Cervical Spine Injury Patterns in Children

AUTHORS: Jeffrey R. Leonard, MD,[a] David M. Jaffe, MD,[b] Nathan Kuppermann, MD, MPH,[c] Cody S. Olsen, MS,[d] and Julie C. Leonard, MD, MPH,[b] for the Pediatric Emergency Care Applied Research Network (PECARN) Cervical Spine Study Group

[a]Department of Neurosurgery, Division of Pediatric Neurosurgery, and [b]Department of Pediatrics, Division of Emergency Medicine, Washington University in St Louis School of Medicine, St Louis Children's Hospital, St Louis, Missouri; [c]Departments of Emergency Medicine and Pediatrics, University of California, Davis School of Medicine, Davis Medical Center, Sacramento, California; and [d]The Data Coordinating Center, University of Utah School of Medicine, Salt Lake City, Utah

KEY WORDS

children, cervical spine injury

ABBREVIATIONS

AARS—atlanto-axial rotatory subluxation
CSI—cervical spine injury
MVC—motor vehicle crash
PECARN—Pediatric Emergency Care Applied Research Network
SCIWORA—spinal cord injury without radiographic abnormality

Dr Jeffrey Leonard conceptualized this secondary analysis, conducted secondary review and coding of injury data, interpreted data, and drafted the initial manuscript; Dr Jaffe conceived and obtained grant funding for the original parent study, designed original parent study, and reviewed and revised the manuscript; Dr Kuppermann designed original parent study and reviewed and revised the manuscript; Mr Olsen conducted the data analysis, interpreted the data, and reviewed and revised the manuscript; Dr Julie Leonard conceived and obtained grant funding for the original parent study, designed and oversaw the original parent study, conceptualized this secondary analysis, conducted secondary review and coding of injury data, interpreted data, and critically reviewed and revised the initial manuscript; and all authors approved the final manuscript as submitted.

www.pediatrics.org/cgi/doi/10.1542/peds.2013-3505

doi:10.1542/peds.2013-3505

Accepted for publication Feb 7, 2014

Address correspondence to Julie C. Leonard, MD, MPH, One Children's Place, Campus Box 8116, St Louis, MO 63110. E-mail: leonard_ju@kids.wustl.edu

(Continued on last page)

WHAT'S KNOWN ON THIS SUBJECT: Practice standards for managing adult cervical spine injuries (CSIs) are well established. However, pediatric CSIs are rare and different from those of adults, preventing extrapolation from adult practice and illustrating the need for larger multicenter investigations of CSIs in children.

WHAT THIS STUDY ADDS: This study comprehensively describes CSIs in a large multicenter pediatric cohort. The large number of young children included allowed us to comprehensively explore the relationship between CSI pattern and age, mechanism of injury, comorbid injuries, surgical interventions, and neurologic outcome.

abstract

FREE

BACKGROUND AND OBJECTIVE: Pediatric cervical spine injuries (CSIs) are rare and differ from adult CSIs. Our objective was to describe CSIs in a large, representative cohort of children.

METHODS: We conducted a 5-year retrospective review of children <16 years old with CSIs at 17 Pediatric Emergency Care Applied Research Network hospitals. Investigators reviewed imaging reports and consultations to assign CSI type. We described cohort characteristics using means and frequencies and used Fisher's exact test to compare differences between 3 age groups: <2 years, 2 to 7 years, and 8 to 15 years. We used logistic regression to explore the relationship between injury level and age and mechanism of injury and between neurologic outcome and cord involvement, injury level, age, and comorbid injuries.

RESULTS: A total of 540 children with CSIs were included in the study. CSI level was associated with both age and mechanism of injury. For children <2 and 2 to 7 years old, motor vehicle crash (MVC) was the most common injury mechanism (56%, 37%). Children in these age groups more commonly injured the axial (occiput–C2) region (74%, 78%). In children 8 to 15 years old, sports accounted for as many injuries as MVCs (23%, 23%), and 53% of injuries were subaxial (C3–7). CSIs often necessitated surgical intervention (axial, 39%; subaxial, 30%) and often resulted in neurologic deficits (21%) and death (7%). Neurologic outcome was associated with cord involvement, injury level, age, and comorbid injuries.

