Physical Examination Sensitivity for Skull Fracture in Pediatric Patients with Blunt Head Trauma: A Secondary Analysis of the National Emergency X-Radiography Utilization Study II Head Computed Tomography Validation Study

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Study objective: We evaluated the emergency department providers' ability to detect skull fractures in pediatric patients presenting with blunt head trauma.

Methods: This was a secondary analysis of the National Emergency X-Radiography Utilization Study (NEXUS) Head computed tomography (CT) validation study. Demographics and clinical characteristics were analyzed for pediatric patients. Radiologist interpretations of head CT imaging were abstracted and cataloged. Detection of skull fractures was evaluated through provider response to specific clinical decision instrument criteria (NEXUS or Canadian head CT rules) at the time of initial patient evaluation. The presence of skull fracture was determined by formal radiologist interpretation of CT imaging.

Results: Between April 2006, and December 2015, 1,018 pediatric patients were enrolled. One hundred twenty-eight (12.5%) children had a notable injury reported on CT head. Skull fracture was present in most (66.4%) children with intracranial injuries. The sensitivity and specificity of provider physical examination to detect skull fractures was 18.5% (95% confidence interval 10.5% to 28.7%) and 96.6% (95.3% to 97.7%), respectively. The most common injuries associated with skull fractures were subarachnoid hemorrhage (27%) and subdural hematoma (22.3%).

Conclusion: Skull fracture is common in children with intracranial injury after blunt head trauma. Despite this, providers were found to have poor sensitivity for skull fractures in this population, and these injuries may be missed on initial emergency department assessment. [Ann Emerg Med. 2022;■:1-9.]

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INTRODUCTION

Background

Pediatric traumatic brain injury is a major cause of morbidity and mortality in the pediatric population, accounting for over 600,000 emergency department (ED) visits annually.[1] The mainstay of diagnosis for these injuries is computed tomography (CT), and multiple clinical decision instruments have been developed to aid clinicians in determining which children can be safely discharged without imaging and its associated risk of malignant transformation.[2-14] Physical examination of the evidence of skull fracture is a common criterion among multiple clinical decision instruments derived from populations of patients with head injury, indicating its importance as a predictor of serious injury.[10,12,15,16]

Importance

Despite the emphasis on skull fractures in clinical decision instruments used to evaluate blunt head injury, there are limited data evaluating provider ability to detect these injuries. An inability to detect these injuries could lead to missed serious intracranial injuries. Therefore, further analysis of the frequency of skull fractures and providers' ability to detect them on initial examination may further our understanding of the evaluation of patients with head injury.

Editor's Capsule Summary

What is already known on this topic

The physical examination assessment for skull fracture is a required part of pediatric head computed tomography decision rules.

What question this study addressed

How accurate is the skull fracture examination in injured children?

What this study adds to our knowledge

In this secondary analysis of a rigorous, prospective database, there were 1,018 injured children of whom 85 (8.3%) had a radiographically verified skull fracture. Physical examination was 18.5% (10.8%, 28.7%) sensitive and 96.6% (95.3%, 97.7%) specific in identifying skull fracture.

How this is relevant to clinical practice

The physical examination for skull fracture has limits that can impact use in decision rule supported imaging.

Goals of This Investigation

This was a preplanned secondary analysis of the National Emergency X-Radiography Utilization Study (NEXUS) II Head CT Validation Study. The main goal of this study was to evaluate provider ability to detect skull fractures in pediatric patients presenting to the ED with blunt head trauma. In addition, this study sought to describe further the frequency and characteristics of skull fractures within a population of pediatric patients with head injury.

MATERIALS AND METHODS

Study Design and Setting

We performed a post hoc secondary analysis of pediatric patients from the validation studies of the NEXUS Head CT decision instrument.[7,14] The primary goal of the original study was to validate the previously derived NEXUS Head CT decision instrument, with a secondary goal of evaluating the performance of another previously derived clinical decision instrument, the Canadian CT Head rule.[10,15] Our current preplanned secondary analysis examines data from patients less than 18 years of age from this study. In addition, we retrospectively analyzed the prevalence of skull fractures and the provider's ability to detect these injuries.

