PECARN prediction rule for cervical spine imaging of children presenting to the emergency department with blunt trauma: a multicentre prospective observational study

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Summary

Background Cervical spine injuries in children are uncommon but potentially devastating; however, indiscriminate neck imaging after trauma unnecessarily exposes children to ionising radiation. The aim of this study was to derive and validate a paediatric clinical prediction rule that can be incorporated into an algorithm to guide radiographic screening for cervical spine injury among children in the emergency department.

Methods In this prospective observational cohort study, we screened children aged 0–17 years presenting with known or suspected blunt trauma at 18 specialised children's emergency departments in hospitals in the USA affiliated with the Pediatric Emergency Care Applied Research Network (PECARN). Injured children were eligible for enrolment into derivation or validation cohorts by fulfilling one of the following criteria: transported from the scene of injury to the emergency department by emergency medical services; evaluated by a trauma team; and undergone neck imaging for concern for cervical spine injury either at or before arriving at the PECARN-affiliated emergency department. Children presenting with solely penetrating trauma were excluded. Before viewing an enrolled child's neck imaging results, the attending emergency department clinician completed a clinical examination and prospectively documented cervical spine injury risk factors in an electronic questionnaire. Cervical spine injuries were determined by imaging reports and telephone follow-up with guardians within 21–28 days of the emergency room encounter, and cervical spine injury was confirmed by a paediatric neurosurgeon. Factors associated with a high risk of cervical spine injury (>10%) were identified by bivariable Poisson regression with robust error estimates, and factors associated with non-negligible risk were identified by classification and regression tree (CART) analysis. Variables were combined in the cervical spine injury prediction rule. The primary outcome of interest was cervical spine injury within 28 days of initial trauma warranting inpatient observation or surgical intervention. Rule performance measures were calculated for both derivation and validation cohorts. A clinical care algorithm for determining which risk factors warrant radiographic screening for cervical spine injury after blunt trauma was applied to the study population to estimate the potential effect on reducing CT and x-ray use in the paediatric emergency department. This study is registered with ClinicalTrials.gov, NCT05049330.

Findings Nine emergency departments participated in the derivation cohort, and nine participated in the validation cohort. In total, 22 430 children presenting with known or suspected blunt trauma were enrolled (11 857 children in the derivation cohort; 10 573 in the validation cohort). 433 (1·9%) of the total population had confirmed cervical spine injuries. The following factors were associated with a high risk of cervical spine injury: altered mental status (Glasgow Coma Scale [GCS] score of 3–8 or unresponsive on the Alert, Verbal, Pain, Unresponsive scale [AVPU] of consciousness); abnormal airway, breathing, or circulation findings; and focal neurological deficits including paresthesia, numbness, or weakness. Of 928 in the derivation cohort presenting with at least one of these risk factors, 118 (12·7%) had cervical spine injury (risk ratio 8·9 [95% CI 7·1–11·2]). The following factors were associated with non-negligible risk of cervical spine injury by CART analysis: neck pain; altered mental status (GCS score of 9–14; verbal or pain on the AVPU; or other signs of altered mental status); substantial head injury; substantial torso injury; and midline neck tenderness. The high-risk and CART-derived factors combined and applied to the validation cohort performed with 94·3% (95% CI 90·7–97·9) sensitivity, 60·4% (59·4–61·3) specificity, and 99·9% (99·8–100·0) negative predictive value. Had the algorithm been applied to all participants to guide the use of imaging, we estimated the number of children having CT might have decreased from 3856 (17·2%) to 1549 (6·9%) of 22 430 children without increasing the number of children getting plain x-rays.

Interpretation Incorporated into a clinical algorithm, the cervical spine injury prediction rule showed strong potential for aiding clinicians in determining which children arriving in the emergency department after blunt trauma should undergo radiographic neck imaging for potential cervical spine injury. Implementation of the clinical algorithm could decrease use of unnecessary radiographic testing in the emergency department and eliminate high-risk radiation exposure. Future work should validate the prediction rule and care algorithm in more general settings such as community emergency departments.

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Introduction

Cervical spine injuries in children are serious but uncommon.[1–3] Emergency department clinicians often fear missing these injuries and opt for plain radiographs (x-rays) and CT scans to evaluate children presenting with blunt trauma.[4–11] In the USA, more than 8 million injured children are evaluated for potential cervical spine injury annually, yet fewer than 1% will have cervical spine injuries.[2,12] CT is often preferred for imaging a child with potential cervical spine injury due to apprehension regarding x-ray interpretability of the immature spine.[4–8] Unfortunately, CT is associated with substantial radiation exposure, and neck CT is particularly concerning due to well documented age-related radiation sensitivity and malignancy risk.[13–17] The incidence of cancer within the first decade is 24% higher among children who had CT imaging than among unexposed children.[14] A single cervical spine CT scan in childhood increases the lifetime risk of thyroid cancer by 78%.[14]