CONCLUSIONS: We demonstrated a high degree of variability of CSI patterns, treatments and outcomes in children. The rarity, variation, and morbidity of pediatric CSIs make prompt recognition and treatment critical. *Pediatrics* 2014;133:e1179–e1188

Cervical spine injuries (CSIs) in children can be devastating, resulting in death or life-changing neurologic deficits. Fortunately, <1% of pediatric trauma patients sustain CSIs.[1] Although they are rare, health care providers often evaluate children for potential CSIs caused by blunt trauma. Understanding CSI patterns and their relationship to mechanism, treatment, and neurologic outcomes in children is important. To date, our knowledge of pediatric CSI has been based on either large adult trials with limited numbers of children or single-center pediatric case series.[1–4] Children <2 years of age are particularly underrepresented in the literature.[1]

CSIs in children are unique in both the wide anatomic differences and the variety of mechanisms of injury. In children, the head is larger relative to the body, resulting in a higher center of gravity and fulcrum of neck motion; there are multiple vertebral ossification centers; and the ligamentous structures are lax.[5] These differences affect the epidemiology of spine injuries in children, of which 60% to 80% occur in the cervical region, whereas among adults, CSIs account for only 30% to 40% of all spine injuries.[6–9] Furthermore, in young children CSIs are reported to occur most often in the upper cervical spine and are associated with higher morbidity and mortality.[10]

Mechanisms of CSIs also differ between children and adults. Adults are injured predominantly in motor vehicle crashes (MVCs) and falls; children experience a broader range of traumatic events that place them at risk for CSIs.[11,12] Although MVCs and falls are also common in children, young children are more vulnerable to pedestrian and inflicted injuries, whereas older children participate in sports and recreational activities that predispose them to CSIs.[3,11,13]

These age-related differences in cervical spine anatomy and mechanisms of injury illustrate the need to better describe CSIs in children. The purpose of this study was to provide a detailed description of a large cohort of children with CSIs to elucidate specific injury patterns relative to age and mechanisms of injury and to review treatments and outcomes by injury patterns.

METHODS

Study Design

We performed a secondary analysis of a multicenter retrospective cohort of children <16 years of age with blunt trauma–related CSI.[14] Patients included in this cohort were treated for CSI at 17 hospitals participating in the Pediatric Emergency Care Applied Research Network (PECARN) in 2000 to 2004. Participating sites obtained institutional review board approval with waiver of informed consent.

Patient Identification

We conducted an electronic query of the billing databases at each of the participating PECARN sites to identify children who had CSI. The query identified International Classification of Diseases, Ninth Revision, Clinical Modification codes indicating injuries to the cervical cord, vertebrae, or ligaments. The sites' principal investigators reviewed the medical records to verify subject eligibility.[14]

Inclusion Criteria

We included all children <16 years of age evaluated for blunt trauma–related CSI whose injury could be verified by spine surgeon consultative reports or cervical spine imaging reports.

Exclusion Criteria

We excluded children in whom the CSI could not be verified by review of the medical record. We also excluded children transferred from the study site elsewhere before definitive diagnosis and treatment.

Data Collection

We collected data by using a structured screening method and abstracting of medical records onto study case report forms by trained research personnel at each of the study sites.[15] Data elements included information about each patient's demographics, mechanism of injury, clinical presentation, diagnostic evaluation, substantial comorbidities (life-threatening or warranting surgical intervention or inpatient observation), injury pattern, and neurologic outcome. The study's consulting pediatric spine surgeon (J.R.L.) and principal investigator (J.C.L.) reviewed the imaging reports and spine surgeon consultations for every study patient and assigned a final CSI classification.

