Factors Associated With Cervical Spine Injury in Children After Blunt Trauma

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Study objective: Cervical spine injuries in children are rare. However, immobilization and imaging for potential cervical spine injury after trauma are common and are associated with adverse effects. Risk factors for cervical spine injury have been developed to safely limit immobilization and radiography in adults, but not in children. The purpose of our study is to identify risk factors associated with cervical spine injury in children after blunt trauma.

Methods: We conducted a case-control study of children younger than 16 years, presenting after blunt trauma, and who received cervical spine radiographs at 17 hospitals in the Pediatric Emergency Care Applied Research Network (PECARN) between January 2000 and December 2004. Cases were children with cervical spine injury. We created 3 control groups of children free of cervical spine injury: (1) random controls, (2) age and mechanism of injury-matched controls, and (3) for cases receiving out-of-hospital emergency medical services (EMS), age-matched controls who also received EMS care. We abstracted data from 3 sources: PECARN hospital, referring hospital, and out-of-hospital patient records. We performed multiple logistic regression analyses to identify predictors of cervical spine injury and calculated the model's sensitivity and specificity.

Results: We reviewed 540 records of children with cervical spine injury and 1,060, 1,012, and 702 random, mechanism of injury, and EMS controls, respectively. In the analysis using random controls, we identified 8 factors associated with cervical spine injury: altered mental status, focal neurologic findings, neck pain, torticollis, substantial torso injury, conditions predisposing to cervical spine injury, diving, and high-risk motor vehicle crash. Having 1 or more factors was 98% (95% confidence interval 96% to 99%) sensitive and 26% (95% confidence interval 23% to 29%) specific for cervical spine injury. We identified similar risk factors in the other analyses.

Conclusion: We identified an 8-variable model for cervical spine injury in children after blunt trauma that warrants prospective refinement and validation. [Ann Emerg Med. 2011;58:145-155.]

Please see page 146 for the Editor's Capsule Summary of this article.

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*Participating centers and investigators are listed in the Appendix.

Editor's Capsule Summary

What is already known on this topic

Clinical decision rules have been developed and validated for adult trauma patients to guide imaging decisions for cervical spine injury. No such rules exist for children.

What question this study addressed

The authors performed a case-control study and multiple logistic regression using Pediatric Emergency Care Applied Research Network (PECARN) data on children younger than 16 years to identify cervical spine injury predictors.

What this study adds to our knowledge

Using 540 cases and 1,060 controls, the authors developed an 8-risk-factor model that, when all were absent, had a sensitivity of 98% and a specificity of 26%.

How this is relevant to clinical practice

A decision rule might reduce the amount of cervical spine imaging in children.

[Ann Emerg Med. 2011;58:145-155.]

INTRODUCTION

Cervical spine injury occurs in fewer than 1% of children presenting for trauma evaluation.[1] Interventions aimed at protecting the cervical spine during out-of-hospital transport and subsequent radiographic assessment of the cervical spine during evaluation in the emergency department (ED) are common and known to be associated with adverse effects, including pain, pressure wounds, encumbered airway management and respiratory function, and exposure to ionizing radiation.[2-10] More than 99% of children evaluated after trauma do not have cervical spine injury and therefore may be unnecessarily exposed to these harms.

Risk stratification strategies that have been developed in adults allow clinicians to limit these potentially harmful interventions to those at non-negligible risk of cervical spine injury. The best known of these rules, the National Emergency X-Radiography Utilization Study (NEXUS) criteria[11,12] and the Canadian C-spine Rule for alert and stable trauma patients[13] are more than 99% sensitive for cervical spine injury in adults. When applied prospectively, these strategies were shown to significantly reduce the use of spinal immobilization and radiographic clearance without missing significant cervical spine injuries.[14-19]

Efforts to develop similar risk stratification strategies in children with blunt trauma have been limited by small sample sizes, particularly among young children.[1,20,21] Generalization of adult-derived cervical spine injury decision rules to children may be hazardous because children have age-dependent differences in cervical spine anatomy and injury patterns, as well as different mechanisms of injury and abilities to report symptoms. There is a pressing need to develop cervical spine injury risk stratification strategies for use in injured children. The purpose of our study was to identify risk factors associated with cervical spine injury in children after blunt trauma.

MATERIALS AND METHODS

Selection of Participants

We conducted a retrospective case-control study in which we evaluated the medical records of children presenting to 17 medical centers (study sites) in the Pediatric Emergency Care Applied Research Network (PECARN) between 2000 and 2004.[22,23] We obtained institutional review board approval from all participating sites. Children were eligible if they were evaluated at a study site with cervical spine radiography after blunt trauma before 16 years of age.

