## Title
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# Cervical Spine Injury Risk Factors in Children With Blunt Trauma

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abstract

**BACKGROUND:** Adult prediction rules for cervical spine injury (CSI) exist; however, pediatric rules do not. Our objectives were to determine test accuracies of retrospectively identified CSI risk factors in a prospective pediatric cohort and compare them to a de novo risk model.

**METHODS:** We conducted a 4-center, prospective observational study of children 0 to 17 years old who experienced blunt trauma and underwent emergency medical services scene response, trauma evaluation, and/or cervical imaging. Emergency department providers recorded CSI risk factors. CSIs were classified by reviewing imaging, consultations, and/or telephone follow-up. We calculated bivariable relative risks, multivariable odds ratios, and test characteristics for the retrospective risk model and a de novo model.

**RESULTS:** Of 4091 enrolled children, 74 (1.8%) had CSIs. Fourteen factors had bivariable associations with CSIs: diving, axial load, clotheslining, loss of consciousness, neck pain, inability to move neck, altered mental status, signs of basilar skull fracture, torso injury, thoracic injury, intubation, respiratory distress, decreased oxygen saturation, and neurologic deficits. The retrospective model (high-risk motor vehicle crash, diving, predisposing condition, neck pain, decreased neck mobility (report or exam), altered mental status, neurologic deficits, or torso injury) was 90.5% (95% confidence interval: 83.9%–97.2%) sensitive and 45.6% (44.0%–47.1%) specific for CSIs. The de novo model (diving, axial load, neck pain, inability to move neck, altered mental status, intubation, or respiratory distress) was 92.0% (85.7%–98.1%) sensitive and 50.3% (48.7%–51.8%) specific.

**CONCLUSIONS:** Our findings support previously identified pediatric CSI risk factors and prospective pediatric CSI prediction rule development.

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Dr J.C. Leonard conceptualized and designed the study, designed the data collection instruments, coordinated and supervised data collection, collaborated on data analyses, and drafted the manuscript; Drs Browne, Ahmad, Schwartz, J.R. Leonard, and Lerner designed the data collection instruments and coordinated and supervised data collection; Dr Wallendorf designed the data collection instruments, managed the data, and conducted the analyses; Dr Kuppermann conceptualized and designed the study, designed the data collection instruments, collaborated on data analyses, and drafted the manuscript; and all authors critically reviewed the manuscript for important intellectual content and approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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**WHAT'S KNOWN ON THIS SUBJECT:** Pediatric cervical spine injury (CSI) risk factors from a large, multicenter, retrospective case-control study warrant prospective evaluation: predisposing condition, diving, high-risk motor vehicle crash, neck pain, inability to move neck, altered mental status, neurologic deficits, and torso trauma.

**WHAT THIS STUDY ADDS:** In this 4-center prospective observational study of 4091 children with blunt trauma, 14 factors were associated with CSIs. Risk models with these variables accurately predicted CSIs and support conducting a larger study to fully derive a prediction rule.

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Pediatric cervical spine injuries (CSIs) are associated with significant morbidity and mortality.[1] Cervical plain radiographs and computed tomography (CT) use is prevalent during trauma evaluation.[2–4] CSIs, however, are uncommon in children, and the great majority who undergo radiographic screening are injury free.[5] Indiscriminate use of radiographic screening for pediatric CSIs is controversial because of concerns that radiation exposure will increase lifetime risk of malignancy.[6–14]

Further controversy relates to prehospital use of spinal motion restriction (SMR) devices (cervical collars and rigid longboards). Theoretically, these devices protect from spinal cord injury if unstable injuries are present but are associated with known risks. Most germane during trauma evaluation is that mere presence of these devices leads to increased cervical spine imaging.[15] This may be due to increased pain complaints with SMR or physicians deferring neck examinations when devices are present.[15,16]