Data Analysis

We described patient characteristics including demographics and mechanism of CSI by using frequencies and percentages and compared characteristics between age groups (<2 years, 2–7 years, and 8–15 years) by using Fisher's exact test.

We described the relationship between age, level, and type of injury and between mechanism of CSI and level of injury by using relative frequencies. We also described the prevalence of multilevel injuries and cervical cord injuries and tested the association between cervical cord injuries and age by using Fisher's exact test. We explored the relationship between level of injury (axial versus subaxial, excluding spinal cord injury without radiographic abnormality [SCIWORA]) and mechanism of CSI, age, and head-first impact by using a logistic regression model.

We summarized outcome by age and injury classification using relative frequencies. We used a generalized logistic regression model to explore the relationship between neurologic outcome (death versus persistent neurologic deficit versus normal outcome) and change in cervical cord appearance on MRI, level of injury (axial versus subaxial, excluding SCIWORA), age, and substantial comorbidities to the head, face, neck, torso, and extremities.

We described interventions for CSI by using frequencies and percentages. When multiple interventions were used, the highest level was described. Interventions, ordered from highest to lowest level, included internal fixation, halo, traction, brace, rigid cervical collar, soft cervical collar, and none. We also described the prevalence of corticosteroid administration and described special populations within the sample. We used SAS/STAT software (Version 9.3; SAS Institute, Inc, Cary, NC).

RESULTS

Demographic Characteristics

We identified 540 children with sufficient detail in the medical record to classify their CSIs. Demographic characteristics for these children are presented in Table 1. The median age for the cohort was 12 years (interquartile range, 6.1–14.4), with distribution in our 3 age categories as follows: 5% <2 years, 26% 2 to 7 years, and 69% 8 to 15 years.

Mechanisms of Injury

Mechanisms of CSI varied by age ($P <$ .01). (Table 1) For children <2 years, MVC was the most common mechanism, followed by falls. The most common mechanisms for children age 2 to 7 years were MVC, falls, and pedestrian struck by a motor vehicle. For children age 8 to 15 years, sports injuries and MVC were the most common causes of CSI; however, falls and diving were also important mechanisms.

TABLE 1 Characteristics of Children With CSIs

Characteristic	Age <2, *N* = 27, (%)	Age 2–7, *N* = 140, (%)	Age 8–15, *N* = 373, (%)	*P*
Gender				
Female	19 (70)	53 (38)	124 (33)	<.01
Male	8 (30)	87 (62)	249 (67)	
Race				
Black	8 (30)	29 (21)	57 (15)	.08
White	13 (48)	76 (54)	243 (65)	
Other or not documented	6 (22)	35 (25)	73 (20)	
Payer source				
Commercial or government insurance	11 (41)	80 (57)	268 (72)	<.01
Medicaid	12 (44)	44 (31)	68 (18)	
Self-insured or uninsured	3 (11)	8 (6)	17 (5)	
Not documented	1 (4)	8 (6)	20 (5)	
Mechanism of injury				
Occupant in MVC	15 (56)	52 (37)	85 (23)	<.01
Fall down stairs or from standing, walking, or running	0 (0)	12 (9)	23 (6)	
Diving injury	0 (0)	1 (1)	34 (9)	
Fall from elevation	6 (22)	29 (21)	40 (11)	
Other motorized transport crash (eg, ATV, motorcycle)	0 (0)	1 (1)	17 (5)	
Bike or other nonmotorized transport (eg, go-cart, scooter, wagon) collision or fall	0 (0)	3 (2)	26 (7)	
Bike or other nonmotorized rider struck by moving vehicle	0 (0)	6 (4)	10 (3)	
Pedestrian struck by moving vehicle	1 (4)	15 (11)	22 (6)	
Blunt injury to the head or neck	2 (7)	6 (4)	8 (2)	
Sports injury	0 (0)	3 (2)	87 (23)	
Other	3 (11)	12 (9)	21 (6)	

ATV, all-terrain vehicle.