Children who had cervical spine injury were designated as "cases" and were identified by query of the study site billing database, using the *International Classification of Diseases, 9th Revision* (*ICD-9*) codes for cervical spine injury. These codes encompass children with injuries to the cervical vertebrae, ligaments, or spinal cord and children with spinal cord injury without radiographic association. Each study site investigator confirmed the presence of a cervical spine injury by screening the medical record. The principal investigator and a pediatric neurosurgeon also verified every cervical spine injury by reviewing abstracted radiology reports and spine consultation notes.

We assigned children without cervical spine injury to control groups. Children with Current Procedural Terminology codes for cervical spine radiography but without *ICD-9* codes for cervical spine injury were identified as potential controls; study site investigators confirmed the absence of cervical spine injury by record review. We selected appropriate controls who presented closest in time within 1 year of their assigned case. We created 3 different control groups: a random control group ("random controls"); a group matched to cases according to age and mechanism of injury category (defined in Table 1) ("mechanism of injury controls"); and for cases receiving emergency medical services (EMS) out-of-hospital care, a control group matched on age who had also received EMS out-of-hospital care ("EMS controls"). For each control group, we selected up to 2 controls per case to enhance the power of identifying risk factors.

Analyses of matched control groups were used to assess possible bias and confounding effects of age, mechanism of injury, and receipt of out-of-hospital care. Additionally, the EMS control group allowed for enhanced ability to identify factors observable in the out-of-hospital setting. Consistency in results between the random, mechanism of injury, and EMS control group analyses would strengthen confidence in their

Table 1. Description of the study sample.

	CSI Cases, No. (%), N=540	Random Controls, No. (%), N=1,060	MOI Controls, No. (%), N=1,012	EMS Controls, No. (%), N=702
Age, y*				
0 to <2	27 (5)	116 (11)	41 (4)	34 (5)
2 to <8	140 (26)	318 (30)	264 (26)	173 (25)
8 to <16	373 (69)	626 (59)	707 (70)	495 (71)
Sex				
Male	344 (64)	634 (60)	620 (61)	414 (59)
Female	196 (36)	426 (40)	391 (39)	288 (41)
Race*†‡				
White	332 (61)	497 (47)	451 (45)	333 (47)
Black	94 (17)	280 (26)	270 (27)	170 (24)
Other	37 (7)	51 (5)	67 (7)	45 (6)
Not documented	77 (14)	232 (22)	224 (22)	154 (22)
Payer*†‡				
Commercial/government/workmen's compensation	359 (66)	547 (52)	585 (58)	389 (55)
Medicaid	124 (23)	304 (29)	242 (24)	175 (25)
Self/uninsured	28 (5)	69 (7)	68 (7)	54 (8)
Not documented	29 (5)	140 (13)	117 (12)	83 (12)
Transported from scene by EMS*	364 (67)	777 (73)	716 (71)	702 (100)
Transfer from referring hospital*†‡	297 (55)	205 (19)	163 (16)	97 (14)
Mechanism of injury matching category*†				
Occupant of an automobile involved in an MVC	151 (28)	259 (24)	276 (27)	204 (29)
Nonautomobile MVC (includes children hit by cars and crashes involving motorcycles/all-terrain vehicles)	73 (14)	218 (21)	129 (13)	185 (26)
Falls (includes falls from bikes and during sports; and diving)	193 (36)	386 (36)	368 (36)	198 (28)
Other (includes other types of sport injuries and injuries involving animals)	123 (23)	197 (19)	239 (24)	115 (16)

CSI, Cervical spine injury; *MOI,* mechanism of injury; *MVC,* motor vehicle crash.
*Cases significantly different from random controls at α=.05 in *t* test or χ^2 test of homogeneity.
†Cases significantly different from MOI controls at α=.05 in *t* test or χ^2 test of homogeneity.
‡Cases significantly different from EMS controls at α=.05 in *t* test or χ^2 test of homogeneity.

validity, whereas inconsistency would suggest possible biased control group selection.[24]

Data Collection and Processing

We adhered to standard methods of chart reviews in emergency medicine.[25] Before participation, all study personnel attended research training sessions that included review of study materials and procedures, as well as mock chart reviews using standardized medical records. Once trained, on-site research assistants conducted structured chart reviews, and all data abstraction was subsequently verified by study site investigator (physician) review of the medical record. Variables under consideration as risk factors for cervical spine injury were defined a priori and selected from previous literature demonstrating associations with cervical spine injury or selected because of biological plausibility (Table 2).

