correctly diagnosed infants at initial presentation are assumed to attain full recovery. The costs of medical treatment were equally applied to both true- and false-positive diagnoses of abusive head trauma. Infants with missed abusive head trauma have an increased risk of death, disability, and reinjury. Reinjured infants represent to the ED. Those who are diagnosed incur the costs of medical treatment and return to a well state, and those with recurrent missed abusive head trauma remain at risk for death, disability, and reinjury. The transition between health states is shown in Figure 1. We used a 1-year time horizon and tracked disutilities for long-term outcomes as outlined elsewhere in this article. Disutility was defined as a decrease in quality of life and/or length of life associated with a particular event or health state.[16]

For a CT-only ED, we considered 3 strategies for identifying abusive head trauma: clinical judgment, PIBIS with head CT (PIBIS+CTH), and universal head CT. In the clinical judgment strategy, we assumed imaging was at the discretion of the physician and, based on practice patterns of the past 30 years, a sensitivity of 70% was assigned.[3,4] A specificity of 95% for this strategy was assumed. For PIBIS+CT, all infants received a PIBIS score. Those with a score of ≥2 underwent CTH. In universal CTH, all infants with high-risk chief complaints underwent CTH.

In an rMRI-capable ED, we considered the impact of rMRI in evaluation of an identical hypothetical infant cohort. Four strategies were added to those considered in the CT-only ED model: PIBIS with rMRI for infants with PIBIS score ≥2 (PIBIS+rMRI); PIBIS with rMRI for infants with PIBIS score ≥2 followed by confirmatory CT scan for abnormal or equivocal rMRI (PIBIS+rMRI+CT); universal rMRI; and universal rMRI followed by confirmatory CT scan for abnormal or equivocal rMRI (universal rMRI+CT). Strategies combining rMRI and CT scan were based on previously published studies.[13,14,17,18] Hypothetical rMRI-only strategies were analyzed in keeping with International Society for Pharmacoeconomics and Outcomes Research recommendations to consider all plausible strategies.[19]

Input parameters for probabilities, costs, and outcomes are presented in Table I. For each category, we included an estimated 95% probability range. Probabilities of outcomes from undiagnosed abusive head trauma were derived from published literature (Table I), with ranges accounting for variation among sources. We included risk for radiation-induced cancer from HCT. A baseline risk of neurologic disability was estimated. Costs include direct medical costs of ED visits, detection strategies, hospitalization, and medical treatment. The analysis took a healthcare perspective, and thus indirect costs were not included in the model. All-cause mortality was estimated using US National Center for Health Statistics life tables.[28]

All costs were adjusted to 2016 US dollars based on the medical cost component of the Consumer Price Index.[43] Imaging costs included costs of performing the test and interpretation by a radiologist. We assumed a willingness to pay of $100 000 per quality-adjusted life-year (QALY) gained, a commonly cited benchmark for the US healthcare system.[44]

Health state utilities were assigned a value of 0-1, with 0 equivalent to death and 1 representing perfect health.[45] The disutility of radiation induced cancer and infant mortality were factored as lifetime disutilities. All costs and utilities, including QALYs lost owing to infant mortality, were discounted at 3% per year, as recommended for cost-effectiveness analysis design.[42] QALY loss was derived from the literature.[29,39-41]