Assaults accounted for injury in 6 children (1% of the entire cohort); 3 of these were attributed to child abuse. No children were injured by hanging. Clotheslining, biomechanics by which a cable or similar item exerts traction on the neck while the child is in motion, occurred in 2% of children.

Injury Patterns

Figure 1 illustrates the relationship between age and level of CSI. The relative frequency of axial injuries peaked at age 3 and then markedly decreased between the ages of 8 and 10. In contrast, the relative frequencies of subaxial CSI and SCIWORA (defined as focal neurologic deficits at presentation but normal cervical radiographs, computed tomography, and MRI) were low in early childhood until age 8.

Injury classifications are listed by age in Table 2. For children <2 years, 74% had CSIs involving the axial region, with atlanto-occipital dislocation being the most common injury. For children 2 to 7 years, 78% of CSIs occurred in the axial region; atlanto-axial rotatory subluxation (AARS) and atlanto-occipital dislocation were the most common injuries. Among children 8 to 15 years old, subaxial injuries were more prevalent (53%), with subaxial vertebral body fractures being the most common. SCIWORA was uncommon in the younger age groups but accounted for 16% of the injuries in children 8 to 15 years old.

Multilevel CSI was uncommon in our cohort; only 1% of the cohort had dislocation at >1 cervical level, and 3% had fractures involving >1 cervical vertebra. Disruption of the posterior

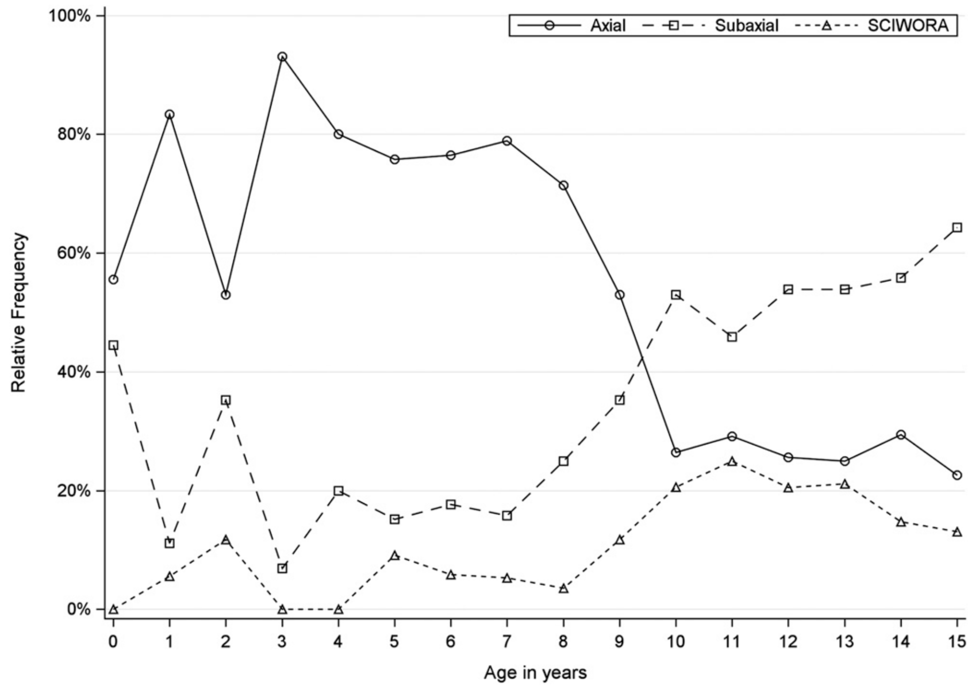

FIGURE 1
Relative frequency of CSI level by age.

elements of the vertebra was also uncommon in children; 5% had flexion–distraction injuries, and another 2% had injuries to the posterior ligament.

