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. 2010;xx:xxx.]

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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. 2010;■■:■■■.]

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 $\alpha=.05$ in *t* test or χ^2 test of homogeneity.
†Cases significantly different from MOI controls at $\alpha=.05$ in *t* test or χ^2 test of homogeneity.
‡Cases significantly different from EMS controls at $\alpha=.05$ 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.

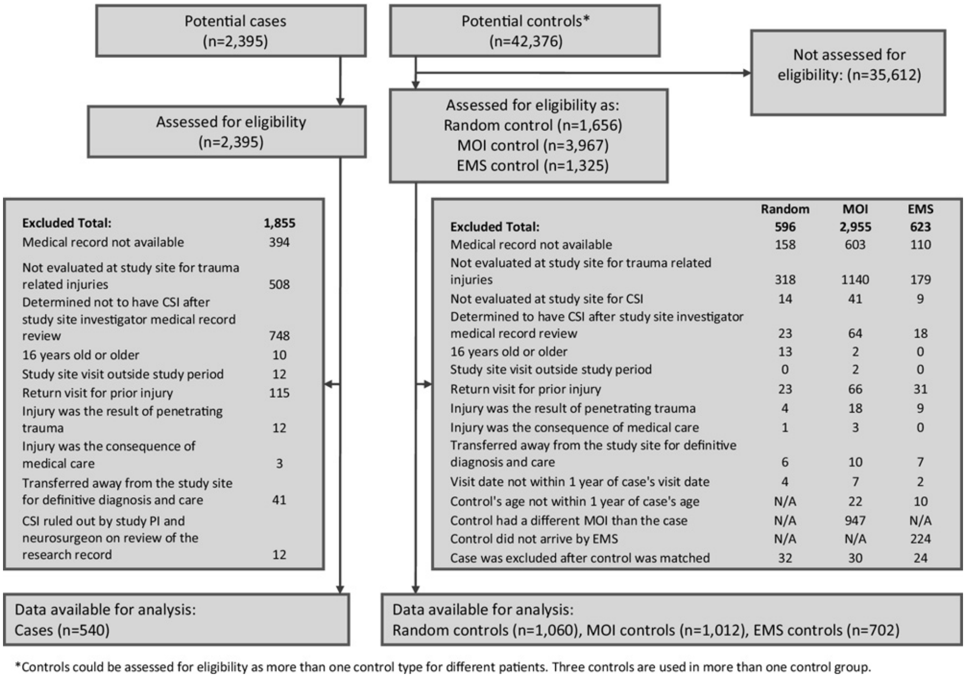
comparing cases with the mechanism of injury and EMS control groups.

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



Excluded Total:	**1,855**
Medical record not available	394
Not evaluated at study site for trauma related injuries	508
Determined not to have CSI after study site investigator medical record review	748
16 years old or older	10
Study site visit outside study period	12
Return visit for prior injury	115
Injury was the result of penetrating trauma	12
Injury was the consequence of medical care	3
Transferred away from the study site for definitive diagnosis and care	41
CSI ruled out by study PI and neurosurgeon on review of the research record	12

	Random	MOI	EMS
Excluded Total:	**596**	**2,955**	**623**
Medical record not available	158	603	110
Not evaluated at study site for trauma related injuries	318	1140	179
Not evaluated at study site for CSI	14	41	9
Determined to have CSI after study site investigator medical record review	23	64	18
16 years old or older	13	2	0
Study site visit outside study period	0	2	0
Return visit for prior injury	23	66	31
Injury was the result of penetrating trauma	4	18	9
Injury was the consequence of medical care	1	3	0
Transferred away from the study site for definitive diagnosis and care	6	10	7
Visit date not within 1 year of case's visit date	4	7	2
Control's age not within 1 year of case's age	N/A	22	10
Control had a different MOI than the case	N/A	947	N/A
Control did not arrive by EMS	N/A	N/A	224
Case was excluded after control was matched	32	30	24

*Controls could be assessed for eligibility as more than one control type for different patients. Three controls are used in more than one control group.

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

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.

we used several measures 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

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

	Multicenter Studies			Single-Center Studies	
Children With CSI in Study Sample	**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.

previously established adult screening criteria and those from smaller pediatric studies (Table 5).[1,11-13,20,21]

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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Editor's Capsule Summary *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%.

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Spinal Cord Injury in the Pediatric Patient

David J. Mathison, MD,* Nadja Kadom, MD,† Steven E. Krug, MD‡

Traumatic spinal cord injury (SCI) in pediatrics, although uncommon, can be devastating. Whereas there have been many evidence-based adult trials in SCI management, the data in the pediatric population are limited. Researchers continue to explore both clinical and radiographic guidelines to help better identify potential SCI without adding significant cost burden or potentially deleterious radiation. Treatment options, although promising, remain limited in clinical practice.

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KEYWORDS spinal cord injury, spinal fracture, pediatrics, SCIWORA, steroids, immobilization, cervical spine clearance, seat belt syndrome, cervical spine injury

Traumatic spinal cord injury (SCI) is uncommon in the pediatric population, with approximately 1000 new cases occurring each year in children 0 to 15 years of age [1]. Although the incidence in pediatrics is low, the potential for neurologic disability can be catastrophic.

Relative to that of adults, the pediatric spine is both more resilient to injury and more compliant to traumatic stress, yet the detection of injury is challenging because it can be radiographically occult. Because the diagnosis can be difficult and because there are few prospective studies of the management of suspected pediatric SCI, management both in the field and in the emergency department (ED) remains conservative and somewhat controversial.

This article provides a review of the pathophysiology of the pediatric spinal cord, SCI fundamentals, and current trends and recommendations for SCI evaluation and management in the ED.

Spinal Cord Basics

Biomechanics of the Pediatric Spine

The pediatric spine has unique developmental properties that explain why young children experience very different spinal injuries from adults. As compared with the adult spine, the immature spine is hypermobile secondary to ligamentous laxity, shallow facet joints, underdeveloped spinal processes, and physiologic wedging of the vertebral bodies. This is most notable in the cervical spine, where hypermobility combined with a large head-to-body ratio and poorly developed cervical musculature predisposes younger children to high torque forces.

The fulcrum of the cervical axis changes as children grow. In children younger than 8 years, the maximal mobility occurs at C1 to C3. As the ossification centers form and the C2 body fuses with the odontoid process (3-6 years of age), the fulcrum moves down to the C3 to C5 region. At 12 years of age, the fulcrum settles at C5 to C6, where it remains throughout adulthood. Younger children are therefore at higher risk of upper cervical injury [2,3]. In 2 large series of cervical spine injuries, 69% to 78% of patients 9 years and younger sustained upper cervical injuries (occiput to C2), whereas 70% to 73% of patients 10 years and older sustained lower cervical spine injuries (C3-C7) [4,5].

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The intervertebral discs in children have a unique morphology characterized by a higher water content relative to adult discs [6]. The result is a pliable and deformable pediatric disc that is more compliant with spinal injury.

Spinal Cord Neuroanatomy

The vertebral canal contains the spinal cord, spinal meninges (arachnoid, dura, and pia mater), and various related structures such as nerve roots and ganglia. The spinal cord begins at the foramen magnum level as the inferior continuation of the medulla and terminates in the conus medullaris, which ascends from level L3 (at birth) to L1 by 2 months of age. The lumbar and sacral thecal sac hold the cauda equina, a bundle of lumbosacral spinal nerves. The spinal cord is protected in the canal by the vertebral bodies anteriorly, the laminae and spinal processes posteriorly, and by the cerebrospinal fluid/meninges enveloping the cord (Figure 1A and B).

The spinal cord contains several tracts, each with a unique signaling pathway. Pain and temperature input sensations ascend in the lateral spinothalamic tracts, whereas touch sensation ascends primarily in the ventral spinothalamic tracts, each crossing over to the opposite cord side before ascending. Proprioceptive position and vibratory sensation fibers ascend in the posterior column and cross at the level of the brainstem. Sensory input arises from dermatomes that correspond to specific spinal levels. Testing sensation by dermatomes can help identify the level and location of injury.

The spinal cord conveys motor signals transmitted from the brain as well as from simple reflex arcs.

Upper motor neurons originate in the cerebral cortex, cross to the opposite side in the midbrain, and descend in the lateral corticospinal tracts to their synapses with the lower motor neurons in the anterior horn cells. The muscle reflex arcs are simple motor loops that do not directly communicate with the brain; therefore, they can remain functional despite disruption of the spinal cord above the level of the arc, which also aids in determining the level of injury.