Data were collected for each candidate risk factor from 3 separate sources: the study site medical record, referring ED record (if applicable), and EMS out-of-hospital run sheet (if applicable). We abstracted data by following an explicit manual of operations, which specified using findings from the first visit for the injury event and included a source hierarchy for identification of findings within each medical record. The data obtained from the study site medical record were used in all analyses unless otherwise specified.

We performed both remote and on-site monitoring to ensure adherence to data abstraction procedures. To assess the interrater reliability of the chart abstraction, a second investigator abstracted select variables for 10% of the study sample. Interobserver agreement was assessed with the κ statistic, with lower 95% confidence limit greater than 0.4 denoting at least moderate agreement.[26] Variables with less than moderate interobserver agreement were retained in the analysis for exploratory purposes; however, the reliability of these variables should be interpreted cautiously.

Primary Data Analysis

We described children with cervical spine injury and children in each control group in terms of mean age and frequencies for sex, race, payer source, EMS out-of-hospital care, transfer from a referring ED, and mechanism of injury category. We calculated bivariable odds ratios for cervical spine injury and 95% confidence intervals (CIs) for each candidate risk factor, using unconditional logistic regression when comparing cases with random controls and conditional logistic regression when

Table 2. Variables under consideration for modeling risk of cervical spine injury in children.

Risk Factor	Definition for Chart Abstraction
Altered mental status	Glasgow Coma Scale score <15, AVPU scale (Alert, Voice, Pain, Unresponsive) <A, evidence of intoxication, or mental status descriptions deemed by consensus panel to represent altered level of consciousness
Loss of consciousness	History of loss of consciousness postinjury
Nonambulatory	Child >2 y reported as unable to ambulate postinjury
Focal neurologic findings	Paresthesias, loss of sensation, motor weakness, or other neurologic finding deemed consistent with spine injury by consensus panel (eg, priapism)
Complaint of neck pain	History states that the child (if >2 y) complained of neck pain
Posterior midline neck tenderness	Physical examination notes neck tenderness as posterior, midline, or at a designated cervical level; or a descriptor that consensus panel deemed consistent with posterior midline neck tenderness
Any neck tenderness	Any documented tenderness on physical examination of the neck
Torticollis	Torticollis, limited range of motion, or difficulty moving the neck noted in history or physical examination
Substantial injury	Observable injuries that are life threatening, warrant surgical intervention, or warrant inpatient observation
Extremity	Considered legs to hip and arms to clavicle (eg, long bone fractures, degloving injuries)
Face	Considered noncranial region of the head (eg, orbital, maxilla, or mandible fractures)
Head	Considered cranial region of the head (eg, skull fracture, intracranial hemorrhage)
Torso	Thorax including clavicles, abdomen, flanks, back including the spine and the pelvis (eg, rib fractures, visceral or solid organ injury, pelvic fracture)
Predisposing condition*	Conditions known to predispose to CSI and that are observable on physical examination (Down syndrome, Klippel-Feil syndrome, achondrodysplasia, mucopolysaccharidosis, Ehlers-Danlos syndrome, Marfan syndrome, osteogenesis imperfecta, Larsen syndrome, juvenile rheumatoid arthritis, juvenile ankylosing spondylitis, renal osteodystrophy, rickets, history of CSI or cervical spine surgery)
High-risk mechanism	
Diving	Diving
Fall	Fall from a height >10 ft
Hanging	Hanging
Hit by car	Pedestrian, bicycle rider, or nonmotorized vehicle struck by a motor vehicle
MVC	Head-on collision, rollover, ejected from the vehicle, death in the same crash, or speed >55 miles/h
Other MV	Nonautomobile, MVC (eg, motorcycle)
Axial load to any region of the head*	The impact was noted in history to be head first, any region of the head
Axial load to top of the head*	The impact was noted in history to be head first, region noted to be top of head
Clothes-lining	Injury the result of a rope, cable, or similar item exerting traction on the neck while the child is in motion

*Not evaluated for interrater reliability.

comparing cases with the mechanism of injury and EMS control groups.

To identify a parsimonious group of variables independently associated with cervical spine injury, we constructed a multivariable unconditional logistic regression model with the cervical spine injury case group and the random control group, using forward variable selection. This procedure considered all potential variables, adding individual variables with the largest score χ^2 statistic to the model until no remaining variable had a score χ^2 $P<.05$ when added to the model. Using the same forward selection process, we constructed 2 conditional logistic regression models: (1) cervical spine injury cases compared with mechanism of injury controls, and (2) cervical spine injury patients brought to the hospital by EMS with EMS controls.

For the unconditional model, we explored the influence of study site on the model by introducing study site as a random effect.