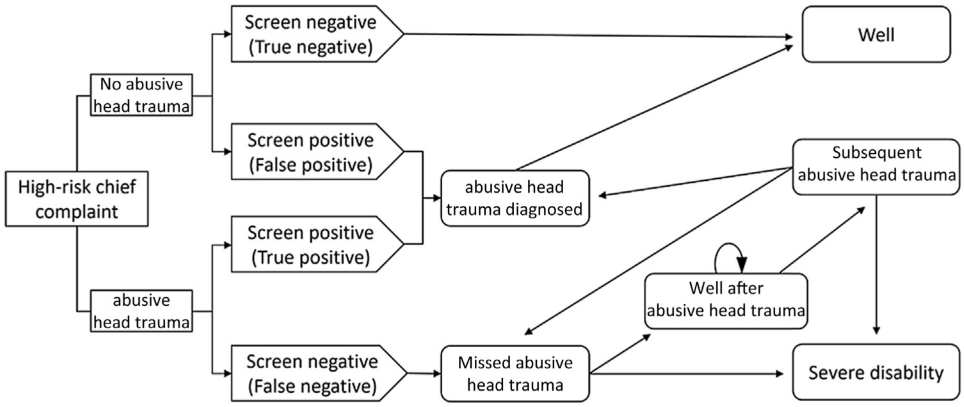

Figure 1. Model schematic. Infants begin the model in the ED with a high-risk chief complaint and with or without abusive head trauma. After undergoing strategy-specific abusive head trauma screening, they are either correctly or incorrectly diagnosed. Infants without abusive head trauma who screen negative return to the well state. Those without abusive head trauma who screen positive incur costs of care and return to the well state. Correctly diagnosed infants with abusive head trauma incur the same costs of care and return to the well state. Infants with missed abusive head trauma have an increased risk of death and disability and can progress to the well state after abusive head trauma; in this health state, infants are well but remain at risk for recurrent abusive head trauma for several cycles. Infants who experience recurrent abusive head trauma represent to the ED where they are either correctly or incorrectly diagnosed. All infants have a baseline risk of death (data not shown).

Outcome Measures

The primary outcomes evaluated were effectiveness (abusive head trauma cases correctly identified), cost, and cost effectiveness (cost per case identified) for each strategy. Strategies were ranked by cost then compared in terms of cost, effectiveness, and incremental cost-effectiveness ratio (additional cost in dollars per event or disutility cost averted). Secondary outcomes included hospitalizations, deaths, and QALYs lost. In the cost-effectiveness calculation, effectiveness was tracked as a disutility, representing lost quality and duration of life from abusive head trauma, diagnostic strategies, medical management, and death. A secondary analysis of cost per case was performed.

Sensitivity Analyses

We conducted 1-way sensitivity analyses to determine if varying any single parameter across its listed range (**Table I**) substantially changed results. Probabilistic sensitivity analyses (using 1000 simulated event combinations, simultaneously varying all parameter values over distributions) were performed to estimate uncertainties in the primary and secondary outcomes resulting from that variation. Distributions were chosen to reflect the level of certainty and the characteristics of the parameter range and methodological standards. β distributions were used for probabilities and quality adjustments; γ distributions were used for costs. Threshold analyses were performed to determine the point at which changes to input parameters resulted in differing strategies being preferred. A structural sensitivity analysis was performed to test the assumption of full recovery after correct diagnosis of abusive head trauma. In this analysis, correctly diagnosed infants with abusive head trauma experienced loss of QALYs after accruing medical costs of treatment varied over a range of values.

Results

CT-Only ED Model

In the base case analysis, clinical judgement was the least expensive and the least effective strategy (with a cost of $1237, and a loss of 0.482 QALYs). PIBIS+CT was preferred, costing an additional $17 722/QALY gained (**Table II**). Universal CT scan was more effective and more costly than PIBIS+CTH, exceeding the $100 000/QALY willingness to pay threshold, indicating that the added cost outweighed added effectiveness. Comparative clinical outcomes in a hypothetical population are shown in **Table III** (available at www.jpeds.com).

In 1-way sensitivity analyses, results were impacted by changes in several key variables, including radiation-induced cancer disutility and risk, and abusive head trauma risk (**Table IV**; available at www.jpeds.com). Results were not sensitive to variation in costs associated with ED evaluation, neuroimaging, or transient quality of life parameters (**Figure 2**; available at www.jpeds.com). Threshold analyses demonstrated that universal CT scan would be favored if the risk and disutility of radiation-induced cancer were lower or if abusive head trauma risk was higher (**Table IV**). Clinical judgement was favored when the risk of abusive head trauma was <0.9%. Structural sensitivity analysis did not change overall model outcomes. Results of the cost-per-case analysis are shown in **Table V** (available at www.jpeds.com).

Probabilistic sensitivity analysis results are summarized as acceptability curves, showing the likelihood that strategies are favored over a range of willingness to pay (or acceptability) thresholds, as shown in **Figure 3**. PIBIS+CT remained the preferred strategy from a willingness to pay