The original study was performed in 4 EDs (Antelope Valley Hospital, Lancaster, CA; San Francisco General Hospital, San Francisco, CA; the University of California, Los Angeles Ronald Reagan Medical Center, Los Angeles, CA; University of California San Francisco Fresno Community Regional Medical Center, Fresno, CA) from April 2006 through December 2015. These centers encompass a wide variety of hospital environments, including community and academic hospitals, in differing geographic locations, including urban, suburban, and rural environments. The institutional review committees at each study center reviewed and approved the study protocol.

Selection of Participants

Consecutive pediatric patients under 18 years of age were eligible for enrollment if they presented with blunt head trauma being evaluated by CT head at one of the participating centers. Enrollment occurred at the time the CT order was placed by the provider. Patients were excluded for the following reasons: penetrating traumatic injuries, delayed presentations (more than 24 hours after injury), patients receiving imaging for reasons other than traumatic injury, and patients with known intracranial injuries transferred to one of the participating hospitals from an outside facility. In an effort to maximize provider compliance, a protocol was adopted to delay CT imaging from being performed until decision instrument criteria were assessed and recorded.[17] Providers were allowed to bypass the data collection and proceed immediately to imaging if they felt delay might harm the patient. In such cases, providers were instructed to obtain demographic and decision instrument criteria as soon as following possible enrollment. Imaging was ordered at the provider's discretion, and providers were cautioned against the sole use of decision instruments in determining which patients should receive imaging.

Methods of Measurement

The methodology for data collection has been previously published in detail.[14] Briefly, on enrollment, limited patient demographic data (age, sex, race, and ethnicity), as well as the criteria for each of the NEXUS and Canadian Head CT decision instruments, were recorded by the treating provider. The criteria for the decision instruments were deemed present, absent, or unable to be assessed. As part of this process, the provider was required to specifically document the presence of "signs of depressed or displaced skull fracture" and "signs of basilar skull fracture." Criteria that were unable to be assessed were deemed abnormal to maximize safety and ensure low-risk assignments were not based on missing data but rather on measured variables.

Outcome Measures

Formal radiographic interpretations and outcome assignments were performed without knowledge of the demographic or decision instrument criteria. Each patient was assigned to the following categories: (1) uninjured, (2) no significant injury (or minor injury), (3) significant injury, and (4) injury requiring neurosurgical intervention. Patients in the "significant injury" group included those who were also classified as "injury requiring neurosurgical intervention."

Patients were deemed to have a clinically significant head injury, as defined by Stiell et al,[15] which included all injuries found on CT head imaging except for the following injuries in patients with intact neurologic status: solitary small contusions, localized subarachnoid hemorrhage less than 1 mm thick, subdural hematoma less than 4 mm thick, isolated pneumocephaly, and closed depressed skull fractures that did not violate the inner table.

The need for neurosurgical intervention was defined as any of the following within 7 days of injury: (1) death because of head injury, (2) need for craniotomy, (3) elevation of skull fracture, (4) intubation related to head injury, or (5) intracranial pressure monitoring. Outcome assessments were performed by 2 separate reviewers, with a third independent reviewer assigning outcomes in instances of initial assignment discordance.

The detection of skull fracture on physical examination (index test) was based on responses to decision instrument criteria. Specifically, clinicians were asked to determine whether patients had evidence of skull fracture, which included signs of any of the following: basilar skull fracture, including ecchymosis in the periorbital or preauricular area, hemotympanum, and clear drainage from the ear or nose; depressed or diastatic skull fracture (palpable step-off, stellate laceration from a point source); or any injury produced by striking a localized region of the skull (including sports balls, club-like weapons, or other blunt objects). In addition, the presence of skull injury (reference standard) was determined by formal radiologist interpretation of the CT head images.

Abstraction of Radiographic Results and Mechanism

The CT head results from each of the injured patients within the study were independently abstracted by 1 of 3 study investigators (TEA, JLW, or WRM). Injuries were classified based on formal radiologist interpretations to include the classification of injury (subdural hematoma, epidural hematoma, nonspecific extraaxial injury, subarachnoid hemorrhage, parenchymal hemorrhage, parenchymal contusion, and diffuse axonal injury or diffuse edema, nondisplaced skull fracture, displaced skull fracture, depressed skull fracture, and basilar skull fracture) and their locations (frontal, temporal, parietal, falx, tentorium, Sylvian fissure, brainstem, intraventricular, brainstem, or cerebellum). Where present, midline shift and herniation were also noted.

A subset of radiographic interpretations (100 charts from the entire NEXUS II study population) was reviewed by 2 study investigators (TEA, JLW, or WRM) to assess for subjectivity bias. Interrater reliability was calculated based on a concordance of the injury's classification and location.