The forward variable selection procedure for each of the 3 models was repeated with 1,000 bootstrap samples to assess the stability of the selected risk factors. We considered a variable to be validated as a predictor if it was identified as significant in more than 50% of the bootstrap analyses.[27] To determine the influence of missing data on the regression models, we fit final conditional and unconditional models to multiple imputed data sets and re-estimated adjusted odds ratios.[28]

To evaluate how well the combination of risk factors identified in the unconditional regression model distinguished cases from controls, we calculated the proportion of cervical spine injury cases with at least 1 risk factor (sensitivity of the model for cervical spine injury) and the proportion of controls with no risk factors (specificity of the model). To be classified as having no risk factors, the patient's medical record had to have each of the factors documented as absent. The presence of any factor placed the subject in the at-risk category. Patients with otherwise missing data were eliminated from this analysis. To estimate the maximum sensitivity (and minimum specificity) of the model, we repeated this analysis with positive findings from the transferring hospital ED record and EMS out-of-hospital run sheet to replace missing or negative study site findings. To further explore the performance of the unconditional model, we repeated the sensitivity analysis for the subset of

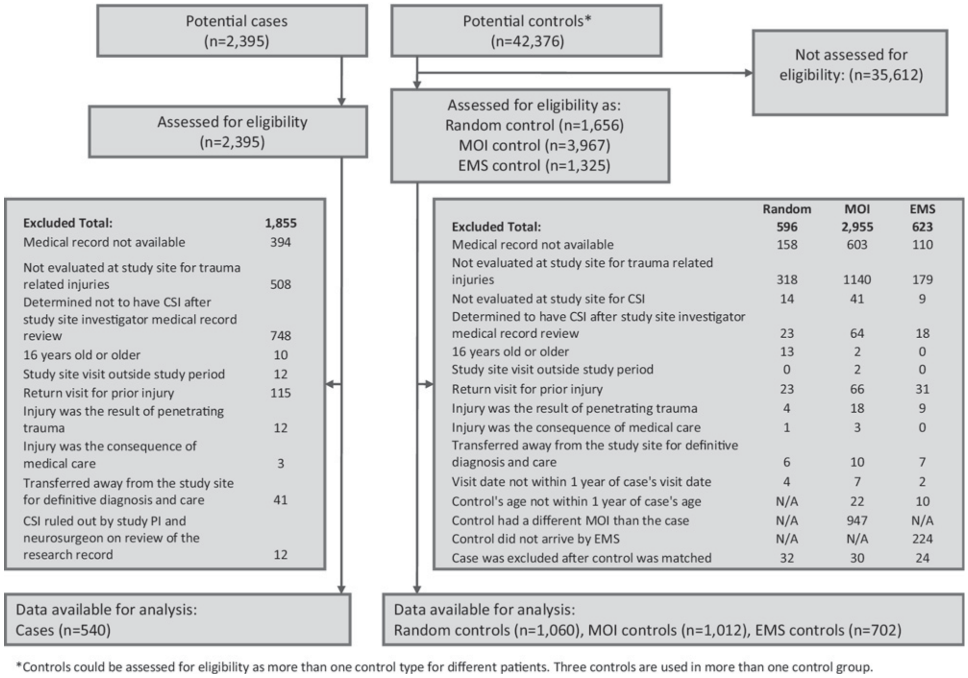

Figure. Subject identification.

cases with injuries requiring stabilization (internal fixation, halo, or brace). In addition, we evaluated a model composed of only the risk factors common to all 3 regression models.

We performed all analyses with SAS/STAT software (version 9; SAS Institute, Inc., Cary, NC), using the LOGISTIC procedure. We performed multiple imputation of missing data with IVEware (Survey Research Center, University of Michigan).

RESULTS

We identified 2,395 children as potential cases (Figure). Of these, 540 (23%) met inclusion criteria and were enrolled. Potential controls included 42,376 children, of whom 1,060 met inclusion criteria and were enrolled as random controls; 1,012, as mechanism of injury controls; and 702, as EMS controls. There was very little overlap between the control groups, with only 3 control patients being used in more than 1 control group. Descriptive characteristics of the cases and control groups are presented in Table 1. Case patients were significantly older than random controls (mean age 10.4 years versus 8.9 years). Compared with all controls, case patients were more likely to be white, have private insurance, and be transferred to the study site from a referring hospital.

Fifteen of the 19 candidate variables that were evaluated had at least moderate interrater agreement. Variables with less than moderate agreement included substantial injuries to the head, face, and torso; and clothes-lining. These findings tended to have low prevalence or required the abstractor to make a subjective judgment about the severity of the finding.