Two large prospective observational studies, National Emergency X-Radiography Utilization Study (NEXUS) and Canadian C-Spine Rule for Radiography, derived adult CSI prediction rules aimed at reducing cervical spine imaging.[17–22] These rules were validated in adults and used to safely limit prehospital SMR and cervical imaging during trauma evaluation.[23–26] Unfortunately, these studies were not focused on children (NEXUS: 3065 children, 30 with CSIs; Canadian C-spine: no children).[5] Researchers have attempted to validate these rules in children with small prospective studies and retrospective analyses; however, results were mixed and sample sizes small.[5,27–30] There are no CSI prediction rules specifically derived and validated in a pediatric population.

The Pediatric Emergency Care Applied Research Network (PECARN) conducted a 17-center, 5-year, retrospective case-control study that identified risk factors associated with CSIs in children with blunt trauma (altered mental status, focal neurologic findings, neck pain, torticollis [decreased neck mobility by report or exam], substantial torso injury, conditions predisposing to CSI, diving, and high-risk motor vehicle crash [MVC]).[31,32] These factors were 98% sensitive for CSIs within the study cohort and, if used as a prediction rule, would reduce cohort imaging by at least 25%.

Because of risks of SMR and neck irradiation during evaluation of children after blunt trauma, there is a need to derive and validate a CSI prediction rule that guides clinical decision-making. Our primary aim was to determine test accuracies of retrospectively identified PECARN CSI risk factors in a prospective cohort of children. Our secondary aims were to derive a de novo model for predicting CSIs in children after blunt trauma, to compare this with the PECARN model, and to evaluate potential effects on cervical spine imaging rates if these models are used in decision support.

## METHODS

### Study Design and Setting

Between March 2014 and November 2016, we conducted a prospective observational study of consecutive children evaluated at 4 tertiary care children's hospitals. Participating hospitals were academic freestanding children's hospitals, American College of Surgeons Pediatric Level 1–verified, and PECARN members.

### Selection of Participants

Inclusion criteria consisted of children younger than 18 years who presented to the emergency department (ED) for blunt trauma and were transported from scene of injury by emergency medical services (EMS) in SMR, underwent trauma team evaluation, and/or had cervical spine imaging ordered in the ED. We excluded children whose injury mechanism was solely penetrating trauma, whose legal guardian had a substantial language barrier, who were in state's custody, or who were transferred from the study site for definitive care.

### Methods and Measurements

Data collection methods for this study were previously reported.[33] In brief, trained research personnel administered electronic branch-logic questionnaires to treating ED providers to gather observations regarding CSI risk factors before knowledge of cervical spine imaging results, if ordered or if obtained at a transferring hospital, before knowledge of their institutional radiologist's interpretation. Risk factors included those previously demonstrated to be associated with CSIs, that had biological and/or anatomic plausibility, and with good interrater reliability.[16,34–36] These factors included mechanisms of injury and injury biomechanics (high-risk MVC[37]: passenger compartment intrusion including roof >12 inches at occupant site or >18 inches at any site, partial or complete ejection from vehicle, death of a passenger in the same compartment, and/or vehicle telemetry consistent with high-risk crashes; diving; axial load; or clotheslining: biomechanical force caused by a rope, cable, or similar item exerting traction on the neck while the body is in forward motion), patient history variables (predisposing conditions, loss of consciousness, neck pain, inability to move neck, paresthesia, numbness or weakness), and physical examination findings (altered mental status, intubation, signs of substantial head injury other than altered mental status, signs of basilar skull fracture, posterior midline tenderness to palpation, limited range of neck motion, substantial torso injury, substantial thoracic injury, respiratory distress, decreased oxygen saturation, substantial abdominal injury, substantial pelvic injury, thoracic spine tenderness, lumbar spine tenderness, sacral spine tenderness, focal neurologic deficits [paresthesia, decreased sensation, and weakness]). We defined substantial injuries as life-threatening and warranting surgical intervention or warranting inpatient observation. Respondents could not skip items but could indicate if a risk factor was unknown, unable to be assessed, not assessed, or unknown.