Cervical spine injury prediction rules for adults with trauma were developed to reduce radiographic testing without missing injuries. The National Emergency X-ray Utilization Study (NEXUS) prediction rule demonstrated 100% sensitivity for cervical spine injury when used by emergency physicians.[18] The Canadian C-spine Rule (CCR), similarly, had nearly 100% sensitivity for cervical spine injury when used by emergency department physicians on alert and stable adult patients with trauma.[19] However, NEXUS included only 30 children (aged 2–17 years) with cervical spine injuries, and CCR excluded children altogether.[2,19] Preverbal children who rarely experience cervical spine injuries but are potentially at greatest risk of inappropriate imaging are particularly under-represented in research to date.[2,14,16,20] A recent multicentre retrospective cohort study, PEDSPINE, evaluated a risk scoring system for cervical spine injury in children younger than 3 years, but it had only modest sensitivity (75·9%).[21] Because of age-related differences in anatomy, injury patterns, and ability to report symptoms, prospective derivation and validation of a cervical spine injury prediction rule for children is warranted.[1,22,23] Early attempts to prospectively develop clinical screening criteria specific to children have been limited by small cohort sizes and few children with cervical spine injuries.[20]

The Pediatric Emergency Care Applied Research Network (PECARN) has been systematically developing a paediatric cervical spine injury risk assessment tool.[22,24–28] Using case–control methods, we identified initial risk factors for cervical spine injury.[26] A pilot study subsequently established a multicentre, prospective, observational infrastructure and showed the test accuracy of risk factors identified in the original case–control study within the setting of a relatively small multicentre cohort.[24,25] The aim of this present study was to prospectively derive and validate a clinical prediction rule

Research in context

Evidence before this study

While we did not conduct a systematic review before this study, our previous work indicates that CT scans of the neck are overused in emergency departments during paediatric blunt trauma evaluation. Indiscriminate use of CT scans unnecessarily exposes children to ionising radiation and cancer risk. Although there are validated clinical prediction rules to guide the use of CT scans for cervical spine injury screening in adults, no such rules are available for paediatric emergency care. Our PECARN pilot work suggested that it was feasible to develop a clinically sensible and useful clinical prediction rule, leading to the present study.

Added value of this study

In this multicentre prospective observational study of 22 430 children with blunt trauma arriving at PECARN-affiliated children's hospitals with dedicated trauma centres across the USA, we derived and validated an accurate cervical spine injury prediction rule, which performed with a sensitivity of 94·3% (95% CI 90·7–97·9), specificity of 60·4% (59·4–61·3), and negative predictive value of 99·9% (99·8–100·0). The rule is clinically sensible, relying solely on the child's symptoms and results of a physical examination upon arrival in the emergency department. When incorporated into a clinical care algorithm, the cervical spine injury prediction rule showed promising potential for reducing unnecessary use of CT without increasing use of plain x-ray.

Implications of all the available evidence

Incorporating the cervical spine injury prediction rule into a clinical care algorithm to guide neck imaging in children presenting to an emergency department with known or suspected blunt trauma could substantially improve the quality of their clinical care and reduce unnecessary radiation exposure. Future work is needed to validate the cervical spine injury prediction rule and the rule-based imaging algorithm in non-PECARN settings, such as community emergency departments, and to determine the best methods for implementing this rule into emergency care.

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for cervical spine injury after blunt trauma in a large and diverse sample of injured children and to create a definitive decision aid for risk stratifying children for neck imaging.

Methods

Study design and participants

In this prospective observational study, we screened children aged 0–17 years presenting at PECARN-affiliated children's hospitals with dedicated emergency departments across the USA. All participating emergency departments are level-1 paediatric trauma centres. Nine sites enrolled in the derivation cohort and nine sites enrolled in the validation cohort. We enrolled children with known or suspected exposure to blunt trauma and who met at least one of the following criteria: evaluation by a trauma team; transported from the scene of injury to the participating hospital by emergency medical services; underwent cervical spine imaging at the participating hospital; underwent cervical spine imaging before transfer to the participating hospital. No exclusion was made on the basis of the child's sex, race, ethnic group, or language skills. We excluded children with solely penetrating trauma (eg, gunshot or stab wound).

This study was approved by PECARN's single Institutional Review Board at the University of Utah (Salt Lake City, UT, USA) with a waiver of informed consent for prospective observational data collection and medical record review and waiver of written consent for parental telephone follow-up. The study was registered with ClinicalTrials.gov, NCT05049330.