Table I. Model inputs: Baseline parameter values and ranges

Descriptions	Point estimate (range)
Probabilities	
Risk of abusive head trauma[12,20-23]	3% (0%-4%)
Risk of recurrent abusive head trauma[3-5]	39% (28%-53%)
CTH[13,17,18,24]	
Sensitivity	99% (95%-100%)
Specificity	98% (94%-100%)
rMRI sensitivity[13,14,18]	
Sensitivity	98% (95%-99%)
Specificity	91% (80%-99%)
PIBIS score ≥2[12]	
Sensitivity	93% (74%-100%)
Specificity	53% (42%-64%)
Clinical judgement[3,4,17,25]	
Sensitivity, first ED visit	70% (69%-75%)
Sensitivity, second ED visit	92% (85%-99%)
Specificity	95% (90%-100%)
Risk of radiation-induced cancer, CTH[10,11,26,27]	0.1% (0.02%-0.2%)
Risk of death, baseline[28]	0.54%
Risk of death, abusive head trauma misdiagnosis[29]	10% (5%-20%)
Risk of disability, baseline	0.11% (0.1%-0.12%)
Costs*	
ED visit[30]	560 (448-672)
CTH[31]	117 (94-250)
rMRI[31]	232 (186-360)
Complete blood count[32]	12 (10-14)
Hospitalization, abusive head trauma[33]	21 995 (17 596-26 394)
Severe disability, first year of life[34-38]	5824 (824-10 824)
Utilities and disutilities†	
Well, infant[39,40]	0.95
Abusive head trauma[39,40]	0.88 (0.65-0.97)
Recurrent abusive head trauma[39,40]	0.51 (0.39-0.63)
Severe neurologic disability[39,40]	0.59 (0.36-0.83)
Radiation induced cancer, disutility[41]	9.9 (8.3-11.5)
Death in infancy, disutility[28]	30.98
Discount rate[42]	0.03

*Costs are in 2016 US dollars.
†Disutility values are lifetime QALY lost.

of $20 000-$200 000/QALY. At a willingness to pay of $100 000/QALY, PIBIS+CT was favored 64% of the time (**Figure 3**, top).

rMRI-Capable ED Model

With the addition of rMRI strategies, clinical judgement remained the least expensive strategy. PIBIS+rMRI+CT was more effective and cost $9476/QALY gained. Universal rMRI+CT was the favored strategy, costing an additional $25 791/QALY gained (**Table II**). Universal rMRI alone cost >$400 000/QALY. All other strategies were less effective and more costly. In 1-way sensitivity analyses, results were sensitive to rMRI specificity, PIBIS sensitivity, and abusive head trauma risk (**Table III**). Probabilistic sensitivity analysis indicated that at a threshold of $100 000/QALY, universal rMRI+CT was favored 79% of the time (**Figure 3**, bottom).

Discussion

We found that applying PIBIS to identify abusive head trauma in a CT-only ED setting was more cost effective than either clinical judgment or universal CT scans. When rMRI was available, PIBIS was again a cost-effective option but universal rMRI with a CT scan for abnormal or equivocal findings was preferred. Universal rMRI+CT was more expensive but more effective than PIBIS, adding QALYs at economically reasonable rates.

One of the strengths of this study is the consideration of 2 ED settings. In keeping with the "as low as reasonably achievable" principle, radiation exposure must be minimized and alternative means of diagnosis sought when possible.[46] rMRI is suggested as an alternative to CT scans, but its availability remains limited. More than 90% of children seeking emergency medical care are evaluated in nonspecialized EDs, many of which do not have rMRI capabilities.[47,48] Thus, strategies to identify abusive head trauma in EDs with only a CT scanner available must be evaluated.

We found PIBIS+CT was preferred for abusive head trauma prevalence of ≤0.3%. An effective clinical decision rule has strong predictive power, changes physician decision making, and has minimal implementation barriers.[49] PIBIS uses simple scoring criteria and is practical to implement.[12] Moreover, PIBIS provides an objective rationale for pursuing imaging, as opposed to prior recommendations of awareness or a high index of suspicion.[50,51] Campbell et al found a cost-savings advantage of using CT to identify abusive head trauma, compared with clinical judgment, was present when abusive head trauma prevalence was >1.8%.[29] Our model adds to these findings by offering a strategy to apply CT to a more targeted population, increasing the yield and decreasing infant radiation exposure.

We selected a PIBIS score of 2 as the evaluation threshold in our base case. The PIBIS study authors do not make recommendations on the optimal application of PIBIS, instead publishing sensitivity and specificity by score. Our sensitivity analysis demonstrated that a PIBIS sensitivity of >98% would make PIBIS+rMRI+CT the preferred strategy in the rMRI-capable ED model. A PIBIS score of 2 has a sensitivity of 93% and specificity of 53%. A PIBIS score of 1 has a 99% sensitivity and 12% specificity.[12] Owing to the marked decrease in specificity, it is unlikely that a threshold score of 1 offers an advantage.