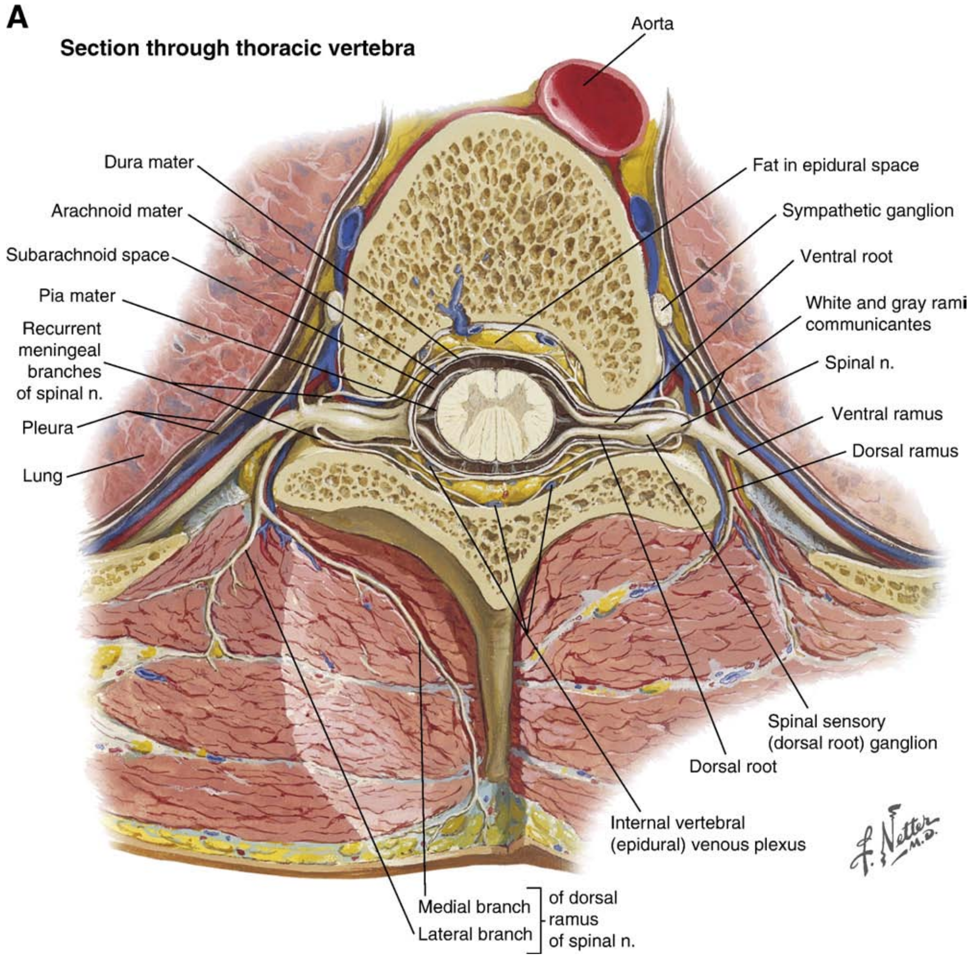


Figure 1 (A) Cross section of spinal cord at the thoracic vertebra. (B) Anterior, lateral, and posterior views of the spine showing the cervical (C1-C7), thoracic (T1-T12), lumbar (L1-L5), and sacral (S1-S5) levels. Reprinted from Netter Anatomy Illustration Collection, © Elsevier Inc. All rights reserved.

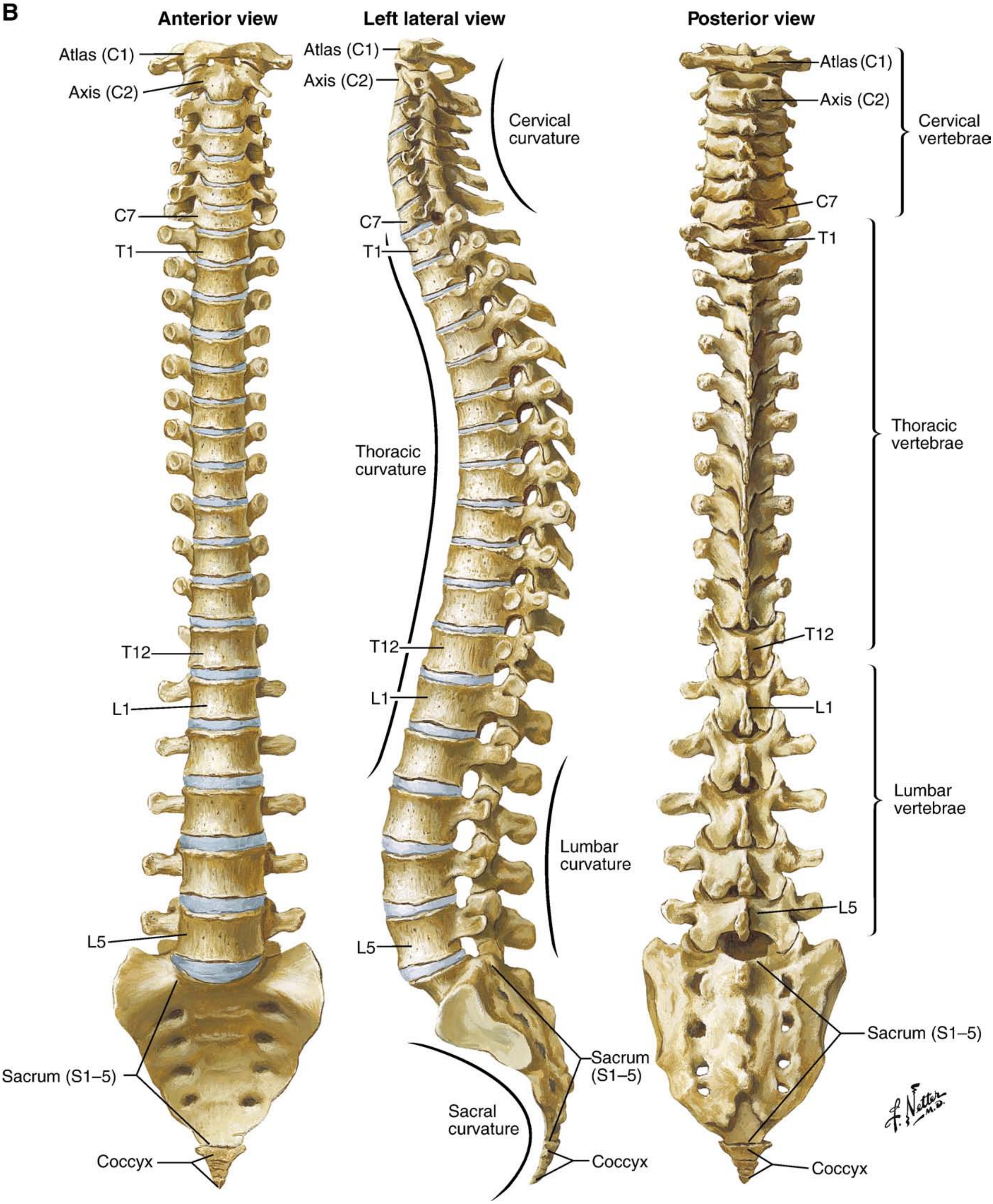


Figure 1 (*continued*).

Figure 2 (A) Lateral cervical conventional radiograph. Pseudosubluxation. Note the step-off between the 2 vertical white lines placed parallel to the anterior vertebral body contours of C2 and C3. These markers are expected to form a contiguous line in healthy adults, but stepping off can be normal in children where the ligaments are more pliable and allow for more physiologic displacement between vertebral bodies. (B) Lateral cervical conventional radiograph. C2-C3 fracture dislocation (arrow).

Postinjury Regeneration

Unlike the peripheral nervous system, the central nervous system (CNS) is less resilient in its ability to regenerate after an acute injury. Within hours of a cord injury, a glial scar is formed primarily by reactive astrocytes. These cells increase the expression of chondroitin sulfate proteoglycans, which have a potent inhibitory influence on regrowth [7]. In addition, the inflammatory cascade of phagocytic macrophages leads to the destruction of trophic factors, cell adhesion molecules, and cytoskeletal

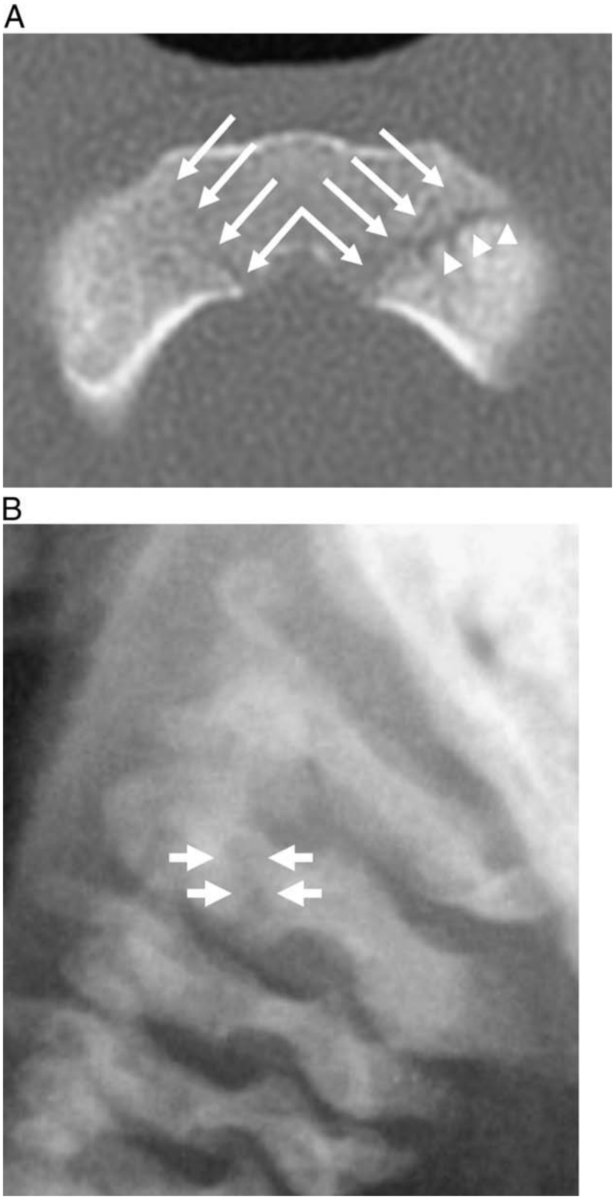


Figure 3 (A) Axial CT through C2 vertebral body. Nondisplaced fracture and synchondroses. This image illustrates the difficulty of differentiating physiological structures from abnormalities in the pediatric spine. The long arrows mark the course of the normal bilateral C2-odontoid synchondroses, and the arrowheads show a nondisplaced fracture. (B) Oblique cervical conventional radiograph. C2 synchondrosis (arrows). Frequently, intended lateral radiographs in children turn out to be somewhat oblique because of reduced cooperation by very young children.

proteins that are required for developing axons to attempt regeneration. The resultant apoptosis (programmed cell death) and unfavorable extracellular matrix render the resultant tissue irrecoverable.