### Outcomes

CSI was defined as vertebral fractures, ligamentous injury, intraspinal hemorrhage, or spinal cord injury (either on magnetic resonance imaging or spinal cord injury without radiographic association) involving the cervical region (occiput to seventh cervical vertebra, including ligamentous structures attaching the seventh cervical vertebra to first thoracic vertebra). Study personnel determined CSI diagnosis by reviewing cervical spine imaging reports and, if applicable, spine surgeon consultation notes. If imaging report diagnoses conflicted with spine surgeon consultation, we contacted the treating spine surgeon and/or the study's spine surgeon for clarification. For children who did not undergo ED cervical spine imaging, the medical record was reviewed 21 days later for subsequent imaging. If no subsequent imaging was noted, a follow-up call with the legal guardian was conducted 21 to 28 days after the ED visit to verify absence of CSI.

### Statistical Analysis

The analytic cohort was described by using counts and frequencies. We dichotomized observations of CSI risk factors into 2 categories: present versus all other responses. Relative risks (RRs) of CSI with 95% confidence intervals (CIs) were estimated for all candidate risk factors. Risk factors from the PECARN retrospective case-control model were fit to prospective data by multivariable logistic regression and odds ratios (ORs), and 95% CIs were calculated for each risk factor. In a separate analysis, we derived a de novo CSI risk model using only variables with a bivariable lower 95% confidence limit $>1$ as candidates for inclusion and multiple stepwise logistic regression. Multivariable ORs and 95% CIs were calculated for variables retained in the model.

To assess model performance characteristics, each model was applied to the data as a decision tool where subjects were considered at risk for CSI if they had at least 1 positive value for any model variable. Sensitivity, specificity, negative predictive value, and positive predictive value for CSI were calculated for each model. Observer bias was assessed by repeating this assessment with the subcohort of children presenting directly from scene of injury (ie, excluding those transferred from referring institutions).

Expected overall cervical spine imaging rates were estimated for each model by assuming that any 1 positive variable would result in imaging. Estimates for CT use were calculated by applying each model as a prediction rule to the subpopulation that underwent CT.

All analyses were conducted by using SAS version 9.4 (SAS Institute, Inc, Cary, NC).

### Human Subjects

This study was approved by all sites' institutional review boards to be conducted under waiver of written informed consent. Legal guardians of enrolled subjects were provided an informational handout that contained withdrawal instructions.

## RESULTS

### Enrollment

Supplemental Fig 1 summarizes study enrollment. In total, we screened 11 809 children who experienced blunt trauma, of whom 5764 were eligible and 4144 were enrolled. Characteristics of the 1620 children missed for enrollment were previously described.[33] Compared with enrolled children, these children were slightly younger (median age 8.5 vs 9.4 years), more likely white (63% vs 60.8%), and less likely involved in MVCs (22.5% vs 27.3%) and all-terrain vehicle, motorcycle, or scooter crashes (5.1% vs 10.0%). Legal guardians withdrew 53 children.

### Characteristics of Study Subjects

Table 1 presents total cohort and CSI subpopulation characteristics. Of 4091 children, 74 (1.8%) had CSIs. Cohort mean age was 9.4 years, and mean age of those with CSIs was 10.7 years. A total of 39.3% of the cohort was younger than 8 years and 23 (1.4%) of these children had CSIs. The CSI subpopulation included more boys, white children, and non-Hispanic children. The most common mechanisms of injury for both groups were MVC and sports-related mechanisms. Children with CSIs were more likely to undergo trauma team evaluation and less likely to be discharged.