In our CT-only ED model, sensitivity analyses indicated that both the radiation-induced cancer risk and disutility substantially affected results, suggesting that the cost-effectiveness of universal CT is sensitive to potential radiation effects, an area of uncertainty. We used a radiation-induced cancer risk of 1 in 1000. Others have suggested that the risk is as low as 1 in 3000-10 000.[8,52-55] Our use of what may be a high value for radiation risk reflects caution in the analysis. Despite this, PIBIS+CT was the preferred strategy in the CT-only ED.

Table II. Results of cost-effectiveness analyses

Results	Cost ($)	Incremental cost ($)	Effectiveness (QALY)	Incremental effectiveness (QALY)	ICER ($/QALY)
CTH-only ED					
Clinical judgement	$1237	–	−0.482	–	–
PIBIS+CTH	**$1561**	**$324**	**−0.464**	**0.018**	**$17 722**
Universal CTH	$1865	$304	−0.462	0.002	$161 238
rMRI-capable ED					
Clinical judgement	$1237	–	−0.482	–	–
PIBIS+rMRI+CTH	$1437	$199	−0.461	0.021	$9476
PIBIS+CTH	$1561	$124	−0.464	−0.003	Dominated*
Universal rMRI+CTH	**$1597**	**$160**	**−0.455**	**0.006**	**$25 791**
Universal CTH	$1865	$268	−0.462	−0.007	Dominated
PIBIS+rMRI only	$2384	$787	−0.458	−0.004	Dominated
Universal rMRI only	$3611	$2015	−0.451	0.004	$473 842

ICER, incremental cost-effectiveness ratio.
Bold text: Favored strategy at a $100 000 per QALY threshold.
*A dominated strategy is more costly and less effective than other strategies.

The utility and application of rMRI in abusive head trauma continues to be studied in multiple US children's hospitals.[12,13,15,17,26,27] To our knowledge, there is no prior evaluation of rMRI cost effectiveness compared with CT scans in these patients. When rMRI was available, universal rMRI followed by a CT scan was favored. Without the risk