Data for the specific mechanism of injury were abstracted from the chart for all patients noted to have injuries. These were classified into the following categories: ground-level fall, fall from height, assault, motor vehicle accident, automobile versus pedestrian, or nonmotorized vehicle accident.

Primary Data Analysis

Data were abstracted manually and processed in Microsoft Excel software (Microsoft). Relative risks and operator characteristics were calculated using standard formulae. Study participants in whom the presence of skull fracture was recorded as "unknown" were excluded from the sensitivity and specificity analysis.

Evaluation of Verification Bias

Because all patients enrolled in the original study received CT head imaging, it is possible that some number of patients who went unimaged had significant, yet unrecognized, injuries. Therefore, we enrolled 118 pediatric patients who did not undergo CT imaging during their initial presentation to the University of California, Los Angeles ED between July 2011 and March 2015. To evaluate for potential verification bias because of patient selection, 3-month follow-up interviews were conducted, and reviews of the case and trauma logs were reviewed to identify any instances of significant injury or injury requiring neurosurgical intervention in this population.

Reporting Guidelines

Where applicable, we have followed the Standards for Reporting Diagnostic Accuracy (STARD) 2015 guidelines for reporting characteristics of diagnostic tests.

RESULTS

Characteristics of Study Subjects

Between April 2006 and December 2015, 1,160 patients were approached as part of the NEXUS validation study, of whom 1,018 had both clinical decision criteria completed and head CT results. Of these, 14 participants had the specific criterion for evidence of skull fracture marked as "unknown" and were therefore excluded from the test characteristic analysis (Figure).

The median age of all enrolled participants was 11.9 years (interquartile range, 4.5 to 15.5), and 64.7% were men (Table 1). The majority of participants were either non-Hispanic White (42.3%) or Hispanic (30.0%) patients. The cohort included 128 (12.5%) participants with any injury identified on a CT scan, of whom 85 (66% of all injured) had radiographically identified skull fractures and 18 (14% of all injured) had depressed or basilar skull fractures (median ages, 9 [3 to 14.9] and 10.5 [5.5 to 14.6] years, respectively).

Presenting characteristics of the patients are presented in Table 2. Overall, 23 of 1,018 (2.3%) participants were deemed to be unstable by initial provider evaluation, and 27 of 1,018 (2.7%) received a neurosurgical intervention. Among all injured children, 97 (75.8%) of 128 were deemed to have injuries caused by a dangerous mechanism. The most common abnormal examination finding was scalp hematoma which was present in 77 (60.2%) of 128 injured participants and 53 (62.4%) of 85 of those with skull fractures. Comorbidities were reported in 33 (3.2%) of 1,018 total participants, and 12 (1.2%) of 1,018 participants had concomitant coagulopathy. Fall from height and nonmotorized vehicle accidents were the most common presenting mechanisms, accounting for 31 (24.2%) and 25 (19.5%) of all injured, respectively.

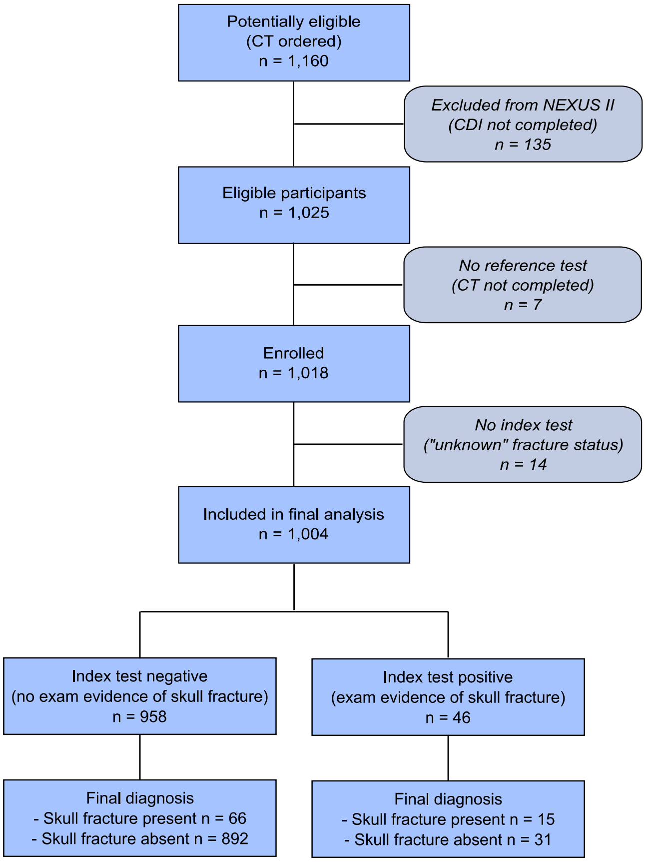

Figure. Study flow chart. *CDI*, Clinical decision instrument.