**TABLE 1** Patient Characteristics

| Characteristics | All Children in the Analytic Cohort, *N* = 4091 | Children With CSI in the Analytic Cohort, *N* = 74 |
|---|---|---|
| | *n* (%) | *n* (%) |
| Age, y | | |
| 0–2 | 824 (20.1) | 10 (13.5) |
| 3–7 | 785 (19.2) | 13 (17.6) |
| 7–15 | 1927 (47.1) | 35 (47.3) |
| 16–18 | 555 (13.6) | 16 (21.6) |
| Sex, male | 2373 (58.0) | 48 (64.9) |
| Race | | |
| White | 2471 (60.4) | 48 (64.9) |
| African American | 1290 (31.5) | 18 (24.3) |
| Other | 312 (7.6) | 8 (10.8) |
| Ethnicity | | |
| Non-Hispanic | 3829 (93.6) | 70 (94.6) |
| Hispanic | 129 (3.2) | 3 (4.1) |
| Unknown | 133 (3.3) | 1 (1.4) |
| Mechanism of injury | | |
| MVC | 1115 (27.3) | 22 (29.7) |
| Fall | 1100 (26.9) | 18 (24.3) |
| Sports | 523 (12.8) | 9 (12.2) |
| ATV, motorcycle, or scooter | 407 (10.0) | 7 (9.5) |
| Hit by car | 159 (3.9) | 4 (5.4) |
| Diving | 17 (0.4) | 4 (5.4) |
| Other | 363 (8.9) | 4 (5.4) |
| Unknown | 317 (7.8) | 5 (6.8) |
| Presenting directly to study site from the scene of injury | 3095 (76.7) | 43 (58.1) |
| Disposition | | |
| Home | 2632 (64.3) | 14 (18.9) |
| Admit general inpatient | 835 (20.4) | 25 (33.8) |
| Admit ICU | 318 (7.8) | 28 (37.8) |
| Operating room | 137 (3.4) | 5 (6.8) |
| Death in ED | 13 (0.3) | 0 |
| Diagnosed with CSI | 74 (1.8) | n/a |

ATV, all-terrain vehicle; ICU, intensive care unit; n/a, not available.

Thirteen children died in the ED, none of whom had documented CSIs.

## Main Results

The bivariable RRs for all risk factors and multivariable ORs for risk factors in the PECARN and de novo models are presented in Table 2. Fourteen factors had significant bivariable associations with CSIs in the study cohort: diving, axial load, clotheslining, loss of consciousness, neck pain, reported inability to move the neck, altered mental status, signs of basilar skull fracture, substantial torso injury, substantial thoracic injury, intubation, respiratory distress, decreased oxygen saturation, and focal neurologic deficits on examination.

Most PECARN model risk factors maintained independent associations with CSIs in the multivariable analysis (diving, neck pain, reported inability to move neck, altered mental status, substantial torso trauma, and focal neurologic deficits); however, 3 variables did not (high-risk MVC, predisposing conditions, and limited neck range of motion on exam). The de novo model for CSI risk included 7 variables: diving mechanism, axial load, neck pain, reported inability to move neck, altered mental status, respiratory distress, and intubation.

In Table 3, we report test accuracies for each model. Compared with the PECARN model, the de novo model had marginally better sensitivity and specificity (90.5% and 45.6% vs 91.9% and 50.3%, respectively) and negative and positive predictive values (99.6% and 3.0% vs 99.7% and 3.3%, respectively). When the analysis was repeated for the 3138 children who presented directly to the study sites, including 43 with CSIs, the results were similar. The sensitivity and specificity of the PECARN model in this subcohort were 93.0% (95% CI 85.4%–100%) and 42.1% (95% CI 40.3%–43.8%), respectively. The sensitivity and specificity for the de novo model in the subcohort were 95.3% (95% CI 89.1%–100%) and 45.9% (95% CI 44.1%–47.7%), respectively.

In Table 4, we present extrapolated imaging rates if these CSI risk models guided decision-making. Overall imaging rates would decrease by more than a third, from an observed rate of 78.2% to 55.1% or 50.5%, in the PECARN and de novo models, respectively. CT scan use would decrease by more than half, from 15.8% to 7.5% or 7.1%. However, both models would have missed children with CSIs; 7 with the PECARN model and 6 with the de novo model.