Bivariable analysis using random controls revealed 17 variables significantly associated with cervical spine injury and 5 variables without significant associations (Table 3). The multivariable analysis resulted in an 8-variable model that included altered mental status, focal neurologic deficit, complaint of neck pain, torticollis, predisposing condition, substantial injury to the torso, high-risk motor vehicle crash, and diving. The random effect of study site was negligible, resulting in odds ratios and CIs equal to those in the presented model, which ignored study site.

Bivariable analysis comparing children with cervical spine injury with mechanism of injury controls revealed 13 variables significantly associated with cervical spine injury and 9 variables without significant associations (Table 3). The multivariable analysis using mechanism of injury controls resulted in an 8-variable model that included altered mental status, focal neurologic deficit, complaint of neck pain, substantial injury to the torso, diving, high-risk motor vehicle crash, axial load to any region of the head, and clothes-lining.

Bivariable analysis comparing children with cervical spine injury who received EMS out-of-hospital care with EMS controls revealed 13 variables significantly associated with cervical spine injury and 9 variables without significant associations (Table 3). The multivariable analysis using EMS controls resulted in an 8-variable model that included altered mental status, nonambulatory patient, focal neurologic deficit, complaint of neck pain, torticollis, substantial torso injury, high-risk motor vehicle crash, and diving.

Bootstrapping validation of the multivariable analyses identified the same set of significant predictors greater than 50% of the time in all the models except for high-risk motor vehicle crash, which appeared in 45% of bootstrapped mechanism of injury models.

Table 3. Factors associated with cervical spine injury.

	Odds Ratio (95% CI)					
	Random Controls		MOI Controls*		EMS Controls*	
Predictor	**Bivariable Analysis**	**Multivariable Model**	**Bivariable Analysis**	**Multivariable Model**	**Bivariable Analysis**	**Multivariable Model**
Altered mental status	2.0 (1.5–2.5)	3.0 (2.1–4.3)	2.6 (1.9–3.4)	3.6 (2.2–5.7)	2.7 (2.0–3.7)	3.4 (1.9–6.1)
Loss of consciousness	1.4 (1.1–1.8)	†	1.1 (0.9–1.4)	†	1.4 (1.0–1.8)‡	†
Nonambulatory	1.0 (0.8–1.3)	†	1.3 (1.0–1.8)	†	2.6 (1.6–4.4)	2.8 (1.2–6.6)
Focal neurologic findings	8.1 (5.9–11.2)	8.3 (5.6–12.2)	5.7 (4.1–7.9)	5.5 (3.6–8.6)	8.5 (5.5–13.1)	8.8 (4.7–16.4)
Complaint of neck pain	2.0 (1.6–2.5)	3.2 (2.3–4.4)	1.9 (1.5–2.5)	3.0 (2.1–4.4)	1.9 (1.4–2.5)	2.3 (1.4–3.8)
Posterior midline neck tenderness	1.4 (1.1–1.8)	†	1.3 (1.0–1.6)‡	†	1.2 (0.8–1.6)	†
Any neck tenderness	1.3 (1.1–1.7)	†	1.1 (0.9–1.4)	†	1.3 (1.0–1.7)	†
Torticollis	1.8 (1.2–2.7)	1.8 (1.1–2.9)	2.1 (1.4–3.3)	†	11.7 (3.4–39.7)	64.5 (6.9–602.6)
Substantial injury: extremity	1.1 (0.7–1.5)	†	1.3 (0.9–2.0)	†	1.1 (0.7–1.6)	†
Substantial injury: face§	1.0 (0.6–1.7)	†	0.7 (0.4–1.2)	†	1.3 (0.7–2.3)	†
Substantial injury: head§	1.6 (1.2–2.1)	†	1.9 (1.4–2.6)	†	2.0 (1.4–2.9)	†
Substantial injury: torso§	1.9 (1.3–2.8)	1.9 (1.1–3.4)	3.7 (2.2–6.3)	4.3 (1.8–10.3)	2.8 (1.8–4.3)	2.6 (1.2–5.7)
Predisposing condition	5.0 (1.6–16.0)	15.0 (2.9–78.0)	5.0 (1.6–15.9)	†	1.5 (0.3–6.7)	†
High-risk mechanism: diving	73.3 (10.0–536.7)	73.0 (9.6–555.6)	16.3 (5.8–45.9)	15.4 (4.0–58.6)	32.0 (4.2–241.3)	74.3 (0.9–>999)
High-risk mechanism: fall	0.5 (0.2–0.9)	†	0.5 (0.3–1.1)	†	0.5 (0.2–1.1)	†
High-risk mechanism: hanging	0.8 (0.0–10.4)‡	‖	2.0 (0.0–78.0)‡	‖	0.8 (0.0–10.6)‡	‖
High-risk mechanism: hit by car	0.5 (0.4–0.7)	†	0.6 (0.3–1.5)	†	0.6 (0.4–0.8)	†
High-risk mechanism: MVC	1.7 (1.3–2.3)	2.5 (1.8–3.6)	6.6 (2.5–17.0)	2.8 (1.0–8.3)¶	2.1 (1.5–2.8)	3.6 (2.1–6.1)
High-risk mechanism: other MV	1.1 (0.6–2.0)	†	1.4 (0.6–3.2)	†	0.9 (0.4–1.7)	†
Axial load to any region of the head	1.6 (1.3–2.0)	†	1.5 (1.2–1.9)	1.5 (1.0–2.2)#	1.5 (1.1–2.1)‡	†
Axial load to top of the head	2.4 (1.4–4.2)	†	3.2 (1.7–5.8)	†	6.0 (2.2–16.5)	†
Clothes-lining§	3.0 (1.2–7.5)	†	2.9 (1.1–7.5)	3.0 (1.0–9.4)	4.0 (0.7–21.8)	†