Main Results

The overall prevalence of skull fracture in patients with any injury was 66.4%, and basilar or depressed skull fractures were present in 14.0% (Table 3). Provider sensitivity and specificity for detection of any skull fracture was 18.5% (95% confidence interval [CI], 10.5% to 28.7%) and 96.6% (95.3% to 97.7%), respectively. Sensitivity and specificity of basilar or depressed skull fractures as 11.1% (1.4% to 34.7%) and 95.9% (94.5% to 97.1%). Additional test characteristics stratified by severity of the injury and tabular matrices are displayed in Table 3 and Table E1 (available online at http://www.annemergmed.com). Temporal and parietal bone fractures were most commonly identified on imaging (Table E2).

Table 4 displays additional injuries sustained by patients in our cohort. Pneumocephalus was present in 29 (34.1%) of 85 skull fractures and 9 (50%) of 18 depressed/basilar skull fractures. The most common injuries overall were subdural hematoma and subarachnoid hemorrhage, with 37 (28.9%) of 128 and 38 (29.6%) of 128 sustaining each, respectively. In patients with skull fractures, subarachnoid hemorrhage was the most common associated injury, present in 23 (27.1%) of 85 of all skull fractures and 8 (44.4%) of 18 of depressed/basilar skull fractures.

Verification Bias and Interrater Reliability

Given that not all patients enrolled in the study received a CT head, we performed an assessment of workup bias through case review and patient follow-ups. In our cohort, 118 patients did not receive a CT head on their initial assessment. However, in a review of the medical center logs of trauma service activations as well as case reviews, none of these patients were discovered to have an injury. Additionally, none of these patients were discovered to have injuries during the follow-up interview.

Our raters agreed on the exact number of injuries in 90% of cases and exhibited an intraclass correlation coefficient of 0.90. Raw agreements on the types and locations of injuries were 93% and 92%, respectively, with intraclass correlation coefficients of 0.89.

Table 1. Participant demographics.

Patient Characteristics	All Participants n=1,018		Uninjured n=890		Any Injury n=128		Any Skull Fracture n=85		Depressed/Basilar Skull Fracture n=18	
Age, y*	11.9 (4.5-15.5)		12 (4.9-15.5)		10 (3.3-15.2)		9 (3-14.9)		10.5 (5.5-14.6)	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Sex										
Male	659	(64.7)	570	(64.0)	89	(69.5)	59	(69.4)	14	(77.8)
Female	356	(35.0)	318	(35.7)	38	(29.7)	25	(29.4)	4	(22.2)
Unknown	3	(0.3)	2	(0.2)	1	(0.8)	1	(1.2)	0	(0.0)
Race/ethnicity										
Asian	41	(4.0)	33	(3.7)	8	(6.3)	7	(8.2)	1	(5.6)
Black	166	(16.3)	153	(17.2)	13	(10.2)	6	(7.1)	1	(5.6)
Hispanic	305	(30.0)	262	(29.4)	43	(33.6)	26	(30.6)	4	(22.2)
Middle Eastern	18	(1.8)	14	(1.6)	4	(3.1)	3	(3.5)	1	(5.6)
Native American	1	(0.1)	1	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)
Non-Hispanic White	431	(42.3)	375	(42.1)	56	(43.8)	40	(47.1)	11	(61.1)
Other	55	(5.4)	51	(5.7)	4	(3.1)	3	(3.5)	0	(0.0)
Unknown	1	(0.1)	1	(0.1)	0	(0.0)	0	(0.0)	0	(0.0)

*Median age in years (interquartile range).