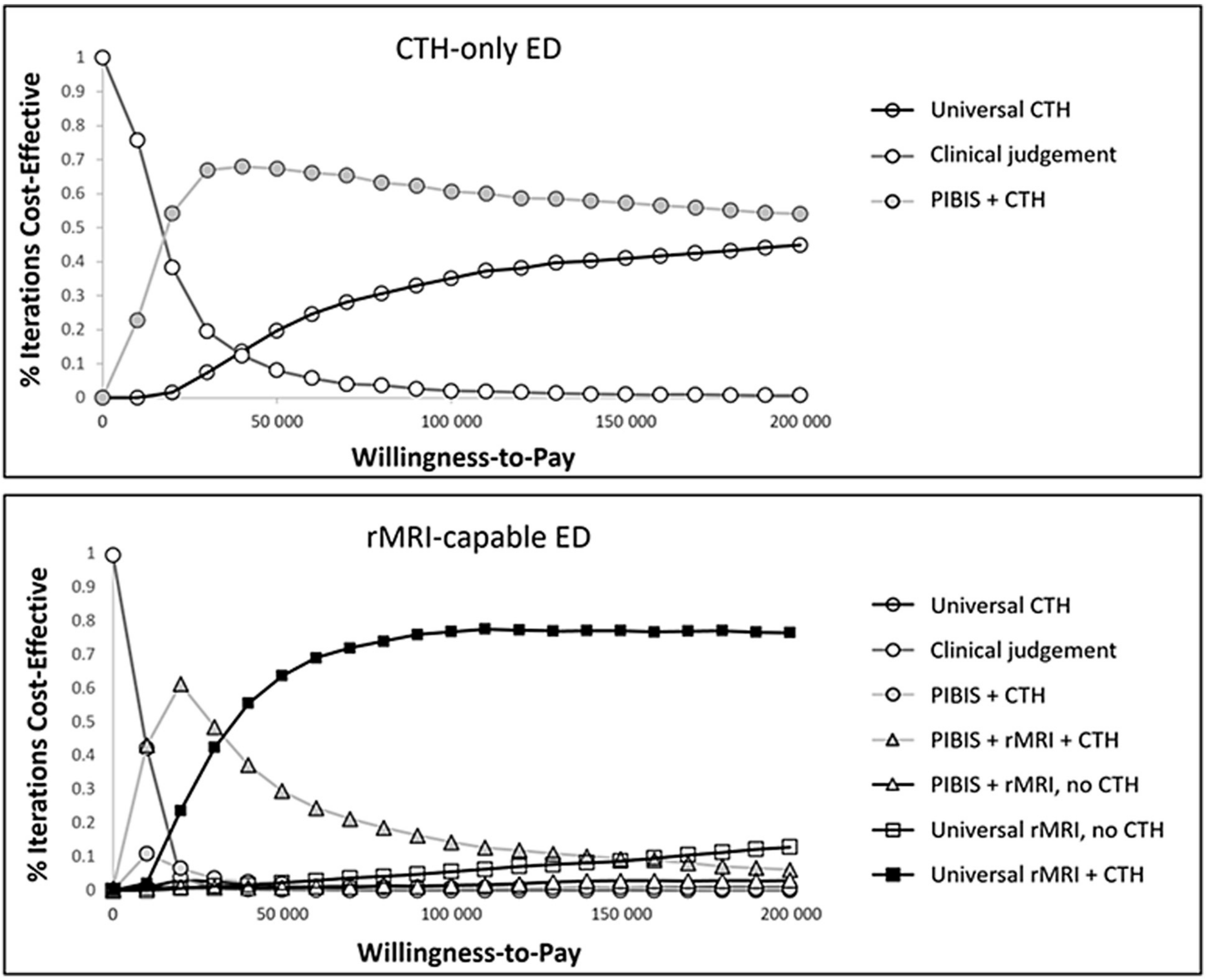

Figure 3. Probabilistic sensitivity analysis. Results are shown as a cost-effectiveness acceptability curve. The *y*-axis shows the likelihood that strategies would be considered cost-effective for a range of cost-effectiveness willingness to pay thresholds (*x*-axis).

of radiation-induced cancer, the upfront costs of imaging all infants with high-risk chief complaints are outweighed by the prevention of recurrent abusive injuries and fatalities. Although universally imaging a population of infants may seem radical, in our model, this $232 test[20] significantly decreased the morbidity and mortality associated with the clinical judgment strategy. Universal rMRI+CT is more sensitive than PIBIS and decreases radiation risks compared with a CT scan for all.

Many of the identified high-risk chief complaints suggest potential neurologic pathologies. In the PIBIS validation cohort of patients, 9% of those with neuroimaging abnormalities had atraumatic findings, including hydrocephalus, tumors, and stroke.[12] Abusive head trauma is one of many potential diagnoses for infants presenting with neurologic symptoms. It is not unreasonable to obtain neuroimaging when potential explanations include diagnoses that must be managed emergently and for which the consequences of misdiagnosis are deterioration and death.

There are several limitations to this study. The prevalence of abusive head trauma in this population is unknown. Population-based reports published more than a decade ago indicate an incidence of approximately 1 in 3000 infants, but this rate primarily reflects fatal or severe abusive head trauma.[1,21,56-58] More recent studies of nonfatal abusive head trauma, based on the Centers for Disease Control and Prevention definition, suggest that abusive head trauma incidence may be higher.[21,22] Infants presenting to the ED for vague or neurologic complaints are a select group. Studies reporting abusive head trauma prevalence among infants presenting with apparent life-threatening events are retrospective, single-institution studies[23,59,60] performed before the terminology change from "apparent life-threatening events" to "brief resolved unexplained events."[61] Abusive head trauma prevalence in the PIBIS validation was >10%, but this is an overestimate, because 100% of patients diagnosed with abusive head trauma during the study period were enrolled, whereas controls were enrolled selectively.[12] In the rMRI-capable ED model, universal rMRI+CT is preferred for an abusive head trauma prevalence down to 0.8%.

Similarly, recurrent abusive head trauma risk in missed infants is unknown and outcomes in children with missed abusive head trauma who are never diagnosed are difficult to measure. Data were derived from studies of children diagnosed with abusive head trauma for whom missed opportunities for diagnosis were retrospectively identified.[3-5] To address these uncertainties, wide ranges for risks, costs, and utilities associated with missed abusive head trauma outcomes were tested in sensitivity analyses and did not impact model outcomes.