Procedures

Trained site research coordinators screened children for eligibility and enrolled patients by providing the treating emergency department clinician with an electronic questionnaire to complete. The electronic questionnaire confirmed study eligibility and gathered information about a fixed list of potential cervical spine injury risk factors that have high clinical plausibility and inter-rater reliability based on previous PECARN research.[1,2,22,24–28] When possible, the electronic questionnaire was administered before viewing the results of cervical spine imaging (if obtained). The list of potential risk factors included predisposing conditions, injury mechanism, neck and neurological complaints, and regionalised physical examination findings (head, torso, and spine).[25,26] Only substantial injuries warranting inpatient observation or surgical intervention were codified in these latter physical examination categories. The questionnaire also provided clinicians with examples of substantial injuries for each body region (eg, skull fracture; pneumothorax; signs of solid organ injury; thoracic, lumbar, or sacral spine fracture; and pelvic fracture). We also collected information on potential effect modifiers and confounders including demographics, mechanism of injury, mode of arrival, and predisposing conditions. To minimise the risk for missing data, clinicians were not able to skip questions in the questionnaire.

Outcomes

The primary outcome of interest was cervical spine injury, defined as fractures or ligamentous injuries of the cervical spine, cervical intraspinal haemorrhage or vertebral artery injury, or cervical spinal cord injury, including changes in the cervical spinal cord on MRI or cervical spinal cord injury without radiographic association.

To determine the presence of cervical spine injury, the child's hospital medical record was reviewed 21–28 days after the emergency department encounter. If available, neck imaging reports and surgical consultation notes were systematically reviewed by the lead site research coordinator and site principle investigator, and cervical spine injury was classified as being present or absent. A single central study adjudicator, a paediatric neurosurgeon, reviewed neck imaging reports and surgical consultation notes (if applicable) to confirm cervical spine injury. If there was inconsistent documentation regarding the presence or absence of cervical spine injury, the treating spine surgeon was contacted for final determination of injury status. If no imaging was obtained, guardians were contacted by telephone to determine whether a cervical spine injury was subsequently diagnosed. All research personnel who categorised the outcome were blinded to the clinical predictors codified by the emergency department providers in the electronic questionnaires.

Statistical analysis

The enrolled study population was divided into derivation and validation cohorts. We powered the derivation of the prediction rule to provide a narrow confidence bound of the point estimate of the sensitivity. We planned for a derivation cohort of 13 333 children, assuming that 240 children would have cervical spine injury, such that one misclassified injury would result in a prediction rule sensitivity of 99·6% and a one-sided CI with a lower bound of 97·8%.

We enrolled children from a separate group of emergency departments into the validation cohort over a later period. Enrolment into the validation cohort continued until it was at least two-thirds the size of the planned derivation cohort (ie, estimated 8889 children, of whom 160 would have cervical spine injuries).

Study population variables were dichotomised (ie, present or absent) or analysed as discrete categories and summarised with counts and percentages. Associations between candidate risk factors, modifiers, confounders, and confirmed cervical spine injuries were analysed by Pearson χ^2 test or Fisher's exact test (as appropriate) and presented as bivariable risk ratios with 95% CIs.

The prediction rule was constructed using data from the derivation cohort by first evaluating the bivariable association of individual variables with cervical spine injury and retaining those with p values of less than 0·15 for subsequent modelling. A clinically sensible variable subset was individually selected to identify children whose risk of cervical spine injury exceeded 10%, a risk at which a cost-effectiveness analysis[29] has shown that screening with CT outweighs the risk of future malignancy. The strength of association of these high-risk variables was confirmed as significant with bivariable Poisson regression with robust error estimates. These variables were then used to categorise participants to the high-risk cervical spine injury group; these participants were removed from further analysis. The remaining participants in the derivation cohort were evaluated by binary recursive partitioning using classification and regression tree (CART) analysis to identify non-negligible risk factors for cervical spine injury. Demographic variables and the event of loss of consciousness were excluded from the CART analysis in model pruning to improve performance. Ten-fold cross-validation was used to tune tree parameters for a more generalisable rule. In the CART analysis, we applied a misclassification cost of 250 to one for failure to identify a patient with cervical spine injury versus incorrect classification of a patient without cervical spine injury.

Rule performance measures and associated 95% CIs were calculated by applying the derived prediction rule to the derivation and validation cohorts. Sensitivity, the ability of the prediction rule to accurately identify children with cervical spine injuries, was calculated as the proportion of children with cervical spine injuries who presented with at least one of the rule's risk factors. Specificity, the ability of the prediction rule to accurately identify children without cervical spine injuries, was calculated as the proportion of children without cervical spine injuries who did not have any of the rule's risk factors. We also derived positive predictive value (PPV), the proportion of children with cervical spine injuries who presented with least one of the rule's risk factors, and negative predictive value (NPV), the proportion of children who did not have cervical spine injuries and who did not present with any of the rule's risk factors.