In other species, spinal regeneration is possible, and there is considerable evidence that mammalian CNS neurons can regenerate in a favorable environment [8]. Many studies in rats have shown neuronal regeneration with stimulation of intrinsic growth capacity through the introduction of neurotrophins or growth factors such as fetal CNS tissue [9], nerve growth factor–producing fibroblasts [10,11], or autologous macrophages [12]. The human spine, however, requires more than a permissive growth substrate. Recent work has focused on combination therapy by removing inhibitory factors, creating a growth-permissive bridge across the scar (such as nerve grafts) [13,14], and increasing the intrinsic growth capacity of regenerating neurons [15].

Pediatric Spinal Trauma

Children and adolescents are exposed to a myriad of environmental and sociocultural factors that make spinal injuries in this population unique. For example, the often incorrect positioning of seat belts in motor vehicles, participation in competitive contact athletics, child abuse (ie, the shaken baby syndrome), and adolescent intentional injuries are typical etiologies in this population. When combining these mechanisms with the properties of the growing physiologic skeleton, it is clear that pediatric spinal injury has its own set of diverse and unique characteristics.

Trauma Mechanisms

Primary spine injury occurs when the initial force of impact exceeds the flexibility of the spinal column. The spinal cord can be directly injured either from a penetrating process such as a gunshot or blunt transecting trauma or from a significant force bending the vertebral column (with or without vertebral injury). Indirect cord injury can occur from the impaction of displaced bone or from associated vascular injury such as arterial disruption or thrombosis. Some mechanisms of spinal injury are described below.

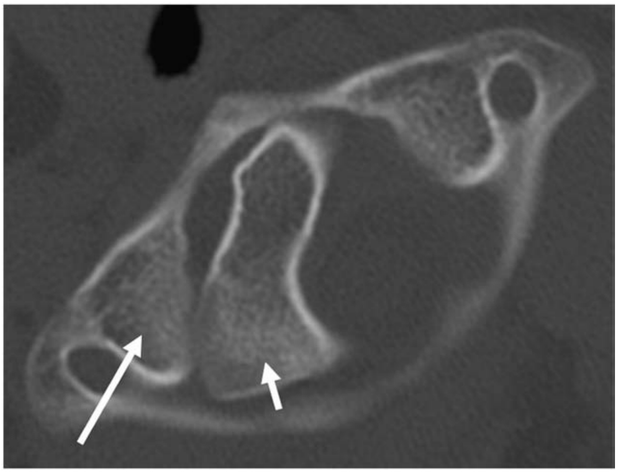


Figure 4 Axial CT through C1-C2 vertebral level. The right articular processes of both C1 (long arrow) and C2 (short arrow) are visualized in one image, diagnostic of dislocation.

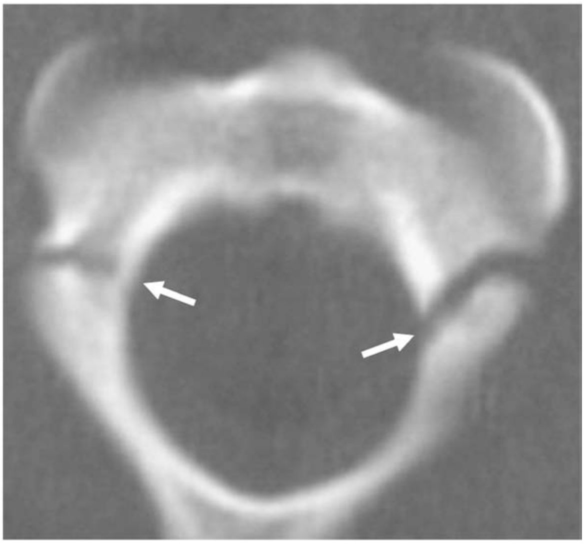


Figure 5 Axial CT through C2 vertebral body. Bilateral C2 pedicle fractures are shown (arrows).

Axial loading (vertical compression) occurs when strain energy overwhelms the absorptive capacity of the vertebral column. This occurs in direct blows to the top of the head, often when the head is lowered so the buffering ability of the soft tissues is diminished. This vertical compression is a common cause of injury to the C5 to C6 region, especially in contact sports such as football where players use the top of the helmet as a point of contact, known as “spearing.” Compression injuries are also common in diving and trampoline accidents. Burst fractures can occur in axial compression when the nucleus of the disc is forced into the vertebral body, often in the lower thoracic region or in the atlas (Jefferson burst-type fracture).

Flexion forces can cause distraction of the posterior ligamentous structures leading to rupture in a posterior-to-anterior direction. This hyperflexion may result in anterior subluxation, wedge compression fractures, or facet dislocations. Flexion distraction injuries occur when the fracture goes through the neural arches and exits the vertebral body anteriorly, often leading to SCI. Flexion injuries are most common in the cervical segments; however, lumbar flexion-distraction injuries occur as part of the seat belt syndrome.

Hyperextension forces are most commonly seen as “whiplash” in motor vehicle collisions (MVCs) but can also be seen in athletics such as illegal face blocking in football. Hyperextension injuries include avulsion fractures of the atlas, traumatic spondylolisthesis, and both laminar and pillar fractures.

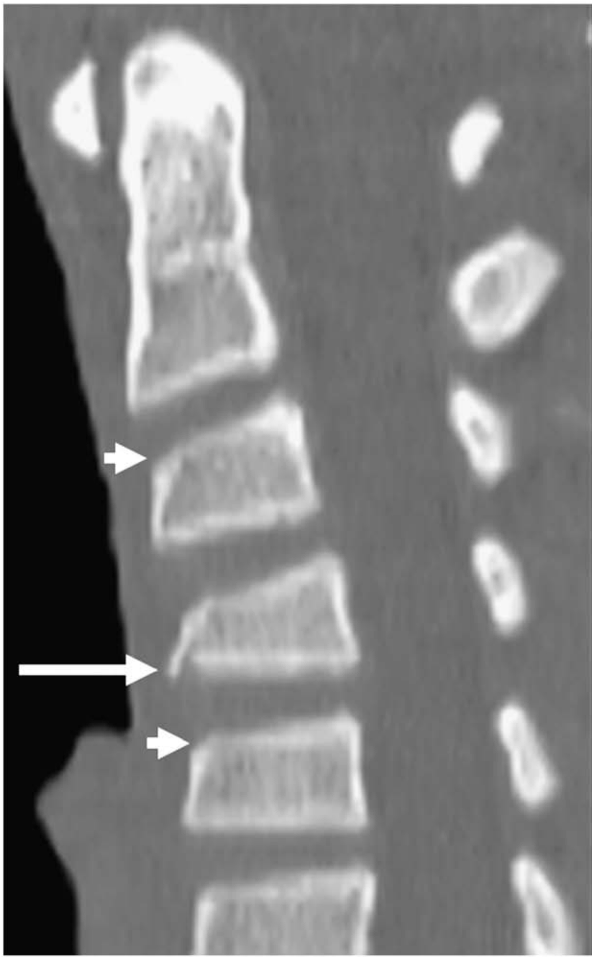


Figure 6 Sagittal reformats of axial CT image set. Subaxial fracture of C4. Note the anterior wedging and small displaced fragment anteriorly (long arrow). The mildly wedged appearance of adjacent vertebral bodies is a normal developmental appearance (small arrows).

Dislocation is less common because it often requires a significant rotational force. The accompanying damage to muscles and ligaments can lead to a compromise in the vascular structures of the spinal cord [16]. Fracture-dislocation injuries usually occur in the cervical segments or at the thoracolumbar junction and often result in an unstable spine necessitating operative stabilization [6].

Pediatric Normal Variants

It is not uncommon for a pediatric tertiary care center to receive a transfer of a neurologically intact trauma patient with a diagnosis of a "spine anomaly" that is subsequently found to represent an anatomical variant. It is therefore critical to understand some normal phenomena that can be confused with spine injury.

Pseudosubluxation is an incidental finding that occurs in children up to 14 years of age, usually at C2 to C3 but can occur as low as the C4 to C5 level. At least 3 mm of anterior displacement at C2 to C3 is present in 40% of children younger than 8 years [17]. It is important to recognize pseudosubluxation because a similar displacement of C2 on C3 can be produced by a Hangman fracture. On a lateral radiograph with physiologic pseudosubluxation, a line can be drawn through the posterior arches of C1 and C3, which should pass through or lie within 1 mm anterior to the anterior cortex of the C2 posterior arch (Figure 2A and B).

Synchondroses are located between ossification centers and are frequently confused with fractures in the growing pediatric cervical spine. The body of the C2 vertebra is a potential area of weakness containing 3 synchondroses that do not ossify until a child is 5 to 7 years of age. The C2 is the most commonly injured vertebra in children, and the odontoid synchondrosis is a potential area for injury until the synchondrosis is fully fused (Figure 3A). Occasionally, an extra ossification center at C2 called the os terminale is seen, and the synchondrosis between the dens and the arch of C2 should again be differentiated from a fracture [18]. A synchondrosis is often visible on an oblique view but not usually on a straight lateral radiograph (Figure 3B).