Clinical judgment parameters were based on the available literature. Rates of missed abusive head trauma were derived from studies of US children's hospitals and may not reflect rates in nonspecialized EDs.[3,4,6,25,62,63] The assumed 95% specificity for clinical judgment biases results in favor of this strategy. Despite this finding, clinical judgment was less effective than alternative strategies in all analyses. Varying the sensitivity of clinical judgement across the range of tested values did not change model outcomes.

We found a range of values reported for rMRI sensitivity and specificity for abusive head trauma, with more recent studies reflecting improved specificity.[13-15] In these studies, abnormal or equivocal rMRI findings were compared with CT imaging. Lindberg et al compared rMRI with CT in pediatric patients with known trauma, showed that rMRI was less sensitive for linear, nondepressed skull fractures, and was able to identify traumatic brain injury in 5 patients not identified with CTH.[18] More data are needed to fully define the optimal application of rMRI for abusive head trauma.

We assumed that all infants correctly diagnosed with abusive head trauma would attain full recovery, including a subset of those diagnosed after a recurrent abusive head trauma episode. We attempted to account for this by limiting our cohort to well-appearing infants, including the potential for long-term disability for those with missed abusive head trauma, including a 10% mortality risk among infants with repeat injury, and performing a sensitivity analysis in which correctly diagnosed infants did not return to their previous well state, but experienced a decreased quality of life. Abusive head trauma comprises a wide spectrum of severity. Inherent to the challenge of identification is that severely injured children may seem to be well. Reinjured children experience escalating morbidity and mortality.[4,5,64] Abusive head trauma sequela go beyond medical treatment and physical healing. Children who experience abuse may go on to develop epilepsy, visual impairment, and cognitive, behavioral, mood, and sleep disorders.[34,65,66] An added consideration of disease complexity, diagnostic challenges, and costs (in both quality of life and medical expenses) of missed abusive head trauma further supports the need to improve current practice.

We used a 1-year time horizon as the selected clinical scenario is unique to infancy. Because of this, the long-term negative impacts of death and radiation-induced cancer were accounted for using discounted lifetime QALYs lost. We did not model the lifetime negative impacts of abusive head trauma, biasing the analysis against strategies that minimize missed abusive head trauma.

We adapted utility values from the Glasgow Outcome Scale-Extended Pediatric utility weights. Infant health state utilities, particularly for victims of abuse, are poorly defined and understudied.[67] It is possible that an older child's experience with head injury or physical abuse is different from that of an infant. For this reason, selected utility values were varied over wide ranges. When lifetime disutility of radiation-induced cancer was <8.6 QALYs, universal HCT was preferred in the CT-only model. Varying remaining utility values did not change favored strategies (**Figure 2**).

We did not account for the societal impact of improved abusive head trauma identification with subsequent enlistment of police and social services. The short-term impact of these costs can be substantial and the long-term societal economic impact of abusive head trauma on educational expenses, economic contributions, and healthcare expenditures are difficult to quantify. Previous studies noted that the societal perspective weighs acute costs more heavily and could suggest an ethically concerning conclusion that abusive head trauma may be too expensive to diagnose.[17] This study focused on novel decision-making tools in the emergency setting, and how can we effectively and efficiently evaluate an infant with symptoms of neurologic pathology from the perspective of clinicians and health systems.

We used a healthcare perspective, which does not consider the perspectives of individual hospitals, providers, and patients. Although neuroimaging enhanced the more cost-effective strategies in these models, the ED length of stay associated with additional testing and radiologic image interpretation could be affected. Data from validation of the PIBIS score suggested that imaging frequency with PIBIS would not increase significantly beyond current practice.[12] Finally, we did not evaluate the perspective of families and caregivers, the costs of missed or lost employment, the impact on siblings in the home, or the aftereffects of a child abuse investigation, confirmed or not, on individuals and relationships.[24,68]

Our findings suggest that more sensitive detection strategies can improve diagnostic accuracy and decrease costs. In an ED setting with only CT available, PIBIS offers a more cost-effective identification strategy than clinical judgment. In an ED with rMRI availability, universal rMRI+CT is more effective than PIBIS and is economically favorable. ■

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Reprint requests: Kathleen A. Noorbakhsh, MD, Children's Hospital of Pittsburgh, 4401 Penn Ave, Pittsburgh, PA 15224. E-mail: Katie.Noorbakhsh@chp.edu