We performed a medical record review of participants in the derivation and validation cohorts who had been misclassified by the derived prediction rule. To evaluate the effect of potential bias in data collection and inclusion criteria, we evaluated the test characteristics of the prediction rule when applied to specific subsets of children. These subsets excluded children with suspected child abuse (for whom the time of injury and injury mechanism are unknown), children transferred to the study site from other emergency departments, children whose data collection occurred after cervical spine imaging results were known, and children aged 9–17 years who might have findings more like those of adults.

Using the prediction rule factors, we developed a clinical care algorithm for determining which children warrant radiographic screening for cervical spine injury after blunt trauma. On the basis of a previous cost-effectiveness analysis, we constructed the imaging algorithm to recommend CT for children presenting with high-risk factors and plain x-rays for children presenting with non-negligible risk factors identified in the CART analysis. In order to quantify the algorithm's potential effect on imaging decisions, we grouped participants into three mutually exclusive groups: no imaging (clinically cleared), cervical spine x-rays obtained, and cervical spine CT with or without x-rays. We then calculated the imaging rates observed in the study population and the imaging rates associated with applying the algorithm to the study

	Enrolment status		Cohort	
	Enrolled (n=22 430)	Missed eligible (n=9837)	Derivation (n=11 857)	Validation (n=10 573)
Age, years				
0–8	11 633 (51·9%)	5347 (54·4%)	5982 (50·5%)	5651 (53·4%)
9–17	10 797 (48·1%)	4478 (45·5%)	5875 (49·5%)	4922 (46·6%)
Sex				
Female	9362 (41·7%)	4126 (41·9%)	5002 (42·2%)	4360 (41·2%)
Male or undifferentiated	13 068 (58·3%)	5711 (58·1%)	6855 (57·8%)	6213 (58·8%)
Race				
White	10 906 (48·6%)	4769 (48·5%)	6471 (54·6%)	4435 (41·9%)
Black or African American	6793 (30·3%)	2840 (28·9%)	2693 (22·7%)	4100 (38·8%)
Other	3539 (15·8%)	1627 (16·5%)	1887 (15·9%)	1652 (15·6%)
Ethnicity				
Hispanic or Latino	4330 (19·3%)	2154 (21·9%)	1712 (14·4%)	2618 (24·8%)
Other	18 100 (80·7%)	7683 (78·1%)	10 145 (85·6%)	7955 (75·2%)
Mechanism of injury				
Motor vehicle crash (driver or passenger)	6358 (28·3%)	2680 (27·2%)	3129 (26·4%)	3229 (30·5%)
Motorcycle, all-terrain vehicle, or motorised scooter crash, etc.	1250 (5·6%)	512 (5·2%)	662 (5·6%)	588 (5·6%)
Hit by car or other motor vehicle (pedestrian, cyclist, or other)	1455 (6·5%)	408 (4·1%)	667 (5·6%)	788 (7·5%)
Fall	7444 (33·2%)	3371 (34·3%)	3897 (32·9%)	3547 (33·5%)
Diving	38 (0·2%)	15 (0·2%)	25 (0·2%)	13 (0·1%)
Sports or recreation related	2219 (9·9%)	1047 (10·6%)	1348 (11·4%)	871 (8·2%)
Suspected child abuse	1327 (5·9%)	912 (9·3%)	954 (8·0%)	373 (3·5%)
Assault or altercation	535 (2·4%)	87 (0·9%)	235 (2·0%)	300 (2·8%)
Emergency medical service scene response	13 453 (60·0%)	537 (5·5%)	6863 (57·9%)	6590 (62·3%)
Emergency department disposition				
Discharged home	14 948 (66·6%)	5717 (58·1%)	7531 (63·5%)	7417 (70·2%)
Admitted to intensive care unit	1614 (7·2%)	709 (7·2%)	1078 (9·1%)	536 (5·1%)
Admitted to hospital floor	5038 (22·5%)	2831 (28·8%)	2742 (23·1%)	2296 (21·7%)
Admitted to operating room	618 (2·8%)	277 (2·8%)	384 (3·2%)	234 (2·2%)
Death in the emergency department	43 (0·2%)	35 (0·4%)	23 (0·2%)	20 (0·2%)
Other	169 (0·8%)	256 (2·6%)	99 (0·8%)	70 (0·7%)
Cervical spine injury	433 (1·9%)	147 (1·5%)	274 (2·3%)	159 (1·5%)

Data are n (%). Percentages might not sum to 100 as a result of rounding.