Another pediatric variant is the absence of cervical lordosis, common in 14% of children between 8 and 16 years of age [17]. Some older infants and children have flattening of the inner lumbar pedicles and posterior scalloping of the vertebral bodies that may be misinterpreted as an expanding intraspinal lesion [19]. By age 8 to 10 years, the pediatric spine begins to have more adult characteristics and the distribution of injuries becomes more similar to that of adults.

Spinal Fractures

Whereas SCI can certainly occur in the absence of vertebral fracture or radiographic abnormality, bone and ligamentous injury of the spinal column can lead to spinal instability with coexisting or subsequent SCI. There are several spinal injuries with which the emergency practitioner should be familiar, particularly in the cervical segments.

Occipitoatlantal Junction

Dislocations of the occipitoatlantal junction are devastating injuries that usually occur from MVCs. Occipitoatlantal injuries were once thought to be universally fatal, although recent improvements have been made with immobilization and internal fixation.

C1 (Atlas) Fractures

Burst fractures of the C1 ring usually result from a compressive force to the occipital condyles that displaces the atlas laterally. As previously discussed, this can be confused with normal synchondroses or anomalous ossification centers of the anterior arch.

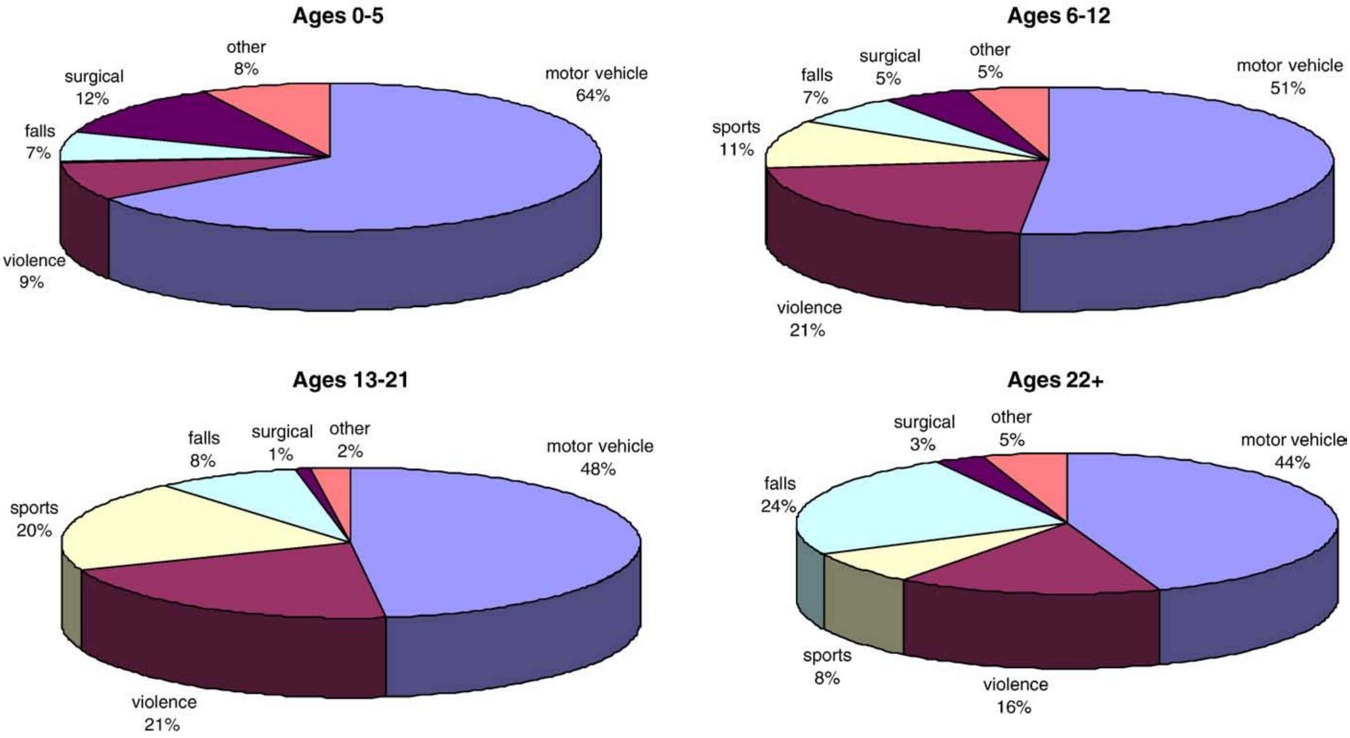


Figure 7 Etiology of pediatric and adult SCI. Data from DeVivo and Vogel [26].

Atlantoaxial (C1-C2) Injury

Approximately 50% of cervical rotation occurs between the first and second vertebral segments [6]. The spinal canal at C1 is larger to accommodate for rotation and can therefore tolerate some displacement; however, significant subluxation can lead to SCI. Injuries to the atlantoaxial junction can be rotational or translational and can be either stable or unstable depending on concomitant ligamentous injury. This highly mobile articulation houses the cervical medullary portion of the spinal cord, and injuries at this level are associated with a 50% risk of neurologic injury [20]. Translational atlantoaxial subluxation usually occurs from acute flexion injuries causing disruption of the broad transverse ligament and posterior ligaments connecting these levels (Figure 4). This injury occurs in the young developing spine when the head is disproportionately large and flexes against the C1-C2 axis. Rotary atlantoaxial subluxation in older pediatric patients, Griesel syndrome, is often nontraumatic in etiology, a result of infection and inflammation [21]. These patients present with neck pain and torticollis caused by swollen synovial tissue and muscle spasm preventing the axis from reducing spontaneously. Atlantoaxial instability can also be associated with several developmental disorders such as Down syndrome and Klippel-Feil syndrome.

Odontoid Fractures

C1-C2 instability can also result from odontoid fractures, which is almost always the cause of a C1 on C2 displacement in children younger than 11 years. The injury is due to an epiphyseal separation at the growth plate between the odontoid and the axis body and can result in the anterior displacement of the odontoid process. This fracture tends to decompress the cord, leading to fewer cord injuries than a true atlantoaxial dislocation. This injury is very uncommon in children after the growth plate has closed.

C2 Pedicle Fracture

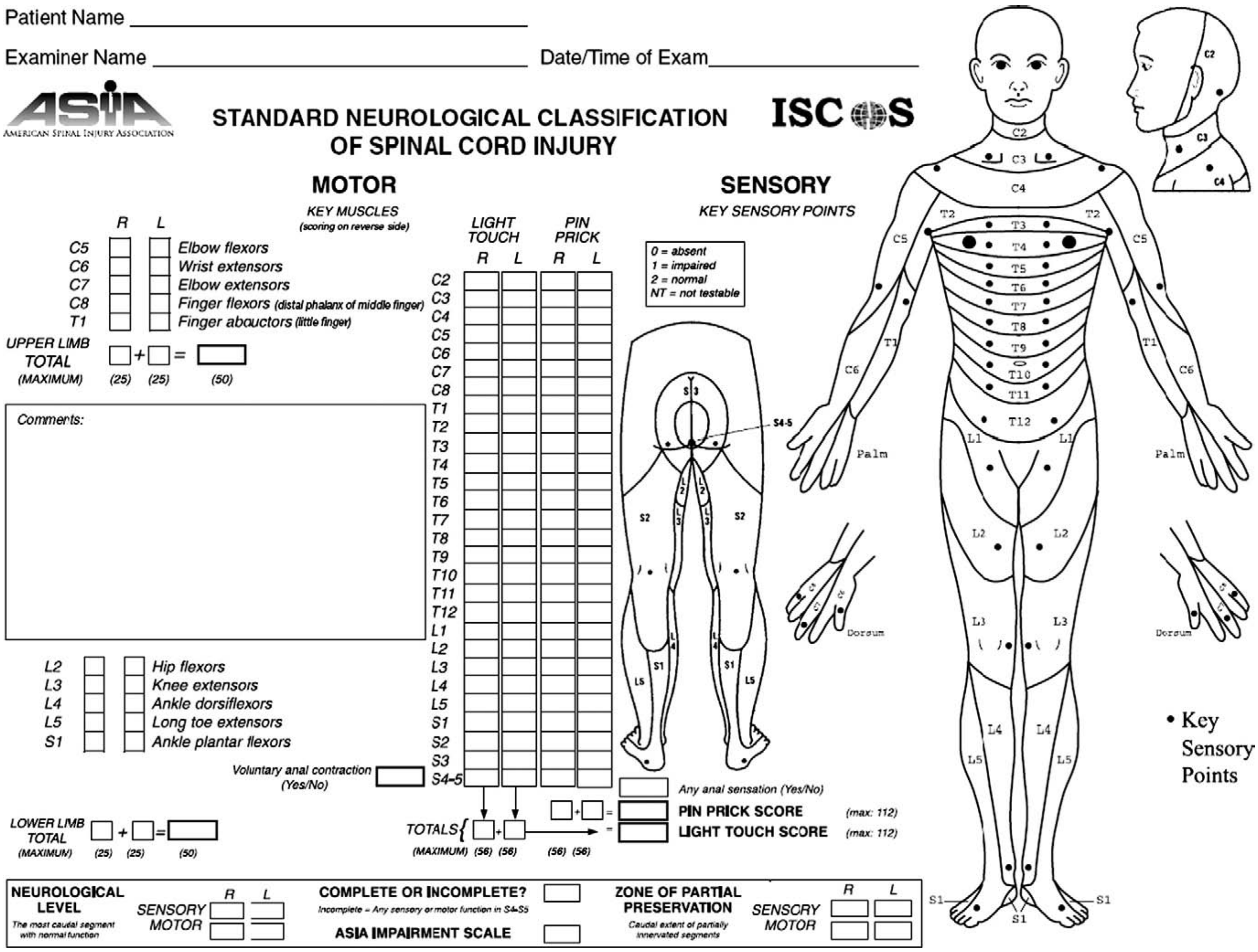
This injury, known as a Hangman's fracture, can lead to C2 spondylolisthesis against C3. Without subluxation, this fracture is difficult to diagnose because the radiograph appearance can mimic a normal synchondrosis until 7 years of age (Figure 5). Hangman's fractures often do not present with neurologic injury.