In Table 5, we present characteristics of the 7 children with CSIs missed by ED providers' assessments of PECARN risk factors. On retrospective chart review, all but 1 child had PECARN risk factors: altered mental status (3), neck pain (3), and focal neurologic deficit (1). The child that lacked a PECARN risk factor reported back pain and severe upper thoracic tenderness and had a C7 burst fracture. None of the missed children required surgical intervention; however, 1 required a brace and another required a rigid cervical collar.

**TABLE 2** Risk Factors for CSI in Children

| Risk Factors | Bivariable RR (CI) | PECARN Model[a] OR (CI) | De Novo Model[b] OR (CI) |
|---|---|---|---|
| Mechanism of injury or biomechanics | | | |
| High-risk MVC[c] | 1.57 (0.64–3.83) | 1.58 (0.63–3.97) | — |
| Diving | 13.69 (5.64–33.27) | 17.60 (5.60–55.32) | 9.16 (2.41–34.83) |
| Axial load | 3.18 (1.74–5.81) | — | 2.51 (1.22–5.16) |
| Clotheslining[d] | 3.28 (1.07–10.08) | — | — |
| Patient history | | | |
| Predisposing conditions | 1.99 (0.29–13.80) | 2.02 (0.27–15.10) | — |
| Loss of consciousness | 2.07 (1.25–3.43) | — | — |
| Neck pain | 1.64 (1.04–2.57) | 1.65 (1.04–2.62) | 2.87 (1.50–5.48) |
| Inability to move neck | 3.61 (1.98–6.60) | 3.77 (2.00–7.12) | 3.51 (1.72–7.17) |
| Paresthesias | 0.56 (0.14–2.25) | — | — |
| Numbness | 0.38 (0.05–2.74) | — | — |
| Weakness | 0.48 (0.07–3.41) | — | — |
| Physical examination | | | |
| Altered mental status | 5.37 (3.42–8.44) | 5.67 (3.54–9.09) | 2.90 (1.37–6.12) |
| Intubated | 11.35 (7.02–18.25) | — | 10.71 (4.43–25.91) |
| Signs of substantial head injury other than altered mental status | 0.40 (0.10–1.61) | — | — |
| Signs of basilar skull fracture | 5.52 (2.32–13.13) | — | — |
| Posterior midline tenderness to palpation | 1.47 (0.94–2.32) | — | — |
| Limited neck range of motion | 1.82 (0.89–3.76) | 1.85 (0.88–3.90) | — |
| Substantial torso injury | 2.54 (1.24–5.22) | 2.61 (1.24–5.53) | — |
| Substantial thoracic injury | 5.74 (2.42–13.63) | — | — |
| Respiratory distress | 13.69 (5.64–33.28) | — | 5.84 (1.56–21.88) |
| Decreased oxygen saturation | 15.67 (5.81–42.27) | — | — |
| Substantial abdominal injury | 1.86 (0.69–5.01) | — | — |
| Substantial pelvic injury | No estimate[e] | — | — |
| Thoracic spine tenderness | 1.11 (0.63–1.94) | — | — |
| Lumbar spine tenderness | 0.42 (0.16–1.16) | — | — |
| Sacral spine tenderness | 0.40 (0.06–2.82) | — | — |
| Focal neurologic deficits | 2.55 (1.05–6.20) | 2.62 (1.04–6.63) | — |
| Paresthesias | No estimate[e] | — | — |
| Decreased sensation | 2.12 (0.53–8.40) | — | — |
| Weakness | 1.67 (0.42–6.66) | — | — |

—, not applicable.

[a] Model including only those variables identified in the PECARN retrospective case-control study.

[b] Model created by using stepwise variable selection.