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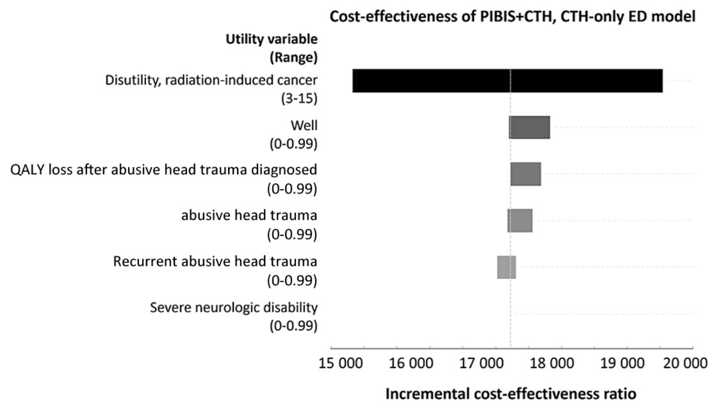

Figure 2. One-way sensitivity analyses of utility values tested across a range of plausible values. The impact on the incremental cost-effectiveness ratio for PIBIS+CT compared with the clinical judgement strategy in CT-only ED model is shown on the *x*-axis. Changing the value of the lifetime disutility associated with radiation-induced cancer shifts the incremental cost-effectiveness ratio by nearly $3000/QALY but does not cause PIBIS+CT to become less costly than CT. Changing other utility values had a smaller impact.

Table III. Outcomes by strategy in a population of 1000 infants with high-risk chief complaints, of whom 30 have abusive head trauma

Strategies	Abusive head trauma cases, n	Correctly diagnosed abusive head trauma	Missed abusive head trauma	Recurrent abusive head trauma	False-positive abusive head trauma	Radiation-induced cancer, %
Clinical judgement	30	70 (21)	30.0 (9)	17.1 (5)	<0.1 (0)	0.01
PIBIS+CTH	30	92 (28)	7.9 (2)	4.5 (1)	0.1 (1)	0.05
Universal CTH	30	99 (30)	1.0 (0)	<0.01 (0)	2.0 (19)	0.1
PIBIS+rMRI only	30	92 (28)	7.9 (2)	4.5 (1)	5.0 (44)	0
PIBIS+rMRI+CTH	30	91 (27)	8.8 (3)	5.1 (2)	0.2 (2)	0.01
Universal rMRI only	30	99 (30)	1.0 (0)	<0.01 (0)	9.5 (92)	0
Universal rMRI+CTH	30	98 (29)	2.0 (1)	<0.01 (0)	0.2 (2)	0.01

Values are percent (n) unless otherwise indicated.

Table IV. One-way sensitivity analysis results

Variables	Base case	Threshold	Preferred strategy: Below threshold	Preferred strategy: Above threshold
CTH-only ED				
Radiation-induced cancer				
Risk	0.1%	0.077%	Universal CTH	PIBIS+CTH
Disutility	9.9 QALY	7.7 QALY	Universal CTH	PIBIS+CTH
CTH specificity	98%	99.1%	Universal CTH	PIBIS+CTH
Risk of abusive head trauma	3%	3.5%	PIBIS+CTH	Universal CTH
Risk of abusive head trauma	3%	0.9%	Clinical judgement	PIBIS+CTH
rMRI-capable ED				
rMRI specificity	91%	99.3%	Universal rMRI+CTH	Universal rMRI only
PIBIS sensitivity	93%	98.0%	Universal rMRI+CTH	PIBIS+rMRI+CTH
Risk of abusive head trauma	3%	0.8%	PIBIS+rMRI+CTH	Universal rMRI+CTH

Table V. Cost-per-case analyses in a population of 1000 infants, of whom 30 have abusive head trauma

Strategies	Total cost per patient, $	Abusive head trauma correctly diagnosed, n	Cost per case correctly diagnosed, $	Recurrent abusive head trauma, n	Cost per recurrent abusive head trauma averted, $
Clinical judgement	1236	21	58 857	5	49 440
PIBIS+CTH	1560	28	55 714	1	53 793
Universal CTH	1865	30	62 167	0	62 167
PIBIS+rMRI only	2384	28	85 143	1	82 207
PIBIS+rMRI+CTH	1436	27	53 185	2	51 286
Universal rMRI only	3611	30	120 367	0	120 367
Universal rMRI+CTH	1596	29	55 034	0	53 200