LIMITATIONS

Our current study has several limitations, which we would like to acknowledge. Primarily, this study was a retrospective secondary analysis of a previously collected database of pediatric patients presenting with a blunt head injury. In addition, the original study was designed to test 2 clinical decision instruments which use evidence of skull fracture as one of several criteria and thus was not primarily designed to test detection of skull fracture per se. Despite this, the NEXUS and Canadian Head CT rules are frequently applied in direct patient care, and therefore we feel our study represents a real-world assessment of skull fracture detection by emergency providers.

Additionally, to be eligible for enrollment, all participants had to have a CT head obtained at the index visit. This has the potential to introduce verification bias into our results, because our study may have missed injuries on patients in whom CT was not obtained. We attempted to mitigate this by follow-up interview and review of trauma logs in which no undiagnosed injuries were discovered. Additionally, previous reports suggest that missed injuries are rare among pediatric patients.[18] Nevertheless, there is a chance a greater number of skull fractures were missed by providers. However, this would be unlikely to change the overall conclusion of our study, because provider detection of skull fractures was generally poor, and missed injuries would further reduce this sensitivity.

Our current evaluation relies on CT image reports and abstraction for confirmation of skull fracture. Although this is the currently accepted reference standard, our images were not independently reviewed or determined by consensus, which may have resulted in the incorrect assignment of injuries. Despite this possibility, reports of interobserver reliability for the detection of skull fractures by CT scan have generally been acceptable.[19,20] Additionally, analysis of our chart abstraction revealed sufficient interrater reliability for types of injuries.

Finally, the numbers of depressed and basilar skull fractures were low; therefore, precise estimations of provider detection of these injuries are somewhat limited. Indeed, the CIs for sensitivity for depressed or basilar skull fractures ranged from 1.4% to 34.7%. Nevertheless, should sensitivity be at the upper limit of our CI, this still amounts to a large number of missed fractures, supporting the conclusion that providers had poor sensitivity for these injuries in our study.

DISCUSSION

The present study is a secondary analysis of the NEXUS II database, evaluating emergency provider ability to detect

Table 2. Presenting characteristics and mechanisms of participants.

	All Participants		Uninjured		Any Injury		Any Skull Fracture		Depressed/Basilar Skull Fracture	
	n=1,018		n=890		n=128		n=85		n=18	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Presenting characteristics										
Unstable*	23	(2.3)	7	(0.8)	16	(12.5)	11	(12.9)	4	(22.2)
Intervention†	27	(2.7)	0	(0.0)	27	(21.1)	15	(17.6)	6	(33.3)
NEXUS positive	688	(67.6)	571	(64.2)	117	(91.4)	79	(92.9)	17	(94.4)
Ottawa positive-high risk	413	(40.6)	317	(35.6)	96	(75.0)	66	(77.6)	15	(83.3)
Ottawa positive-moderate risk	887	(87.1)	766	(86.1)	121	(94.5)	84	(98.8)	18	(100.0)
Scalp hematoma	364	(35.8)	287	(32.2)	77	(60.2)	53	(62.4)	12	(66.7)
Neurologic deficit	122	(12.0)	86	(9.7)	36	(28.1)	25	(29.4)	8	(44.4)
Abnormal level of alertness	269	(26.4)	209	(23.5)	60	(46.9)	35	(41.2)	10	(55.6)
Abnormal behavior	207	(20.3)	163	(18.3)	44	(34.4)	29	(34.1)	9	(50.0)
Recurrent/forceful vomiting	139	(13.7)	112	(12.6)	27	(21.1)	23	(27.1)	5	(27.8)
Coagulopathy‡	12	(1.2)	11	(1.2)	1	(0.8)	1	(1.2)	0	(0.0)
Comorbidity	33	(3.2)	27	(3.0)	6	(4.7)	2	(2.4)	1	(5.6)
Glascow Coma Scale 15	738	(72.5)	683	(76.7)	55	(43.0)	38	(44.7)	6	(33.3)
Eyes open spontaneously	911	(89.5)	821	(92.2)	90	(70.3)	62	(72.9)	12	(66.7)
Oriented	783	(76.9)	719	(80.8)	64	(50.0)	44	(51.8)	6	(33.3)
Obeys verbal commands	846	(83.1)	776	(87.2)	70	(54.7)	50	(58.8)	10	(55.6)
Amnesia >30 minutes	136	(13.4)	118	(13.3)	18	(14.1)	14	(16.5)	3	(16.7)
Dangerous mechanism	675	(66.3)	578	(64.9)	97	(75.8)	69	(81.2)	15	(83.3)
Mechanism§										
Ground-level fall	-	-	-	-	20	(15.6)	9	(10.6)	1	(5.6)
Fall from height	-	-	-	-	31	(24.2)	26	(30.6)	4	(22.2)
Assault	-	-	-	-	9	(7.0)	8	(9.4)	1	(5.6)
Motor vehicle accident	-	-	-	-	24	(18.8)	13	(15.3)	4	(22.2)
Automobile vs pedestrian	-	-	-	-	15	(11.7)	7	(8.2)	2	(11.1)
Nonmotorized vehicle accident	-	-	-	-	25	(19.5)	20	(23.5)	4	(22.2)
Unknown/other	-	-	-	-	4	(3.1)	2	(2.4)	2	(11.1)