Subaxial Injury

The subaxial cervical spine is between C3 and C7. Subaxial injuries occur principally between C5 and C7, near the C5-C6 fulcrum that exists in adolescents. Subaxial spine injuries occur primarily in children older than 8 years, when the vertebrae begin to ossify, the facets become more vertically aligned, and cervical musculature is developed. These injuries are most often fractures (63%) or fractures with dislocations (19%) [22] (Figure 6).

Minor Thoracolumbar Fractures

Fractures to the spinous and transverse processes may be accompanied by severe injuries but, in isolation, can be



Patient Name ____________________

Examiner Name ____________________ Date/Time of Exam____________________

ASIA AMERICAN SPINAL INJURY ASSOCIATION

STANDARD NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

ISCOS

MOTOR

KEY MUSCLES (scoring on reverse side)

	R	L	
C5	☐	☐	Elbow flexors
C6	☐	☐	Wrist extensors
C7	☐	☐	Elbow extensors
C8	☐	☐	Finger flexors (distal phalanx of middle finger)
T1	☐	☐	Finger abductors (little finger)

UPPER LIMB TOTAL ☐ + ☐ = ☐
(MAXIMUM) (25) (25) (50)

Comments:

	R	L	
L2	☐	☐	Hip flexors
L3	☐	☐	Knee extensors
L4	☐	☐	Ankle dorsiflexors
L5	☐	☐	Long toe extensors
S1	☐	☐	Ankle plantar flexors

Voluntary anal contraction (Yes/No) ☐

LOWER LIMB TOTAL ☐ + ☐ = ☐
(MAXIMUM) (25) (25) (50)

SENSORY

KEY SENSORY POINTS

0 = absent
1 = impaired
2 = normal
NT = not testable

	LIGHT TOUCH R	LIGHT TOUCH L	PIN PRICK R	PIN PRICK L
C2	☐	☐	☐	☐
C3	☐	☐	☐	☐
C4	☐	☐	☐	☐
C5	☐	☐	☐	☐
C6	☐	☐	☐	☐
C7	☐	☐	☐	☐
C8	☐	☐	☐	☐
T1	☐	☐	☐	☐
T2	☐	☐	☐	☐
T3	☐	☐	☐	☐
T4	☐	☐	☐	☐
T5	☐	☐	☐	☐
T6	☐	☐	☐	☐
T7	☐	☐	☐	☐
T8	☐	☐	☐	☐
T9	☐	☐	☐	☐
T10	☐	☐	☐	☐
T11	☐	☐	☐	☐
T12	☐	☐	☐	☐
L1	☐	☐	☐	☐
L2	☐	☐	☐	☐
L3	☐	☐	☐	☐
L4	☐	☐	☐	☐
L5	☐	☐	☐	☐
S1	☐	☐	☐	☐
S2	☐	☐	☐	☐
S3	☐	☐	☐	☐
S4-5	☐	☐	☐	☐
TOTALS	☐ + ☐		☐ + ☐	
(MAXIMUM)	(56)	(56)	(56)	(56)

Any anal sensation (Yes/No) ☐

PIN PRICK SCORE ☐ (max: 112)

LIGHT TOUCH SCORE ☐ (max: 112)

NEUROLOGICAL LEVEL The most caudal segment with normal function		R	L	COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-S5	☐	ZONE OF PARTIAL PRESERVATION Caudal extent of partially innervated segments		R	L
	SENSORY	☐	☐	ASIA IMPAIRMENT SCALE	☐		SENSORY	☐	☐
	MOTOR	☐	☐				MOTOR	☐	☐

Figure 8 ASIA worksheet for neurologic classification of SCI. An ASIA impairment scale ranges from A (complete injury) to E (normal motor and sensory function) based on scores from the various categories [34].

considered minor fractures. Isolated transverse process fractures, as seen with blunt trauma to the back, do not cause spinal instability but may have associated injuries such as pleural cavity damage, renal contusion, or unstable pelvic fracture [6].

Epidemiology of Pediatric SCI

For the past 3 decades, the National Spinal Cord Injury Statistical Center has accumulated data on traumatic spinal injuries [23]. Approximately 7800 to 11000 new SCIs occur each year [24], with more than 50% of these injuries occurring in the 16 to 30 years age group [25]. Between 1973 and 2002, only 3.9% of all traumatic cord injuries occurred in children younger than 16 years [26].

Motor vehicle accidents are the most common cause of cord injury in both pediatric and adult populations, implicated in roughly 47% of all cord injuries. Motor vehicle collisions are also more likely to result in “serious” spinal injury [3]. The remainder of SCI in children, relative to adults, is more often from sporting events or violence and less likely from falls (Figure 7).

Sports-related injuries are particularly common in preadolescents, causing 28% of SCI in the 13 to 15 year age group. Sports-related SCI is most often confined to the cervical cord (23% C1-C4 and 66% C5-C8 in ages 13-21 years) [26]. Worldwide, sports such as diving, soccer, rugby, horseback riding, skiing, and wrestling are commonly implicated [27-29]. In the United States, football is most frequently responsible for sports-related SCI [30]. The incidence of football-related SCI has decreased over the past 30 years, likely because of improved on-field medical care and a 1976 rule change eliminating the use of the helmet as a focal point for blocking and tackling. Of football injuries, 71% occur in defensive positions, mostly from tackling rather than from being tackled [31]. In Canada, ice hockey causes most sports-related SCI, most often from colliding headfirst into the boards or by being pushed or checked from behind [32]. Other causes of SCI more frequent in the pediatric population include bicycling accidents (5.7% of SCI in children 6-12 years), trampoline accidents (1.8% of SCI in children 13-15 years), all-terrain vehicle accidents (1.8% of SCI in children 6-15 years), and pedestrian accidents (8.2% of SCI in children 0-12 years) [26].

Violence-related injuries occur most frequently in the adolescent age groups, particularly among certain ethnic groups [26]. Violence was the leading cause of SCI in both Hispanic and African American children aged 13 to 21 years. Among all adolescents aged 16 to 21 years, the proportion of SCI from violence was more than twice as high from 1990-1994 as during several previous time periods, although that trend has since decreased [33]. In the 0 to 5 years age group, child abuse SCI occurs about 5 times more often in African Americans than in white children and 3 times more often than in Hispanic children, as a proportion of SCI in each respective ethnic group [26].

Classification of SCI

Spinal cord injuries can be classified as either complete or incomplete lesions. A complete lesion is defined as an injury in which no motor and/or sensory function exists more than 3 segments below the neurological level of injury. The American Spinal Injury Association (ASIA) defines the level of SCI as the most caudal segment intact for both motor and sensory function on each side of the body [34]. A muscle group is considered intact if it has at least 3/5 (antigravity) strength with the next cephalic level having at least 4/5 strength. Sacral sparing represents partial structural continuity of the white matter long tracts, which indicates connection between lower motor neurons and the cerebral cortex, therefore indicating potential for neurologic improvement. Sacral sparing is defined as perianal sensation, rectal motor function, and great toe flexor activity. In the setting of spinal shock, sacral sparing may be the only sign present in the ED that an SCI is incomplete. The ASIA scoring system can be used for serial testing as an objective method to measure for neurologic improvement (Figure 8).

Incomplete lesions follow several characteristic patterns. *Central cord syndrome* is the most common pattern, with central gray matter destruction and preservation of the peripheral tracts. These patients tend to present with quadriplegia yet sacral sparing, and most gain some motor recovery. *Anterior cord syndrome* presents with complete motor and sensory loss yet retained trunk and lower extremity proprioception and pressure sensation. The prognosis of anterior cord syndrome for functional motor recovery is less than 10% [35]. *Posterior cord syndrome* presents with loss of sensation, pain, and proprioception with otherwise normal cord function (including motor). These patients present with a foot-slapping gait and, although are able to use their extremities, have difficulty controlling them. The *Brown-Sêquard syndrome* is a unilateral cord lesion characterized by a motor deficit ipsilateral to the injured side with a contralateral loss of pain and temperature sensation. Patients with Brown-Séquard syndrome have a very good prognosis, with more than 90% achieving functional recovery [35]. Incomplete cord syndromes can also occur with isolated spinal root injury. Root injury presents with motor and sensory deficit in a dermatomal distribution and generally has a favorable prognosis.

Spinal Shock

Spinal shock, or "spinal cord concussion," is a state of transient suppression of neural function below the level of an acute spinal cord lesion, usually in the setting of trauma, ischemia, hemorrhage, or inflammatory disease [36]. The disconnection from descending input leads to a flaccid paralysis resulting in the temporary loss (or depression) of tendon, cutaneous, and autonomic spinal reflex activity.