[c] Intrusion, including roof; >12 inches occupant site, >18 inches any site; ejection (partial or complete) from automobile; death in same passenger compartment; vehicle telemetry data consistent with a high-risk crash.

[d] Biomechanical force caused by a rope, cable, or similar item exerting traction on the neck while the body is in forward motion.

[e] No children with CSIs within the cohort had the finding.

## Limitations

We included children transferred from other hospitals with imaging. Knowledge of imaging results may have influenced ED providers' reported risk factor observations. This potential bias was mitigated by efforts to capture ED providers' observations before radiologists overread outside imaging. Including children transferred from outlying hospitals was important to ensure that the study population was representative of the entire injured population. Importantly, a subanalysis that included only children presenting directly to the study sites yielded similar prediction model sensitivity and specificity estimates. The analyses were underpowered to provide narrow CIs around ORs and RRs point estimates for uncommon risk factors and therefore lacks sufficient power to fully assess model performance characteristics.

## DISCUSSION

In this 4-center prospective observational study of children experiencing blunt trauma, we identified 14 factors that were associated with CSI in bivariable analyses: diving, axial load, clotheslining, loss of consciousness, neck pain, reported inability to move neck, altered mental status, intubation, basilar skull fracture, substantial torso injury, substantial thoracic injury, respiratory distress, decreased oxygen saturation, and focal neurologic deficits. We also demonstrated by multivariable analyses that both the PECARN model (high-risk MVC, diving mechanism, conditions predisposing for CSI, neck pain, reported inability to move neck, altered mental status, limited neck

**TABLE 3** Model Performance

| | PECARN Model[a] ($N$ = 4091) | | | De Novo Model[b] ($N$ = 4091) | | |
|---|---|---|---|---|---|---|
| | Any 1 Risk Factor | No Risk Factors[c] | Value (95% CI) | Any 1 Risk Factor | No Risk Factors[c] | Value (95% CI) |
| CSI present | 67 | 7 | — | 68 | 6 | — |
| CSI absent | 2186 | 1831 | — | 1998 | 2019 | — |
| Sensitivity | — | — | 90.54% (83.87%–97.21%) | — | — | 91.89% (85.7%–98.11%) |
| Specificity | — | — | 45.58% (44.04%–47.12%) | — | — | 50.26% (48.72%–51.81%) |
| Positive predictive value | — | — | 2.97% (2.27%–3.68%) | — | — | 3.29% (2.52%–4.06%) |
| Negative predictive value | — | — | 99.62% (99.34%–99.90%) | — | — | 99.71% (99.47%–99.94%) |
| Positive likelihood ratio | — | — | 1.66 (1.54–1.80) | — | — | 1.85 (1.71–1.99) |
| Negative likelihood ratio | — | — | 0.21 (0.10–0.42) | — | — | 0.16 (0.07–0.35) |

—, not applicable.
[a] Model including only those variables identified in the PECARN retrospective case-control study.
[b] Model created by using stepwise variable selection.
[c] A risk factor was considered absent if the ED provider classified the risk factor as not present, unable to be assessed, not assessed, or unknown.

range of motion on exam, substantial torso injury, and focal neurologic deficits) and a de novo model (diving mechanism, axial load biomechanics, neck pain, reported inability to move neck, altered mental status, intubation and respiratory distress) have reasonable test accuracy and the potential to limit imaging if used in clinical decision-making. Collectively, these results support the feasibility of deriving a CSI prediction rule for children.

In this study, we confirm the important association between CSI and head injury. Signs of substantial head injury (basilar skull fracture), signs of traumatic brain injury (altered mental status), respiratory failure and intubation, and head-first impact (diving mechanism and axial load biomechanics) held significant independent associations with CSI. Adult CSI prediction rules for cervical imaging after blunt trauma are contingent on normal mental status for clinical clearance. One argument for this practice is that a patient's examination is unreliable when mentation is altered. Another compelling argument is that head-first impact predisposes to CSI and that mental status is a good marker for the severity of the head-first, axial load impact and therefore is also a good marker for CSI risk. Future development of a robust pediatric CSI prediction rule should be focused on stratification based on mental status because it may be meaningful in determining which children to triage to CT scan. If the CSI risk based on altered mental status is sufficiently high, this risk would outweigh the risk of CT-related ionizing radiation exposure.