*Patients deemed unstable by provider assessment and proceeded directly to CT scan followed by clinical decision instrument completion.
†Need for intervention was defined as death because of head injury, need for craniotomy or elevation of skull fracture, intracranial pressure monitoring, or intubation.
‡Coagulopathy defined as the use of anticoagulant or antiplatelet medications or inherited or acquired clotting impairment.
§Mechanism data abstracted only for injured patients.

skull fractures in blunt head trauma in pediatric patients. Despite the majority of patients with intracranial injuries having skull fractures detected on CT scans, we found providers had poor sensitivity for these injuries. Additionally, there was poor sensitivity for skull fractures classically associated with specific physical examination

Table 3. Test characteristics for provider detection of skull fractures.

	All Skull Fractures			Basilar or Depressed Skull Fractures		
Injury Category	% with Skull Fracture	Sensitivity %	Specificity %	% with Skull Fracture	Sensitivity %	Specificity %
All injuries	66.4	18.5 (10.8-28.7)	96.6 (95.3-97.7)	14.0	11.1 (1.4-34.7)	95.9 (94.5-97.1)
Minor injuries	69.6	11.3 (4.3-23.0)	95.5 (77.2-99.9)	13.9	12.5 (0.3-52.7)	96.7 (88.5-99.6)
Significant injuries	61.2	32.1 (15.9-52.4)	93.8 (69.8-99.8)	14.3	16.7 (0.4- 64.1)	93.6 (78.6-99.2)
Intervention	55.6	20.0 (4.3-48.1)	81.8 (48.2-97.7)	22.0	0.0 (0.0-52.2)	75.0 (50.9- 91.3)

Table 4. Associated injuries in patients with and without skull fractures.

	All Injuries		Injuries Without Skull Fracture		All Skull Fractures		Depressed/Basilar Skull Fracture	
	n=128		n=43		n=85		n=18	
Injury Classification	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
Pneumocephalus	30	(23.4)	1	(2.3)	29	(34.1)	9	(50.0)
Subdural hematoma	37	(28.9)	18	(41.9)	19	(22.4)	5	(27.8)
Epidural hematoma	21	(16.4)	3	(7.0)	18	(21.2)	2	(11.1)
Nonspecific extraaxial bleed	10	(7.8)	2	(4.7)	8	(9.4)	1	(5.6)
Subarachnoid hemorrhage	38	(29.7)	15	(34.9)	23	(27.1)	8	(44.4)
Parenchymal hemorrhage	21	(16.4)	5	(11.6)	16	(18.8)	6	(33.3)
Diffuse axonal injury/diffuse edema	2	(1.6)	1	(2.3)	1	(1.2)	1	(5.6)
Other bleed	3	(2.3)	1	(2.3)	2	(2.4)	1	(5.6)

findings (ie, depressed and basilar skull fractures). Overall, this suggests that providers evaluating pediatric patients presenting with blunt head trauma may miss a substantial number of skull fractures during their initial assessment.

Despite numerous studies indicating that examination evidence of skull fracture is predictive of intracranial injury, we are aware of few studies investigating provider ability to detect these injuries.[8,12,13,16,17] Interestingly, an evaluation by Tunik et al[21] of basilar skull fractures in a Pediatric Emergency Care Applied Research Network cohort indicated provider examination missed approximately 60% of these injuries. Of note, this study had a greater overall number and proportion of basilar skull fractures than our current report. This supports our current data that these injuries may be missed, even by providers employing decision instruments that include evidence of skull fracture as a criterion.