Spinal shock can occur from lesions anywhere in the cord. Data suggest that the physiologic cascade can occur from transection as high as the junction between the lower and middle third of the pons [37]. The progression of shock can occur within minutes. A similar concept occurs in the decapitated person who retains knee reflexes a few minutes after the cord transection [38,39]. The area closest to the cord disruption is the most severely affected, whereas the segment most distal to the transection may be depressed later and is more likely to retain reflex capabilities.

This "spinal concussion" can last from hours to weeks. Muscle spindle reflexes tend to return caudal to cephalad, but in an altered form, often producing spasticity as the neurons reorganize and new synapses are formed. Denervation supersensitivity in partially denervated spinal neurons allows spinal reflexes to often return only days after the injury, although it takes weeks of activity-dependent competitive synapse growth to cause hyperreflexia [40]. It is the gradual return of reflex activity that truly defines "spinal shock."

Autonomic Dysreflexia

Autonomic dysreflexia describes a broad syndrome of intermittent autonomic dysregulation that can occur after SCI. Blood pressure changes and heart rate instability are the most notable measurable manifestations of autonomic dysreflexia, but symptoms can include facial flushing, headaches, sweating, and piloerection. Hickey et al [41] found that 51% of pediatric SCI at a T6 level or higher had associated autonomic dysreflexia, comparable with the adult population. The prevalence may be underreported in young children who may manifest autonomic problems with either lethargy or irritability.

Management of Spinal Trauma

Although many pediatric hospitals have trauma protocols for suspected SCI, there is no evidence-based set of criteria to help uniformly exclude SCI. Similarly, there are no consensus national pediatric guidelines for immobilization, clinical clearance of the cervical spine, diagnostic imaging algorithms, or use of adjunctive pharmacotherapy. The following sections describe the various aspects of pediatric SCI management in more detail.

Immobilization and Transport

Management of a patient with a potential SCI begins at the scene of the injury. Important steps include extrication, resuscitation, immobilization, and transport to a medical center. Up to 25% of SCI may occur after the traumatic event, during either the transport or manipulation in the ED [42-45].

Since the initiation of spine immobilization, there have been fewer complete and more partial SCIs, suggesting improved neurologic outcomes with spine immobilization [46,47]. Although there is clinical and biomechanical evidence that spine immobilization is protective, there are no case control studies or randomized trials showing the effect of spine immobilization on neurologic outcome after SCI.

Spine immobilization consists of a rigid cervical collar sized appropriately for age and a backboard with straps to immobilize the entire body to the length of the board. It is not necessary to use sandbags and tape as adjuncts for cervical spine immobilization, and it is not acceptable to use them in place of a cervical collar [48]. In children younger than 6 years, when the head is disproportionately large, lying flat on a spine board may cause excessive flexion of the spine — the supine kyphosis anterior translation phenomenon. Adding a pad under the shoulders to elevate the torso or cutting a hole in the spine board for the head will help maintain a more neutral position for the head and neck in these children [49].

Immobilization of the spine, however, is not without consequence. Most commonly, immobilization causes patient discomfort and delay of transport, but more significant morbidity can occur. Some notable reported morbidities of immobilization include elevation of intracranial pressures, limited respiratory function, aspiration, and pressure sores [50-55]. Techniques to minimize these adverse effects have been attempted. Some argue that simply minimizing the pain of immobilization may decrease voluntary movements associated with secondary SCI.

The biggest question is not *how*, but *who* should be immobilized. Although emergency medical services (EMS) providers may rightfully have a low threshold to prevent catastrophic transport-related SCI, the process of “clearing” an immobilized patient is time and resource intensive. Historically, the decision to immobilize has been based on the mechanism of injury, although some advocate that all trauma patients should be immobilized. In the United States, between 1.9 million and 2.4 million patients are immobilized annually, which undoubtedly carries a significant cost burden [56]. Several protocols for selective spinal immobilization are currently being studied. Domeier et al [57] conducted a prospective study of 13483 trauma patients using a 5-point protocol of altered mental status, intoxication, proximal extremity fracture, neurologic deficit, and spinal pain/tenderness. Their protocol missed 33 patients with spine injuries, although none of these patients sustained SCI. Burton et al [58] conducted a more recent and larger prospective study of 31885 transported trauma patients using a protocol that included mechanism of injury, level of consciousness, presence of distracting injury, motor/sensory examination, and spinal pain/tenderness. This protocol missed only 1 unstable spine fracture while sparing more than half of the patients from being unnecessarily immobilized [58]. There are currently no accepted immobilization protocols for EMS personnel that have been validated in a pediatric population.

Table 1 Comparing the NEXUS and CCR decision rules for C-spine clearance.

NEXUS	CCR
All of the following:	Any one of the following:
1. No cervical spine tenderness	1. Simple rear-end MVC [a]
2. Normal level of alertness	2. Sitting position in the ED
3. Absence of intoxication	3. Ambulatory after trauma
4. No focal neurologic deficit	4. Delayed neck pain
5. No painful distracting injury	5. No cervical spine tenderness
	Plus
	1. Age <65 years and
	2. Absence of dangerous mechanism [b]
	3. Absence of paresthesias in extremities
	4. Ability to rotate neck actively 45° left and right

[a] Simple rear-end MVC excludes being hit by a bus or large truck and being pushed into oncoming traffic.

[b] Dangerous mechanism is defined as a fall of 3 ft or more or 5 stairs; axial load to head; bicycle or recreational vehicle collision; high-speed collision (>100 km/h); or MVC with rollover or ejection.

Resuscitation and Neurogenic Shock

Initial management involves a thorough trauma assessment beginning with airway stabilization and assurance of adequate oxygenation and ventilation. Assessment of circulatory function and support of both tissue perfusion and blood pressure is also critical. In the polytrauma patient, hypotension is frequently the result of hemorrhage and hypovolemia; however, the clinician must consider neurogenic shock in patients with cervical or high thoracic injury. Neurogenic shock presents with bradycardia and vascular hypotension from the disruption of sympathetic outflow and unopposed vagal tone.

Evaluation and Physical Examination

After stabilization and completion of the primary survey, the secondary assessment should include a detailed neurologic examination to determine motor, reflex, and sensory functions.

The responsive patient can be evaluated for active motor function by testing the following muscle groups: biceps flexion (C5), wrist extension (C6), wrist flexion (C7), finger extension (C8), finger flexion (C8), finger abduction (T1), hip abduction (L1-2), knee extension (L5-S1), great toe extension (L5), and great toe flexion (S1). A sensory examination should be conducted to evaluate sensation in different dermatomes. Reflexes commonly checked include biceps (C5), radial/wrist (C6), triceps (C7), cremasteric (T12-L1), plantar (L4), Achilles (S1), and anal wink (S2-4). In the patient with concomitant head injury, it is important to attempt to differentiate lower vs upper motor neuron injury. An abnormal plantar reflex (Babinski sign) may demonstrate signs of upper motor neuron dysfunction. Also, the presence of extremity stretch reflexes in the absence of active spontaneous muscle contraction indicates an upper motor neuron deficit.

In the setting of polytrauma or the obtunded patient, most trauma evaluations will proceed directly to imaging including, but not limited to, radiographs and computerized tomography (CT) imaging evaluating for intracranial and intraabdominal injury in addition to signs of SCI. However, even in a nonresponsive patient, the physical examination is important to look for signs of injury. Examination should include observation for spinous bruising, palpation of the spine for step-offs or interspinous widening, and testing of reflex arcs and rectal tone. Sites of injury may also help to discern the type of SCI. For example, lacerations in the occipital area may suggest flexion injuries, whereas frontal or superior bruising may be the sign of extension injury or axial loading, respectively [59].

Table 2 Algorithm for cervical spine imaging.

- In a responsive non-intoxicated patient with a GCS = 15 and a normal level of alertness:
  Consider clinical clearance without radiograph[a] if the patient meets the NEXUS criteria by demonstrating an absence of: distracting injury, neurologic deficit, midline cervical spine tenderness.
- In the obtunded or polytrauma patient or in the patient who fails NEXUS criteria
  Start with a good AP and lateral neck radiograph, add an odontoid view in a neurologically intact child older than 9 years. Follow the radiographs with CT scan if the patient has a neurological deficit or an abnormality on plain radiograph or if the radiographs are inadequate. A CT of the upper cervical spine can be easily performed at the time of head CT.
- In the patient with neurologic deficit or abnormal finding on initial imaging
  Consult neurosurgery and consider further imaging with MRI to identify SCI.

[a] Use with precaution in children younger than 3 years until the NEXUS criteria is further validated.

When to Image? Cervical Spine Clearance

Clearing the cervical spine is especially difficult in pediatric patients because children may be too young to respond to questions, they are more likely to have radiographically occult injuries, and there are many normal variations in their anatomy that can be interpreted as a sign of injury by radiologists and emergency providers. Patients with potential cervical spine injury total more than 13 million adult and pediatric visits to US and Canadian EDs annually [60]. However, positive findings are noted in only 2.9% of all pediatric cervical spine evaluations, and a fraction of these are clinically significant [61]. Although cervical spine radiography can be a simple low-cost procedure to "screen" for injury, it is both time and resource intensive in an ED. In addition, it results in often unnecessary exposure to ionizing radiation and prolongs uncomfortable immobilization.