The risk factors identified in this study differ from the adult literature with respect to neck findings. The NEXUS and the Canadian C-spine rules rely on the neck examination, both include posterior midline neck tenderness, and the Canadian C-spine rule also includes lack of normal neck range of motion on examination.[17,18,22] Both the PECARN retrospective case-control study of CSI in children and the current study found self-report of neck pain and difficulty moving the neck to be predictive as opposed to being restricted to the examination findings of posterior midline neck tenderness and limited range of motion.[32] One possible reason for this difference is that SMR alters physical examination in the ED. Researchers previously demonstrated increased neck and spine tenderness after supine positioning in a cervical collar on a rigid longboard.[15,38–40] Another possibility is that ED providers defer aspects of the neck examination for children who arrive in a cervical collar, rendering self-report the only means for assessing these findings. Within this study cohort, ED providers did not assess children transported

**TABLE 4** Rates of Cervical Spine Imaging During ED Evaluation and Hospital Admission

| Intervention | Reported by ED Provider at Time of Initial Evaluation | Observed on Medical Record Review | PECARN Model[a] | De Novo Model[b] |
|---|---|---|---|---|
| Any imaging | 2723 of 4091 (66.6%) | 3201 of 4091 (78.2%) | 2253 of 4091 (55.1%)[c] | 2066 of 4091 (50.5%)[c] |
| CT scan | 437 of 4091 (10.7%) | 648 of 4091 (15.8%) | 306 of 4091 (7.5%)[d] | 289 of 4091 (7.1%)[d] |

[a] Model including only those variables identified in the PECARN retrospective case-control study.
[b] Model created by using stepwise forward variable selection.
[c] Estimated by applying model to entire cohort, with the presence of any risk factor indicating need for imaging, and all no indicating imaging unneeded.
[d] Estimated by applying the model to those that had the CT in the cohort, with the presence of any risk factor indicating need for the CT and absence of all risk factors indicating CT unneeded.

**TABLE 5** Characteristics of Children With CSI Whose ED Provider Did Not Report One of the Risk Factors From the PECARN Model

| Age | Mechanism of Injury on Chart Review | Chief Complaint on Chart Review | Examination Findings on Chart Review | PECARN Risk Factors on Chart Review | Diagnosis | Treatment |
|---|---|---|---|---|---|---|
| 5.7 y | Fall from second story (10 ft) | Back pain | Diffuse thoracic spine tenderness | None | C7 burst fracture; T2–T4 compression fractures | Brace |
| 15.3 y | ATV crash | Arrived from OSH with concern for CSI | None | Neck pain | C1 lateral mass contusion and bilateral C1–C2 alar ligament injury | Unknown[a] |
| 6.1 y[b] | Fall (10 ft) | Loss of consciousness; axial load | Signs of substantial head injury other than altered mental status | Neck pain | C1–C2 epidural hemorrhage; no fracture or ligamentous disruption | None |
| 7 wk | Fall from bed reported, suspected NAT | Loss of consciousness | Repeat episodes of unresponsiveness and limp tone | Altered mental status | C1–C4 subdural hemorrhage; no fracture or ligamentous disruption | None |
| 6 mo | NAT | Arrived from OSH with concern for substantial head injury | Irritable; signs of substantial head injury; palpable skull fracture | Altered mental status | C7–T2 compression deformities with associated C7–T1 ligamentous injury | None |
| 8.3 y | MVC >55 MPH | Arrived by EMS with concern for substantial head injury | GCS 14 at scene; persistent somnolence and confusion; tenderness to neck palpation; sixth nerve palsy | Altered mental status; focal neurologic deficit | C2 ventral subdural hematoma | None |
| 3.8 y | Fall from bench hitting head on a table | Transferred with concern for CSI; complained of neck pain and holding neck | Occipital laceration; tenderness to palpation of the posterior midline neck | Neck pain | C1 posterior synchondrosis fracture | Rigid cervical collar |