MV, Motor vehicle.
*Conditional logistic regression was used for EMS and MOI control groups.
†Not selected for inclusion in model.
‡Exact estimate and CI.
§κ Statistic lower bound less than 0.4.
‖Hanging was not included in model selection because of nonprevalence in cases and less than 0.5% prevalence in controls.
¶Not validated with bootstrapping.
#95% CI includes 1.0 when estimated with multiple imputed data.

All factors identified by the unconditional model and the conditional model using EMS controls remained significant when multiple imputed data sets were used. Only the odds ratio for axial load to any region of the head (odds ratio 1.2; 95% CI 1.0 to 1.4) was weakened in the matched analysis using the mechanism of injury control data set and multiple imputation for missing data.

The sensitivity and specificity of identifying cervical spine injury defined by the presence of at least 1 factor in the unconditional model were 94% (95% CI 91% to 96%) and 32% (95% CI 29% to 35%), respectively. The addition of positive findings from the transferring hospital ED record or EMS out-of-hospital run sheet improved sensitivity to 98% (95% CI 96% to 99%) and decreased specificity to 26% (95% CI 23% to 29%). There were no consistent injury patterns among children with cervical spine injury who did not have any of the risk factors identified in the unconditional model (Table 4). All children with cervical spine injury not identified by the model had normal neurologic outcomes (no cognitive, sensory, or motor deficits) at discharge.

The sensitivity of identifying children with cervical spine injury who required neurosurgical stabilization (n=184), defined by the presence of at least 1 factor in the unconditional model, was also 94% (95% CI 90% to 97%). The addition of positive findings from the transferring hospital ED record or EMS out-of-hospital run sheet improved this sensitivity to 98% (95% CI 95% to >99%).

Six variables were common to all 3 models. These included altered mental status, focal neurologic deficit, complaint of neck pain, substantial injury to the torso, high-risk motor vehicle crash, and diving. The sensitivity and specificity for identifying cervical spine injury by the presence of at least 1 of these 6 factors was 92% (95% CI 89% to 94%) and 35% (95% CI 32% to 38%), respectively. The addition of positive findings from the transferring hospital ED record or EMS out-of-hospital run sheet improved sensitivity to 97% (95% CI 95% to 98%) and decreased specificity to 29% (95% CI 26% to 32%).

LIMITATIONS

Most of the limitations of this study are inherent to retrospective chart reviews and include the potential for ascertainment and sampling bias and missing data. The chart abstraction in our study was rigorously conducted, however, and we used several measures

Table 4. Characteristics of children with CSI who did not have one of the 8 factors in the unconditional model.