Table 1: **Participant characteristics by enrolment status and cohort**

	Cervical spine injury (n=274)	No cervical spine injury (n=11 583)	Risk ratio (95% CI)	p value
Glasgow Coma Scale score: 3–8	72 (26·3%)	227 (2·0%)	13·8 (10·8–17·6)	<0·0001
Alert, Verbal, Pain, Unresponsive scale: unresponsive	49 (17·9%)	139 (1·2%)	13·5 (10·3–17·8)	<0·0001
Abnormal airway, breathing or circulation	92 (33·6%)	500 (4·3%)	9·6 (7·6–12·2)	<0·0001
Focal neurological deficit on examination (paresthesia, numbness, or weakness)	35 (12·8%)	324 (2·8%)	4·7 (3·3–6·6)	<0·0001
Any of the above	118 (43·1%)	810 (7·0%)	8·9 (7·1–11·2)	<0·0001

Data are n (%) unless indicated otherwise. Risk ratio (95% CI) were derived from unadjusted Poisson regression with robust error estimates.

***Table 2:* Cervical spine injury risk factors and risk ratio for high-risk variables in the derivation cohort**

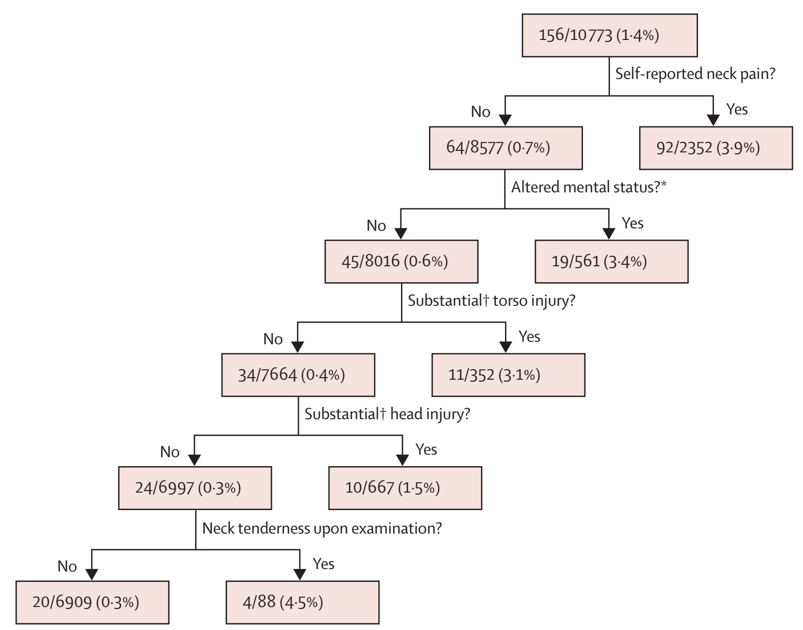

***Figure 1:* Cervical spine injury classification and regression tree**
Data are n/N (%). The classification tree was derived from the data extracted from participants in the derivation cohort who did not meet any of the high-risk findings (Glasgow Coma Scale of 3–8; unresponsive on the Alert, Verbal, Pain, Unresponsive scale; observed abnormal airway, breathing, or circulation findings; or observed focal neurological deficits on examination). Numerators in each of the nodes represent cervical spine injury. *Altered mental status was defined as Glasgow Coma Scale score of 9–14; verbal or pain on the Alert, Verbal, Pain, Unresponsive scale; or other signs of altered mental status. †Substantial injuries were those that warranted inpatient observation or surgical intervention.

See Online for appendix

population. We used Minitab (version 20.2) for the CART analysis and SAS (version 9.4) for all other analyses.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Derivation sites enrolled participants between Dec 11, 2018, and Oct 31, 2021, and the validation sites enrolled participants between July 22, 2020, and Dec 31, 2021. 26 935 children were screened for the derivation cohort, 16 206 (60·2%) of whom were eligible. 11 857 (73·2%) eligible children were enrolled (appendix p 1). 23 320 children were screened for the validation cohort, 16 061 (68·9%) of whom were eligible. 10 573 (65·8%) eligible children were enrolled. Enrolled children were similar to eligible patients who were not enrolled in age, sex, race, ethnicity, injury mechanism, and emergency department disposition (table 1). The prevalence of cervical spine injury was higher among enrolled children than among those who were eligible but not enrolled (1·9% [95% CI 1·8–2·1] *vs* 1·5% [1·3–1·7]).

Of the 22 430 children enrolled in both the derivation and validation cohorts, 11 633 (51·9%) were aged 0–8 years table 1). Falls and motor vehicle crashes were the most common injury mechanisms. Children in the validation cohort were less frequently admitted to the intensive care unit or operating room than those in the derivation cohort. Cervical spine injury was more common in the derivation cohort than in the validation cohort (274 [2·3%] of 11 857 children *vs* 159 [1·5%] of 10 573 children).

51 of the 62 candidate variables met the threshold for consideration for the prediction rule. Bivariable associations with cervical spine injury are shown in the appendix (p 2). Notable variables not meeting this threshold included hanging or strangulation mechanisms, predisposing conditions including history of cervical spine injury, and suspicion of intoxication on examination. Age but not sex was associated with cervical spine injury.