Two clinical decision rules have been created to stratify low-risk patients and avoid radiography. The target populations for these rules are alert, stable adult patients without neurologic deficit. The National Emergency X-Radiography Utilization Study (NEXUS) criteria were described in 1992 [62,63] and validated in a US study of 34 069 patients, with a sensitivity of 99.6% [64,65]. To meet the NEXUS low-risk profile, the patient must satisfy all of the following 5 criteria: no posterior midline cervical spine tenderness, no evidence of intoxication, a normal level of alertness, no focal neurologic deficit, and the absence of painful or distracting injuries (Table 1).

A second decision rule, the Canadian Cervical-Spine Rule (CCR), was created in 2001. This rule added considerations to exclude those who could not actively rotate their neck (45° left and right) and those at high-risk of injury (dangerous mechanisms or advanced age). To further exclude patients without cervical tenderness the criteria were added, any of which would stratify the patient to low-risk: simple rear-end MVC, sitting position in the ED, ambulatory after accident, or delayed (not immediate) onset of neck pain (Table 1).

When these 2 decision rules were compared in a prospective Canadian cohort of 8283 patients, the CCR showed superior specificity and sensitivity, missing only 1 patient, whereas the NEXUS low-risk criteria would have missed 16 [66]. When the NEXUS low-risk criteria were applied retrospectively to Canadian ED data of almost 9000 patients, the sensitivity dropped to 92.7%, with 11 important injuries not identified, 2 patients treated with

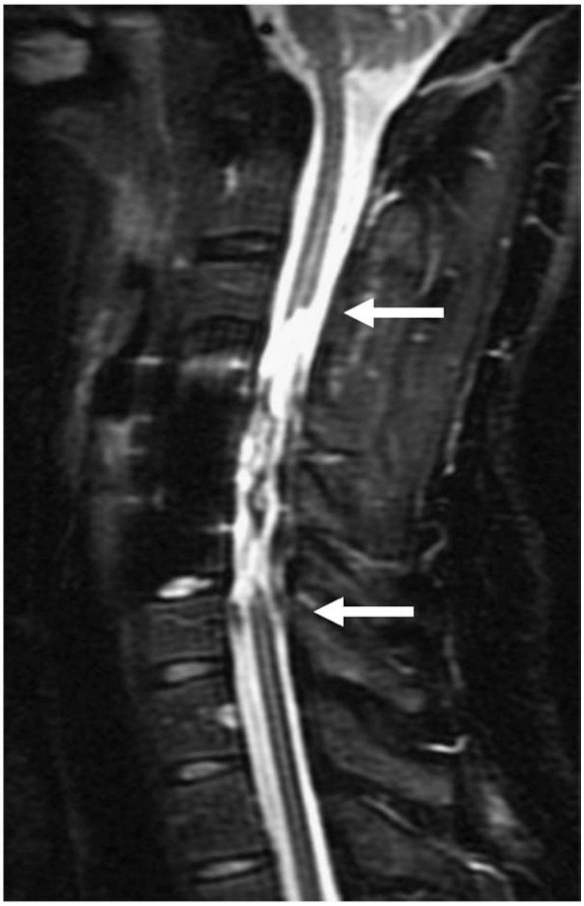


Figure 9 MRI of SCI. Sagittal T2-weighted MRI. Sequelae several years after diving accident. Note the complete destruction of the spinal cord between the levels marked with arrows when compared with the normal spinal cord at the levels superior and inferior to the arrows.

internal fixation and 3 with halos [67]. The results of these studies have been questioned, and it is unclear if either clinical rule is more efficacious [68,69]. Despite having these 2 instruments to help the emergency care provider stratify risk, neither of these rules adequately applies to children. The comparison study by Stiell et al [66] did not include patients younger than 16 years, and both of the original NEXUS and CCR studies had few pediatric SCIs.

Viccellio et al [70] applied the NEXUS criteria in a prospective multicenter trial to more than 3000 pediatric patients 0 to 18 years of age and found that the NEXUS decision instrument performed well with zero low-risk patients having an SCI, a sensitivity of 100%. However, this may be misleading because the incidence of SCI in pediatrics is extremely low and one should therefore expect a very high negative predictive value. This study may also be limited because less than 100 of the 3065 patients were younger than 2 years, of which only 2 sustained SCI, and only 4 of the 30 cervical SCI patients were younger than 9 years. A larger multicenter study of the NEXUS criteria in children is currently in progress.

How to Image? Radiographs and Computerized Tomography (CT)

In the patient who does not meet NEXUS criteria (obtunded, abnormal neurologic examination, distracting injury, etc), the patient is considered high risk and the ED physician has several tools available to evaluate for the presence of spine instability and the potential for SCI. Cervical spine radiographs are often the first step in the evaluation. Lateral and anteroposterior (AP) views are standard. The lateral view should include all 7 cervical vertebral bodies. An open-mouth odontoid view is often obtained to evaluate for C1 and C2 fractures; however, this view is functionally difficult in a noncompliant child, and the usefulness of this view in children is debatable. Buhs et al [71] evaluated 51 pediatric cervical spine injuries and found that 10 children younger than 9 years had injury between the occiput and C3 but none had a positive finding on open-mouth view, concluding that the odontoid view may not be necessary in children younger than 9 years. In a survey of 984 pediatric radiologists by Swischuk et al [72], 37% indicated that they would not routinely recommend an odontoid view and 44% would make one attempt at obtaining an adequate image. The authors concluded that the open-mouth view might not be useful in children younger than 5 years. In a review of odontoid synchondrosis fractures, Fassett et al [73] found that lateral radiographs were able to show anterior angulation or displacement of the dens in 94% of children with these fractures. Some centers therefore advocate protocols that do not require odontoid views in children younger than 5 years [61].

Flexion and extension radiographs are still the gold standard for evaluating the instability of the cervical spine, although this is not a test that should be routinely ordered in the ED. Some authors argue that if the AP and lateral radiographs are normal, then the value of the flexion and extension films is debatable [74,75].

Computerized tomography imaging is typically ordered in either the polytraumatized child or in the patient with abnormal conventional radiographs. Of note, many inadequate x-ray films can be complemented by a limited CT scan, just through the craniocervical or cervicothoracic junction, that way significantly reducing radiation exposure. Barrett et al [76] found that more than one third of patients with fracture-positive radiographs had additional fractures detected by CT. The application of CT as an adjunct for children is unclear because most children younger than 10 years have primarily ligamentous rather than osseous injuries [1].

In the past 20 years, development of faster helical CT has allowed fewer young children to require procedural sedation, which has contributed to CT imaging being more frequently ordered as a diagnostic tool in the ED. Despite efforts to reduce radiation doses in pediatric CT examinations [77] to ALARA (As Low as Reasonably

Achievable), studies estimate that current CT use may be responsible for 1.5% to 2.0% of all cancers in the United States [78]. Children's organs are more sensitive to radiation, and their longer life span allows time for the deleterious effects of radiation to manifest [79,80]. Cervical spine CT, in particular, causes a 14-fold increase in radiation to the thyroid gland relative to traditional radiographs [81]. Whereas CT imaging has improved the diagnosis of cervical spine fractures in adults, the benefits of widespread application in children are not clear. The increased potential for radiation damage within the lifetime of young patients needs to be considered. A simple imaging algorithm for use in the ED is described in Table 2.

Spinal Cord Injury Without Radiographic Abnormality

Spinal cord injury without radiographic abnormality (SCIWORA) describes a broad clinical spectrum of injury to nerve roots with sensory and/or motor dysfunction without evidence of vertebral fracture or malalignment on either plain radiographs or CT imaging. Also known as "pediatric syndrome of traumatic myelopathy without demonstrable vertebral injury," SCIWORA was proposed as a concept in 1907 [82], although its acronym was not coined until 1982 [83]. The reported incidence of SCIWORA varies from 19% to 34% of all pediatric SCI [84].

Although SCIWORA can occur from any variety of causes, it is usually the result of flexion/extension trauma such as from MVCs, falls from heights, and pedestrian accidents. It can be seen in adults; however, it is much more common in children. Theorists propose that the pediatric spine is more elastic and deformable, allowing excessive intersegmental movement that may contribute to neural injury without vertebral fracture [84]. Preexisting spondylosis or congenital stenosis may be aggregating factors [83], although that has been debated in recent literature [85].

Most often, SCIWORA occurs in either the mobile cervical spine or the thoracolumbar junction and less so in the thoracic spine because the rib cage is thought to limit forced thoracic flexion or extension [86]. The mildest form of SCIWORA is the "stinger," which occurs in football and rugby players after tackling an opponent. This injury often causes burning in the arms and hands, lasting only a short duration [8]. Complete injuries can occur from SCIWORA, more often in younger age groups. In the absence of radiographic abnormality, poor prognostic indicators include a severe deficit, clinically complete lesions, and younger children with upper cervical injuries [83,87,88].

Magnetic Resonance Imaging

With the increasing use of magnetic resonance imaging (MRI), physicians are able to detect injury to the spinal cord that can occur with or without vertebral injuries. Magnetic resonance imaging provides superior visualization of soft tissue neck anatomy, disc herniation, soft tissue injury, and spinal cord integrity. It is effective at visualizing edema or hemorrhage caused by trauma (Figure 9). This is particularly true for the obtunded or uncooperative child when clinical evaluation is often severely impaired. Also, MRI is helpful in predicting prognosis and clinical outcomes.