	Age, Years	Mechanism of Injury	Injury	Disposition	Treatment
11 children with CSI missed when all data sources considered	5	Collision or fall from bicycle	Atlantoaxial rotary subluxation	Floor	Rigid collar
	1	Fall from elevation	C1 lateral mass fracture	OR	Brace
	12	Fall from elevation	C5 compression fracture	Home	Soft collar
	9	Fall from elevation	Os odontoideum with ADI >5 mm	Home	Internal fixation*
	15	Motorized transport crash (eg, ATV)	C5-7 spinous process fractures	Floor	Rigid collar
	12	Sports injury	C7 transverse process fracture	Home	Rigid collar
	14	Collision or fall from bicycle	C2 vertebral body fracture	Floor	None
	10	Fall from elevation	C3 lateral mass fracture	Floor	None
	2	Fall down stairs	SCIWORA	Floor	Brace
	10	Fall from standing/walking/running	Odontoid fracture, type 2	ICU	Halo
	12	Bicycle struck by moving vehicle	C6 compression fracture	ICU	Rigid collar
33 children with CSI missed when only study site data considered	14	Collision or fall from bicycle	Odontoid fracture, type 2	ICU	Halo
	13	Motorized transport crash (eg, ATV)	C6 vertebral body fracture	ICU	None
	8	Pedestrian struck by moving vehicle	C2 lateral mass fracture	ICU	Rigid collar
	14	Pedestrian struck by moving vehicle	C7 transverse process fracture	OR	Rigid collar
	13	Collision or fall from bicycle	SCIWORA	Floor	Rigid collar
	12	Collision or fall from bicycle	C3 burst fracture with spinal cord injury	Floor	Halo
	14	Fall down stairs	C5 compression fracture	Home	Rigid collar
	11	Fall from elevation	Os odontoideum with spinal cord injury	ICU	Internal fixation
	13	Sports injury	C2-3 subluxation	Home	Rigid collar
	15	Collision or fall from bicycle	C2 laminar fracture	Floor	None
	15	Sports injury	SCIWORA	Floor	Rigid collar
	10	Blunt injury to the head/neck	Hangman's fracture	Floor	Halo
	14	Collision or fall from bicycle	C5 tear drop fracture with spinal cord injury	Floor	Brace
	9	Sports injury	Odontoid fracture, type 3	Floor	Halo
	1	Fall from elevation	Jefferson fracture	Floor	Rigid collar
	14	Sports injury	C7 spinous process fracture	Home	Soft collar
	12	Sports injury	SCIWORA	Floor	Rigid collar
	5	Fall down stairs	Odontoid fracture, type 2	Floor	Halo
	11	Sports injury	SCIWORA	Floor	None
	6	Fall from elevation	C2 spinous process fracture	Floor	None
	14	Motorized transport crash (eg, ATV)	C2 spinous process fracture	Floor	Rigid collar
	12	Fall from standing/walking/running	SCIWORA	ICU	None

SCIWORA, Spinal cord injury without radiographic association.
*Discharged home with subsequent outpatient surgery.

to limit these biases. These measures included uniform training of all study personnel, explicit instructions for data abstraction for each variable, interrater reliability measurements, and careful study monitoring. We also used multiple control groups to assess sampling bias and multiple imputation analyses to explore the effects of missing data.

Additionally, we identified factors by using a forward selection procedure that allows the entry of a new variable into the model, provided the new model is significantly improved. Because forward selection procedures only add variables, it is possible for the final model to contain variables that are significant when added but are no longer significant when considered in the presence of subsequently added variables. Although this did not occur for factors in the unconditional model, CIs for the high-risk motor vehicle crash, axial load to any region of the head, and clothes-lining odds ratios had a lower limit of 1.0 in the mechanism of injury model, and CIs for the diving odds ratio had a lower limit of 0.9 in the EMS model.

DISCUSSION

In this large, multicenter case-control analysis, we identified 8 factors associated with cervical spine injury in children who experienced blunt trauma (altered mental status, focal neurologic deficits, complaint of neck pain, torticollis, substantial injury to the torso, predisposing condition, high-risk motor vehicle crash, and diving). These historical and physical examination findings are highly predictive of cervical spine injury in children after trauma and differ somewhat from previously established adult screening criteria and those from smaller pediatric studies (Table 5).[1,11-13,20,21]

Table 5. PECARN model compared with previous cervical spine injury models: a comparison of predictive variables.

Children With CSI in Study Sample	Multicenter Studies			Single-Center Studies	
	PECARN Model, n=540	NEXUS Criteria,[1,11,12] n=30	Canadian C-spine Rule,[13] n=0	Jaffe,[20] n=59	Rachesky,[21] n=25
Mental status					
Altered mental status	X	X	X*	X	
History of head trauma					X
Intoxication	X†	X			
Focal neurologic deficits	X	X			
Abnormal reflexes				X	
Strength			X*	X	
Sensation				X	
Paresthesias			X		
Neck findings					
History of neck trauma				X	
Complaint of neck pain	X		X	X	X
Torticollis	X		X	X	
General neck tenderness				X	
Posterior midline neck tenderness		X	X		
Other examination findings					
Painful distracting injury		X			
Substantial torso injury	X				
Predisposing condition	X		X*		
Inability to ambulate			X		
Mechanisms of injury					
High-risk MVC	X		X‡		X‡
Diving	X		X		
Axial load to the head			X		
Fall from an elevation >1 m or 5 stairs			X		
Motorized recreation vehicle			X		
Bicycle collision			X		

*Considered at risk a priori and therefore excluded from derivation cohort.
†Included in definition of altered mental status.
‡Varies in definition when compared to PECARN definition.