Four high-risk factors detected among 928 children were selected for the prediction rule (table 2). These physical examination findings are easily recognised upon a child's initial presentation to the emergency department and include Glasgow Coma Scale (GCS) score of 3–8 or unresponsive on the Alert, Verbal, Pain, Unresponsive scale (AVPU) of consciousness; abnormal airway, breathing, or circulation; or focal neurological deficits including paresthesia, numbness, or weakness. Participants with any one of these factors had a greater risk of cervical spine injury than those without any of these factors (118 of 928 [12·7%]; risk ratio 8·9 [95% CI 7·1–11·2]) and were designated as high-risk factors for cervical spine injury.

After removing children with any of the high-risk factors (n=928), data from the remaining 10 929 children were analysed to identify variables associated with non-negligible risk of cervical spine injury by CART. An additional five variables were identified as important for classifying those at risk for cervical spine injury: neck pain, altered mental status (GCS score of 9–14; verbal or pain on AVPU; or other signs of altered mental status), substantial torso injury, substantial head injury, and posterior midline neck tenderness (figure 1). The four high-risk factors and the five CART-derived factors were combined into a nine-factor prediction rule, which in the validation cohort had a sensitivity of 94·3% (95% CI

90·7–97·9), specificity of 60·4% (59·4–61·3), and NPV of 99·9% (99·8–100·0; table 3).

29 children with cervical spine injuries had none of the final nine risk factors derived for the prediction rule (appendix p 5). However, upon retrospective review, 20 (69%) of 29 children had at least one risk factor recorded in the emergency department medical record or on paired case report forms from emergency medical services or surgical clinicians. None of the remaining nine children with cervical spine injuries that were missed by clinician case report forms and retrospective chart review required surgical intervention.

In all four subanalyses completed on the combined derivation and validation cohorts, the prediction rule test characteristics were similar to the overall test characteristics (appendix p 7). When children with suspected child abuse were removed from the cohort, the rule sensitivity was 92·8% (95% CI 90·3–95·3) and NPV was 99·8% (99·7–99·8). For children not transferred from outside facilities, the rule had a sensitivity of 91·5% (95% CI 88·0–95·0) and NPV of 99·8% (99·7–99·9). For children whose emergency department clinicians' observations were collected before knowledge of cervical spine imaging results, the rule had a sensitivity of 93·0% (95% CI 89·8–96·2) and NPV of 99·9% (99·8–99·9). For children aged 0–8 years, the rule sensitivity was 92·7% (95% CI 89·1–96·4) and NPV was 99·8% (99·7–99·9).

The cervical spine imaging algorithm based on the prediction rule is shown in figure 2. According to this algorithm, a child presenting to an emergency department with any of the four high-risk factors would be triaged to CT. A child without any of the high-risk factors but with any of the five non-negligible risk factors would be triaged to plain x-ray. Application of this imaging algorithm in our study population would have substantially reduced the use of CT and plain x-ray (table 4).

Discussion

In this large, multicentre study of children with blunt trauma, we derived and validated an accurate clinical prediction rule for cervical spine injury. With only nine risk factors, the rule is clinically sensible and parsimonious. The risk factors solely comprise the child's physical complaints and examination: GCS score of 3–8; unresponsive on the AVPU; abnormal airway, breathing, or circulation; focal neurological deficit including paresthesia, numbness, or weakness; altered mental status (GCS score of 9–14; verbal or pain on the AVPU; or other signs of altered mental status); neck pain; posterior midline neck tenderness; substantial torso injury; and substantial head injury. These risk factors are easily incorporated into a clinical care algorithm providing risk-based recommendations for CT, x-ray, and clinical clearance without imaging (figure 2). The rule has excellent test characteristics with high sensitivity and NPV, and we estimated that had the

	Derivation cohort (n=11 857)	Validation cohort (n=10 573)
Children with no cervical spine injury	11 583	10 414
Any factor observed		
No	6889	6287
Yes	4694	4127
Children with cervical spine injury	274	159
Any factor observed		
No	20	9
Yes	254	150
Sensitivity	254/274 (92·7%; 89·6–95·8)	150/159 (94·3%; 90·7–97·9)
Specificity	6889/11 583 (59·5%; 58·6–60·4)	6287/10 414 (60·4%; 59·4–61·3)
Positive predictive value	254/4948 (5·1%; 4·5–5·7)	150/ 4277 (3·5%; 3·0–4·1)
Negative predictive value	6889/6909 (99·7%; 99·6–99·8)	6287/6296 (99·9%; 99·8–100·0)

Data are n or n/N (%; 95% CI). Risk factors were obtained from the electronic questionnaires that were completed by the attending emergency department clinician before viewing the results of neck imaging. In the derived prediction rule, the presence of a risk factor was considered to render the prediction rule positive for cervical spine injury. Sensitivity is the proportion of children with cervical spine injuries who had at least one of the rule's risk factors. Specificity is the proportion of children without cervical spine injuries who did not have any of the rule's risk factors. Positive predictive value is the proportion of children with at least one of the rule's risk factors who have cervical spine injuries. Negative predictive value is the proportion of children who did not have any of the rule's risk factors that do not have a cervical spine injury.