ATV, all-terrain vehicle; GCS, Glasgow Coma Scale; MPH, miles per hour; NAT, non-accidental trauma; OSH, outside hospital.
a Medical record review lacks information regarding treatment rendered.
b Subject not missed by de novo model due to axial load biomechanics noted by ED provider.

from the scene of injury by EMS for posterior midline cervical tenderness in 12.3% and neck range of motion in 41.2%.[16]

Aside from limited range of neck motion on examination, 2 additional PECARN model risk factors did not maintain their associations with CSI in this study: predisposing conditions and high-risk MVC mechanism.[32] Both of these risk factors are included in the Canadian C-spine Rule.[22] Predisposing conditions in this cohort had low prevalence, occurring in <1% of children. The main aim of this study was to establish the infrastructure for conducting a larger cohort study and is therefore underpowered for rare findings and those with weaker but significant associations. High-risk MVCs, however, were prevalent within the cohort. Although high-risk MVC did not maintain a significant association with CSI, it may be important in prediction rule derivation when there is a sufficient sample size to pair high-risk mechanisms with physical examination findings to determine CSI risk.

The PECARN model had sufficiently accurate performance characteristics in this cohort that use of the model for clinical decision support would significantly reduce cervical spine imaging, although 7 CSIs would have been missed. De novo modeling revealed that there are opportunities to improve the PECARN model. Both models were similar in that axial load biomechanics, mental status assessment, and neck complaints were important factors associated with CSI. However, the de novo model included respiratory distress and intubation, which could reflect substantial head, chest, or spinal cord injury. This compares to focal neurologic deficits and substantial torso injury in the PECARN model. With larger sample sizes, it is likely that all factors that are signs of severe traumatic brain injury and spinal cord injury would be identified as significant in prediction rule derivation.

Clinical prediction rule use has come under scrutiny by some authors using the argument that physician judgement is rarely assessed in studies for comparison; in those studies where it was assessed, prediction rules seldom improve on it.[41] In a separate analysis of this cohort, however, we demonstrated ED provider gestalt for identifying children with CSIs is poor.[16] Twenty percent of the children with CSIs in that analysis were rated by providers as having <1% risk for CSI. This is consistent with investigations of head injury in children after blunt trauma.[42,43] Furthermore, PECARN developed a decision support tool for imaging children after blunt head trauma.[44–46] Implementation of the PECARN head injury rule has repeatedly demonstrated reduction in CT use during the evaluation of children after blunt head trauma.[46–50] Developing and implementing clinical prediction rules to aid in identifying children at nonnegligible risk for CSIs after blunt trauma is likely to empower clinical decision-making and appropriate imaging use.

## CONCLUSIONS

In this prospective cohort of children with blunt trauma, we confirmed that there are risk factors with good test accuracy in identifying CSIs. We also demonstrated that incorporating these risk factors into a clinical prediction rule has the potential to substantially reduce cervical spine imaging during trauma evaluation of children. A future, adequately powered prospective observational study aimed at using these risk factors to construct a definitive pediatric CSI prediction rule is warranted.


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## ABBREVIATIONS

CI: confidence interval
CSI: cervical spine injury
CT: computed tomography
ED: emergency department
EMS: emergency medical services
MVC: motor vehicle crash
NEXUS: National Emergency X-Radiography Utilization Study
OR: odds ratio
PECARN: Pediatric Emergency Care Applied Research Network
RR: relative risk
SMR: spinal motion restriction


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