Dare et al [89] found that MRI did not visualize abnormal features in pediatric SCIWORA with partial syndromes. 78% of these patients had resolution of their symptoms within 72 hours, and the two patients with complete lesions had abnormal findings on MRI. However, it can be argued that patients with transient symptoms, negative MRIs, and complete recovery are not clinically significant. Frank et al [90] described an early-initiated MRI protocol for pediatric spine clearance and found that early MRI led to a reduction in time to clear, resulting in a savings of $7700 per patient without a significant change in the diagnosis of cervical spine injuries.

In the setting of a traumatic event, if the clinician suspects a neurologic abnormality or if the child has transient symptoms such as numbness, the child should be treated as a suspected SCI. If the initial radiographs and CT imaging do not demonstrate vertebral damage, the child should have an MRI to evaluate for SCIWORA, particularly in complete lesions. Magnetic resonance imaging can provide additional information on the integrity of the spinal ligaments, which is especially helpful in the assessment of instability in the obtunded patient where dynamic series such as flexion/extension radiographs are not possible.

Pharmacologic Therapy

For more than 20 years, practitioners have searched for an adjunct to be given postinjury that might improve neurologic recovery. Corticosteroids, particularly methylprednisolone, have been studied at length because of their theoretical ability to enhance spinal blood flow, scavenge free radicals, stabilize membrane structures, and limit the inflammatory response. In 1984, Bracken et al published the results of the first double-blind randomized trial of steroids in SCI, the National Acute Spinal Cord Injury Study (NASCIS I). The authors found no treatment effects at 6 weeks, 6 months, or 1 year comparing 10 days of low-dose vs high-dose steroid therapy [58,59]. However, no control group was used, and critics argued that much higher doses were necessary to see the benefits achieved in animal models. A follow-up study published in 1990 (NASCIS II) used higher steroid doses and found significant improvement in both motor and sensory scores at 6 months, particularly when steroids were initiated within the first 8 hours after SCI [91]. This article was the first to cite human benefit from steroids in SCI and received much attention; however, it was highly scrutinized, and many statistical and methodological flaws were described [92-99]. Several large series follow-up studies (both prospective and retrospective) have shown no significant effect of steroids on any neurologic outcome variable [100-103]. In addition, several authors cited the many significant complications of high-dose steroid use in these critically ill patients, most notably the increased incidence of pneumonia, sepsis, gastrointestinal bleeding, and length of intensive care unit stay [101,103-106]. A third NASCIS study by Bracken et al [107] followed, this time looking at shorter courses of high-dose steroids when administered within the first 8 hours after injury. They found that in patients given steroids between 3 and 8 hours, the patients treated for 48 hours had better neurologic recovery than did those treated for only 24 hours. However, there was no placebo group, rather there was a third group treated with tirilazad mesylate, a free-radical scavenger thought to impede the inflammatory reaction. All 3 groups had equal neurologic improvement when therapy was initiated within 3 hours of injury.

Although the evidence is hardly compelling, a 1999 survey indicated that 98% of ED medical directors use steroids in acute SCI [108]. Bracken authored 2 Cochrane reviews in 2000 and 2002, both concluding that methylprednisolone was the only medical therapy shown to be efficacious and supporting the continued use of steroids in SCI. However, other literature reviews have concluded otherwise, citing that there is not enough evidence to continue to recommend the use of steroids in SCI [109, 110].

There are no prospective studies of methylprednisolone in pediatric SCI. In the NASCIS II study, there were no patients younger than 13 years, and only 15% of the study population was between 13 and 19 years. Wang et al [111] retrospectively described 4876 pediatric trauma patients (0-18 years), of which 30 had SCI, 8 of whom received methylprednisolone. This study demonstrated improved neurologic recovery in the pediatric population relative to adults, speculating that pediatric patients with complete SCI were more likely to regain neurologic recovery. However, methylprednisolone did *not* contribute to the improved neurologic outcomes.

Further study and data are needed for there to be an evidence-based recommendation for the pediatric population, but in the authors' opinion, there is not sufficient level I evidence to recommend corticosteroids in the management of suspected acute SCI in children. Other pharmacologic agents that have been studied in SCI include GM_1 ganglioside, tirilazad, and fampridine (calcium channel blocker). These therapies have shown mixed efficacy in clinical trials, but none have been studied exclusively in a pediatric population.

Prognosis and Outcome

In pediatric SCI, the prognosis for neurologic recovery is thought to be improved relative to adults secondary to the rapid healing properties of bone and ligaments in children as well as a greater potential for nervous system regeneration [5]. Despite the younger spine being more flexible and ligamentous, paraplegia is more common in children younger than 12 years, whereas older children and adolescents are more likely to sustain incomplete injuries [26]. Complete injuries tend to have a very poor prognosis, with as few as 3% of patients having functional improvement if the lesion is complete at 24 hours after injury. Incomplete injuries can have total neurologic recovery in as high as 62% of patients [22]. Upper cervical injuries are associated with a higher rate of head injuries, which may contribute to their poorer outcomes and greater mortality [22,112]. Magnetic resonance imaging has improved diagnosis in syndromes such as SCIWORA and provides information to families about prognosis. Although many pharmacologic agents have been studied, there is not sufficient evidence that any pharmacologic agent leads to improved neurologic outcome in pediatric SCI.

Special Circumstances in SCI

Seat Belt Syndrome

When seat belts were introduced, they were shown to be very effective in reducing catastrophic injuries, particularly in front-seat passengers. However, lap belts and shoulder-lap belts (with 3-point fastening) have been implicated as a cause of both abdominal and spinal cord injury in MVCs. The “seat belt syndrome” was first described in 1956 by Kulowski and Rost [113], with the term coined several years later in 1962 by Garrett and Braunstein [114]. Approximately 1% of children using seat belts develop injuries consistent with seat belt syndrome after an MVC, most commonly in children 3 to 9 years of age [115].

When the lap-belt segment is properly positioned, forces are transmitted to the pelvis and iliac crest, but a high-lying lap belt can cause the fulcrum of crash forces to be between the seat belt and the abdominal wall. This results in high-tension forces leading to hyperflexion against a lumbar fulcrum. This can cause a flexion-distraction injury commonly referred to as a Chance fracture. Chance fractures usually occur between L1 and L3 and vary from physeal injuries to horizontal vertebral body fractures that can have associated pedicle fractures, posterior ligament rupture, and vertebral body dislocation. Magnetic resonance imaging can be useful in distinguishing physeal injury from disc injury in pediatric Chance fractures [116].

Motor vehicle flexion-distraction injuries are 4 times more likely to occur with a 3-point belt and 10 times more likely to occur with a lap-only belt [117]. This is a particular problem in young children when restrained incorrectly with passenger seat belts rather than the child safety or booster seats. Greater awareness and compliance with the American Academy of Pediatrics recommendations for age-appropriate restraints would lessen the number of injuries from seat belt syndrome [118].

Traumatic Spinal Cord Infarction

Although uncommon, traumatic spinal cord infarction (TSCI) is well documented in the pediatric literature [119-121]. Traumatic spinal cord infarction occurs almost exclusively in the thoracic cord and may be a subset of SCIWORA because both entities can have normal CT and radiographic imaging on presentation. Patients with TSCI tend to present after blunt thoracic or abdominal trauma, are often hypotensive although neurologically intact, and then develop profound neurologic deficit (often paraplegia) several days after the injury [122]. This differs from true SCIWORA patients, who are often not hypotensive, often do not have abdominal or thoracic trauma, and who have neurologic deficit immediately after the injury.

The mechanism for TSCI is thought to be due to thrombosis of the intercostal arteries leading to delayed occlusion of vessels supplying the spinal cord. The thoracolumbar segments receive their arterial supply from a single artery called the great anterior radiculomedullary artery (also known as the artery of Adamkiewicz). It is unclear if there are predisposing factors for developing TSCI.

Child Abuse

Spinal injuries in nonaccidental trauma are generally the result of a shaking mechanism and likely occur more commonly than reported [123]. Shaking injuries cause high-velocity hyperflexion and/or hyperextension, which can result in fracture or dislocation of the posterior elements, usually in the cervical spine, cervicothoracic, or thoracolumbar junction [124,125]. Compression fractures can also be produced by this mechanism [126].

Other abuse-related spinal injuries occur from blunt trauma and may be easily overlooked if there are no apparent neurologic deficits or suggestive physical findings. The most common inflicted fracture seen on a skeletal survey is an asymptomatic compression fracture of a vertebral body, usually in the lower thoracic or upper lumbar spine [127]. This injury can occur from forceful sitting such as when a child is thrown down into a chair. In one study of abused children with a total of 85 spinal fractures, the average age was 22 months and the vertebral bodies were involved more often than the posterior elements [128].

Although some spinal injuries may not present with signs of SCI, spinal cord hematoma formation or retropulsion of a bone fragment can lead to delayed symptoms of spinal cord compression [126]. In addition, small asymptomatic dislocations not initially visualized may lead to deformities later in life. Although the AP view is always part of a skeletal survey, at some centers, a lateral radiograph may not be included, which could miss evidence of dislocation. Fracture dislocations in the thoracolumbar spine without a well-described mechanism should raise suspicion of child abuse.

Summary

Although back and neck injuries are common in pediatrics, SCI occurs less frequently, yet the potential for devastating sequelae requires a conservative but pragmatic approach both in the field and in the ED. Multicenter randomized trials are required to develop standards and clinical decision rules for managing SCI in the pediatric patient. Treatment options for complete injuries are still limited, but we can hope that the next several decades will offer new pharmacologic and surgical approaches to nerve repair and spinal cord regeneration.

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