Table 3: **Clinical performance of the cervical spine injury prediction rule**

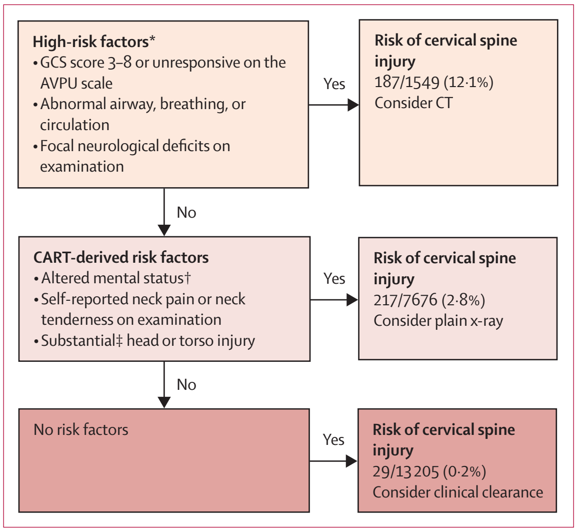

Figure 2: **Clinical algorithm for cervical spine imaging in children after blunt trauma predicated on the PECARN cervical spine injury prediction rule**
Data are n/N (%). The risk of cervical spine injury was calculated from the combined derivation and validation cohorts using eligible children's risk factor data as recorded electronically by attending emergency department clinicians. High-risk factors were used to determine when CT is warranted for a child presenting to an emergency department after blunt trauma, and CART-derived risk factors were used to determine when plain x-rays were warranted. AVPU=Alert, Verbal, Pain, Unresponsive scale of consciousness. CART=classification and regression tree analysis. GCS=Glasgow Coma Scale. PECARN=Pediatric Emergency Care Applied Research Network. *High-risk factors confirmed using bivariable Poisson regression with robust error estimates. †Altered mental status was defined as GCS score of 9–14; verbal or pain on AVPU; or other signs of altered mental status. ‡Substantial injuries were defined as those that warranted inpatient observation or surgical intervention.

	Overall (n=22 430)	Derivation cohort (n=11 857)	Validation cohort (n=10 573)
Observed imaging rates			
Clinically cleared (no imaging)	9662 (43·1%)	4682 (39·5%)	4980 (47·1%)
Plain x-ray	8912 (39·7%)	4639 (39·1%)	4273 (40·4%)
CT	3856 (17·2%)	2536 (21·4%)	1320 (12·5%)
Imaging rates with clinical prediction rule applied			
Clinically cleared (no imaging)	13 205 (58·9%)	6909 (58·3%)	6296 (59·5%)
Plain x-ray	7676 (34·2%)	4020 (33·9%)	3656 (34·6%)
CT	1549 (6·9%)	928 (7·8%)	621 (5·9%)

Data are n (%). Participants were grouped into three mutually exclusive categories: those who received no imaging (clinically cleared), those who received cervical spine plain x-rays only, and those who receive cervical spine CT with or without plain x-rays. Projected imaging categories were determined by applying the PECARN cervical spine injury prediction rule imaging algorithm (figure 3) to the study population. PECARN=Pediatric Emergency Care Applied Research Network.

Table 4: **Actual imaging use in children presenting to an emergency department with known or suspected blunt injury versus projected use when applying the PECARN cervical spine injury prediction rule imaging algorithm**

rule been applied to the study population as intended, the number of children undergoing CT could have been reduced by more than 50% without missing clinically relevant injuries or increasing x-ray use.

This PECARN cervical spine injury prediction rule differs from the CCR and NEXUS criteria in several notable ways (appendix p 8).[2,18,19] The adult-derived CCR relies on historical factors not included in NEXUS.[18,19] Identifying patient history factors requires reliable reporting from the patient or bystanders. Children often present to the emergency department without parents or other witnesses to the injury event.[30,31] Young children might be unable to describe symptoms.[23,32] PEDSPINE relies on age, GCS, and injury mechanism to predict cervical spine injury in preverbal children; however, patient complaints, patient history, and other physical examination findings were not factored into its modelling.[21]

Diving, high-risk motor vehicle crash, and predisposing conditions (eg, Down syndrome) were previously identified as risk factors for cervical spine injury in the PECARN retrospective case–control study.[25,26] High-risk motor vehicle crashes and diving mechanisms are associated with serious injuries and useful in prehospital trauma triage.[33] Although anatomical disorders of the cervical spine are uncommon in children, some might increase cervical spine injury risk.[34,35] The previous PECARN retrospective case–control study included medical documentation of cervical spine injury signs and symptoms, but attending clinician-derived documentation can be inaccurate and incomplete.[26,36,37] For complete and accurate data, emergency department clinicians in this study completed questionnaires about their patient in real time.[37,38] The PECARN cervical spine injury prediction rule relies solely on patient symptoms and physical examination findings, which are more precise and simple to record.