The reason for our demonstrated poor sensitivity to these injuries remains unclear. One simple possibility is that providers, in the presence of other high-risk features warranting CT imaging, were less likely to perform specific diagnostic examinations to seek out these injuries. However, our study did not include direct observation of provider examinations, making it difficult to evaluate whether this was the case. Another possibility is that, even in the presence of thorough examination, these injuries may be difficult to detect. In addition, studies from the otolaryngology literature suggest that specific examination findings may not always be present in patients with skull fractures. For instance, in a retrospective study of pediatric patients with known temporal bone fractures by Lee et al[22] bloody otorrhea was present in only 58% and hemotympanum in 81% despite excluding all patients who did not undergo a complete otolaryngologic examination. Another case series by Liu-Shindo et al[23] found hemotympanum in 58% of admitted pediatric patients with a basilar skull fracture, and none had the classic "Battle's sign." Finally, consistency between provider examinations may vary. Although certain studies have found good interobserver reliability for skull fracture in pediatric head trauma, others have demonstrated disagreement based on level of training, which could potentially account for varying sensitivity for these injuries.[24,25] Nevertheless, the precise reason for our demonstrated poor provider sensitivity remains undetermined.

The overall import of missed skull fractures in the context of blunt head trauma is an open question. In our study, all study participants presumed to have skull fractures received CT imaging, and to the best of our knowledge, based on our sensitivity analysis, no additional skull fractures were missed in patients in whom CT imaging was not performed. This implies that providers relied on other aspects of the history and examination to deem these patients high enough risk of intracranial injury to warrant imaging even in the absence of evidence of skull fracture. This may indicate that it is rare for patients with significant intracranial injury to have a skull fracture as an isolated finding and frequently these patients will have additional historical or examination findings which prompt CT imaging.

Finally, in the absence of additional intracranial pathology or altered mental status, patients with undetected skull fractures are likely to do well. Despite the possibility of serious complications such as growing fractures, cerebrospinal fluid leak, and meningitis, these appear to be rare.[26,27] Indeed, numerous studies have demonstrated few adverse outcomes in isolated linear fractures, pneumocephalus, and basilar skull fractures.[21,28-32] Thus, failure to detect these injuries may not alter the clinical course of otherwise well-appearing patients and may call into question the importance of provider sensitivity for these injuries.

In conclusion, we performed a secondary analysis of pediatric patients in the NEXUS II Head CT validation study. Our present analysis reveals that skull fractures were common in patients in this cohort who had concomitant intracranial injuries. In addition, we found that emergency clinicians had poor sensitivity for detecting skull fractures, with lower sensitivity for basilar or depressed skull fractures. Overall, this suggests that emergency clinicians could potentially miss skull fractures in pediatric patients presenting with blunt head trauma, though the overall impact of these missed injuries is uncertain.

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All authors attest to meeting the four ICMJE.org authorship criteria: (1) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (2) Drafting the work or revising it critically for important intellectual content; AND (3) Final approval of the version to be published; AND (4) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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REFERENCES