The NEXUS collaborative reported a 5-variable decision rule that was derived and validated in a predominantly adult cohort.[1,11,12] Our model of cervical spine injury in children contains 3 of these 5 variables: altered mental status, intoxication (included in our definition of altered mental status), and focal neurologic deficits. Cervical spine injuries are known to be associated with head injuries, which is likely due to the association with axial load as a causal biomechanical force for both. Additionally, individuals with acute injuries to the upper cervical cord may experience respiratory compromise, hypoxic brain injury, and subsequent altered mental status. Focal neurologic findings, although uncommon, are fairly specific for spinal cord injuries.

Posterior midline neck tenderness, which was important in the NEXUS criteria, was not identified in our model. Instead, our model contains self-reported neck pain and torticollis. We considered substantial injuries that were observable on physical examination to be chart-ascertainable proxies for the painful distracting injury variable described by NEXUS. We subcategorized substantial injuries by region of the body, and in our model, only substantial injuries to the torso were important predictors of cervical spine injury in children. In contrast to NEXUS, which relied solely on clinical variables, we found 2 mechanisms of injury to be important cervical spine injury predictors in children: high-risk motor vehicle crash and diving.

The Canadian C-spine Rule is another decision rule for clinical clearance of the cervical spine in adult patients after blunt trauma.[13] Seven of the 8 factors identified in our model are consistent with this rule. The Canadian C-spine Rule does not include associated injury variables such as substantial torso injury. Predisposing condition, a factor absent from the NEXUS criteria, is included in both our model and the Canadian C-spine Rule. These conditions, in particular Down syndrome in children and ankylosing spondylitis in adults, although uncommon, are known to be associated with cervical spine injury.[29,30] The Canadian C-spine Rule, however, contains factors absent from our model, including falls greater than 3 feet or 5 stairs, crashes involving bicycles or motorized recreational vehicles, and inability to ambulate postinjury. Inability to ambulate, however, is a variable in our model of cervical spine injury generated with the EMS control group.

Two small, single-center studies identified risk factors for cervical spine injury in children. One included several variables that were similar to those in our model: altered mental status, focal neurologic findings, complaint of neck pain, and torticollis.[20] Unlike our model, that study included general neck tenderness but did not include any mechanistic factors. Another study proposed a 2-variable model (complaint of neck pain and motor vehicle crash with associated head trauma) that was able to identify all 25 children with cervical spine injury.[21]

Although 6 of the 8 risk factors for cervical spine injury were similar across all control groups, supporting the findings of the unconditional model, there were some different risk factors identified in the conditional models. Predisposing condition was not included in the models derived with the mechanism of injury and EMS control groups; however, this was one of the least prevalent findings in our study sample. Torticollis was not included in the model derived with mechanism of injury controls, which suggests that torticollis may be related to particular mechanisms of injury. Nonambulatory after injury was included in the model derived with EMS age-matched controls, which suggests that this factor may be important in identifying cervical spine injury in children who receive out-of-hospital care.

The mechanism of injury-matched analyses identified biomechanical forces (clothes-lining, axial load) and subsets of motor vehicle crash (high-risk motor vehicle crash) that were predictive of cervical spine injury for subjects within the same mechanism of injury-matching category. This highlights the importance of biomechanics and severity markers in defining risk factors for cervical spine injury. These risk factors, however, warrant prospective refinement because they were the weakest of the risk factors in the mechanism of injury-matched analysis.

This study represents a large investigation of cervical spine injury in children derived from primary source data. Although there were subtle differences between the conditional and unconditional models, the overall consistency between the models and the bootstrapping validation support the stability of the unconditional model. Application of this model as a decision rule within this sample of imaged children would have detected 98% of children with cervical spine injury and reduced exposure to spinal immobilization and ionizing radiation for the non–cervical spine injury children by more than 25%.

We identified 8 predictors of cervical spine injury in children after blunt trauma, including altered mental status, focal neurologic deficits, complaint of neck pain, torticollis, substantial torso injury, predisposing condition, diving, and high-risk motor vehicle crash. These factors should be highly considered in the development of a decision rule for the identification of children at negligible risk for cervical spine injury after blunt trauma, in whom immobilization and radiographic evaluation can be deferred.

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APPENDIX

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