Adult cervical spine injury prediction rules include altered mental status; abnormal airway, breathing, or circulation; neurological deficits; and posterior midline neck tenderness as risk factors, but they differ from the PECARN Cervical Spine Injury Prediction Rule in how they incorporate neck pain, neck mobility, and concomitant injuries (appendix p 8). Musculoskeletal neck pain is uncommon in children but becomes more prevalent with age and affects nearly 10% of the global population by the seventh decade of life.[39] Rather than neck pain alone, the timing of neck pain onset and neck range of motion are probably more specific for cervical spine injury in adults. Restricted range of motion of the neck was identified as a risk factor in the PECARN retrospective case–control study. Yet, the subsequent prospective pilot study demonstrated that neck range of motion was frequently not assessed by emergency department clinicians if a prehospital cervical collar was placed.[25]

Substantial head and torso injuries are risk factors in the PECARN cervical spine injury rule. By contrast, the CCR does not include concomitant injuries, and NEXUS includes all painful, distracting injuries. After the NEXUS criteria were published, several studies challenged the use of painful distracting injuries as non-specific and resulting in increased x-ray use. Torso injuries were identified in several studies as the only important concomitant injuries.[40–43] Substantial head injuries might be an important and reliable proxy for axial load impact in children. Results of the PECARN retrospective case–control and pilot prospective observational studies showed axial load biomechanics and diving mechanisms as significant risk factors.[25,26]

PECARN is a robust environment for researching injured children; however, the findings might not be generalisable to community emergency departments that serve different patient populations and are staffed by clinicians with varying paediatric expertise. To enhance representation, we included children transferred from community emergency departments. However, we might have introduced spectrum and reporting biases by including transferred children, many of whom had already received cervical spine imaging and had injuries warranting transfer to a paediatric trauma centre. We tried to limit reporting bias by obtaining emergency department clinicians' observations before their knowledge of cervical spine imaging results, but this was not always possible. We might have also introduced bias by including children with suspected child abuse, in whom the mechanism and time of injury are unclear. To address these potential biases, we demonstrated that the PECARN cervical spine injury prediction rule performed similarly when each subpopulation was excluded.

The proposed imaging algorithm holds promise for enhancing the screening process for cervical spine injury in children, but there are crucial considerations to bear in mind regarding its implementation. We devised the emergency department cervical spine injury screening algorithm to assist in selecting imaging based on pre-test probability. In cases where the pre-test probability for cervical spine injury is high, children might need additional MRI to clarify their injury status. However, determining which children require MRI as an adjunct was beyond the scope of this study.

In summary, in this large, prospective multicentre study we derived and validated an accurate clinical prediction rule for cervical spine injury in children presenting with blunt trauma. These clinically sensible criteria have high sensitivity and near-perfect NPV without missing any cervical spine injuries requiring surgical intervention. When incorporated into a risk-stratified imaging algorithm, the rule can potentially spare children exposure to medical radiation by reducing CT use. Future work is needed to determine the best methods for implementing this prediction rule into clinical care, particularly in community emergency department settings.

Contributors

JCL: conceptualisation, methodology, funding acquisition, investigation, project administration, supervision, data curation, formal analysis, visualisation, writing original draft manuscript, and manuscript reviewing and editing. MH: project administration, formal analysis, visualisation, software used for data management and analysis, writing of original draft manuscript, and manuscript reviewing and editing. LJC: conceptualisation, methodology, investigation, supervision, formal analysis, visualisation, resources, software used for data management and analysis, and manuscript reviewing and editing. JRL: investigation, supervision, and manuscript review and editing. KMA, FAA, LRB, RKB, PPC, DJC, NWG, LKL, SO-A, LCR, AJR, DMR, RES, MAS, LT, CEW, and KY: data curation, investigation, project administration, and manuscript review and editing. NK: conceptualisation, methodology, supervision, investigation, formal analysis, and manuscript reviewing and editing. JCL, MH, and LJC had full access to and verified the data. All authors had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

De-identified individual data that support the results will be shared from 9 months to 36 months after publication provided the investigator who proposes to use the data has approval from an Institutional Review Board and executes a data use or sharing agreement with the PECARN data coordinating centre. Data can be accessed by contacting the data coordinating centre director (https://pecarn.org/datasets/).

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