1. Taylor CA, Bell JM, Breiding MJ, et al. Traumatic brain injury–related emergency department visits, hospitalizations, and deaths — United States, 2007 and 2013. *MMWR Surveill Summ*. 2017;66:1-16.
2. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380:499-505.
3. Huang WY, Muo CH, Lin CY, et al. Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. *Br J Cancer*. 2014;110:2354-2360.
4. Mathews JD, Forsythe AV, Brady Z, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *BMJ*. 2013;346:f2360.
5. Bozan Ö, Aksel G, Kahraman HA, et al. Comparison of PECARN and CATCH clinical decision rules in children with minor blunt head trauma. *Eur J Trauma Emerg Surg*. 2019;45:849-855.
6. Dunning J, Daly JP, Lomas JP, et al. Derivation of the children's head injury algorithm for the prediction of important clinical events decision rule for head injury in children. *Arch Dis Child*. 2006;91:885-891.
7. Gupta M, Mower WR, Rodriguez RM, et al. Validation of the pediatric NEXUS II head computed tomography decision instrument for selective imaging of pediatric patients with blunt head trauma. *Acad Emerg Med*. 2018;25:729-737.
8. Kuppermann N, Holmes JF, Dayan PS, et al. Identification of children at very low risk of clinically important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374:1160-1170.
9. Lyttle MD, Cheek JA, Blackburn C, et al. Applicability of the CATCH, CHALICE and PECARN paediatric head injury clinical decision rules: pilot data from a single Australian centre. *Emerg Med J*. 2013;30:790-794.
10. Mower WR, Hoffman JR, Herbert M, et al. Developing a decision instrument to guide computed tomographic imaging of blunt head injury patients. *J Trauma*. 2005;59:954-959.
11. Oman JA, Cooper RJ, Holmes JF, et al. Performance of a decision rule to predict need for computed tomography among children with blunt head trauma. *Pediatrics*. 2006;117:e238-e246.
12. Osmond MH, Klassen TP, Wells GA, et al. CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. *CMAJ*. 2010;182:341-348.
13. Palchak MJ, Holmes JF, Vance CW, et al. A decision rule for identifying children at low risk for brain injuries after blunt head trauma. *Ann Emerg Med*. 2003;42:492-506.
14. Mower WR, Gupta M, Rodriguez R, et al. Validation of the sensitivity of the National Emergency X-Radiography Utilization Study (NEXUS) Head computed tomographic (CT) decision instrument for selective imaging of blunt head injury patients: an observational study. *PLOS Med*. 2017;14:e1002313.
15. Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet*. 2001;357:1391-1396.
16. Atabaki SM, Stiell IG, Bazarian JJ, et al. A clinical decision rule for cranial computed tomography in minor pediatric head trauma. *Arch Pediatr Adolesc Med*. 2008;162:439-445.
17. Mower WR, Hoffman JR, Herbert M, et al. Developing a clinical decision instrument to rule out intracranial injuries in patients with minor head trauma: methodology of the NEXUS II investigation. *Ann Emerg Med*. 2002;40:505-514.
18. Mower WR. Improving patient selection for pediatric computed tomographic head imaging. *Ann Emerg Med*. 2019;74:820-821.

19. Chun KA, Manley GT, Stiver SI, et al. Interobserver variability in the assessment of CT imaging features of traumatic brain injury. *J Neurotrauma*. 2010;27:325-330.
20. Pennell C, Aundhia M, Malik A, et al. Utility of skull radiographs in infants undergoing 3D head CT during evaluation for physical abuse. *J Pediatr Surg*. 2021;56:1180-1184.
21. Tunik MG, Powell EC, Mahajan P, et al. Clinical presentations and outcomes of children with basilar skull fractures after blunt head trauma. *Ann Emerg Med*. 2016;68:431-440.e1.
22. Lee D, Honrado C, Har-El G, et al. Pediatric temporal bone fractures. *Laryngoscope*. 1998;108:816-821.
23. Liu-Shindo M, Hawkins DB. Basilar skull fractures in children. *Int J Pediatr Otorhinolaryngol*. 1989;17:109-117.
24. Gorelick MH, Atabaki SM, Hoyle J, et al. Interobserver agreement in assessment of clinical variables in children with blunt head trauma. *Acad Emerg Med*. 2008;15:812-818.
25. Duncan E, Mojica M, Ching K, et al. Low concordance between pediatric emergency attendings and pediatric residents for predictors of serious intracranial injury. *Pediatr Emerg Care*. 2022;38:e422-e425.
26. McCutcheon BA, Orosco RK, Chang DC, et al. Outcomes of isolated basilar skull fracture: readmission, meningitis, and cerebrospinal fluid leak. *Otolaryngol Head Neck Surg*. 2013;149:931-939.
27. Ersahin Y, Gülmen V, Palali I, et al. Growing skull fractures (craniocerebral erosion). *Neurosurg Rev*. 2000;23:139-144.
28. Powell EC, Atabaki SM, Wootton-Gorges S, et al. Isolated linear skull fractures in children with blunt head trauma. *Pediatrics*. 2015;135:e851-e857.
29. Blackwood BP, Bean JF, Sadecki-Lund C, et al. Observation for isolated traumatic skull fractures in the pediatric population: unnecessary and costly. *J Pediatr Surg*. 2016;51:654-658.
30. Rollins MD, Barnhart DC, Greenberg RA, et al. Neurologically intact children with an isolated skull fracture may be safely discharged after brief observation. *J Pediatr Surg*. 2011;46:1342-1346.
31. Blanchard A, Cabrera KI, Kuppermann N, et al. Acute outcomes of isolated Pneumocephali in children after minor blunt head trauma. *Pediatr Emerg Care*. 2018;34:656-660.
32. Kadish HA, Schunk JE. Pediatric basilar skull fracture: do children with normal neurologic findings and no intracranial injury require hospitalization? *Ann Emerg Med*. 1995;26:37-41.