A total of 96 (18%) of CSIs were associated with signal change in the cervical cord on MRI, 53 axial (22%) and 43 subaxial (19%). Although rates of cervical cord injury were higher in the younger age groups (26% for <2 years, 21% for 2–7 years, 16% for 8–15 years), the association was not statistically significant ($P = .22$).

Relationship Between Mechanism and Level of Injury

Mechanism of injury was related to level of CSI within the cohort (Table 3). MVCs, falls from an elevation, being struck by motor vehicles while walking or riding, and blunt blows to the head and neck were more likely to result in axial CSIs. This contrasts with sports CSIs, which were more likely to result in injuries to the subaxial region or SCIWORA. Likewise, children involved in diving and other motorized transportation crashes (eg, all-terrain vehicles and motorcycles) were more likely to sustain subaxial CSI. After we adjusted for age and head-first impacts, the relationship between level of injury (axial versus subaxial, excluding SCIWORA) and mechanism of CSI remained significant ($P = .04$ in the logistic regression model).

Outcomes

Table 4 presents the neurologic outcomes for injured children by age group. Very young children (<2 years old) with CSI had poor outcomes; most either died or were left with permanent neurologic deficits. In contrast, children 2 to 7 years and 8 to 15 years old were less likely to die during hospitalization, and most were discharged with normal neurologic status.

Table 5 presents the neurologic outcomes for each CSI type. In our cohort, the most devastating injury was atlanto-occipital dislocation; almost all patients died or had persistent neurologic deficits. C1–C2 dislocation carried similar degrees of morbidity and mortality.

Level of injury was critical in determining the overall neurologic outcome (Table 6). Children injuring their axial region were 5 times more likely to die than those injuring their subaxial region. Not surprisingly, an abnormality in the cervical cord on MRI was also associated with death and persistent neurologic deficits compared with normal outcomes. Comorbid conditions, particularly substantial head and neck injuries, were also predictive of poor outcome.

Interventions

Treatments for CSIs in our cohort are described in Table 7. Rigid cervical collar was the most common treatment. Internal fixation was more common in the management of subaxial injuries than in the management of axial injuries, but halo placement was more common for axial injuries than for subaxial injuries. Braces and soft

TABLE 2 Injury Pattern by Age Category

Level	Injury Classification	Age<2, *N* = 27, (%)	Age 2–7, *N* = 140, (%)	Age 8–15, *N* = 373, (%)
Axial	Injuries involving C1–2	20 (74)	109 (78)	115 (31)
	C1 arch fracture	0 (0)	6 (4)	4 (1)
	AARS	2 (7)	27 (19)	26 (7)
	Cord injury	1 (4)	4 (3)	5 (1)
	C1–2 dislocation	0 (0)	7 (5)	3 (1)
	C1–2 subluxation	2 (7)	2 (1)	1 (0)
	C2 synchondrosis fracture	3 (11)	12 (9)	0 (0)
	C2 vertebral body fracture, other	0 (0)	4 (3)	3 (1)
	Hangman's fracture[a]	0 (0)	5 (4)	11 (3)
	Jefferson fracture without ligamentous injury[b]	1 (4)	0 (0)	1 (0)
	Ligamentous injury C1–2 without fracture	3 (11)	5 (4)	2 (1)
	Atlanto-occipital dislocation	4 (15)	16 (11)	10 (3)
	Os odontoideum	0 (0)	4 (3)	7 (2)
	Type I odontoid fracture	1 (4)	0 (0)	1 (0)
	Type II odontoid fracture	1 (4)	8 (6)	13 (3)
	Type III odontoid fracture	0 (0)	5 (4)	7 (2)
	Clinically insignificant injury C1–C2[c]	2 (7)	4 (3)	21 (6)
Subaxial	Injuries involving C3–7	6 (22)	24 (17)	198 (53)
	Cord injury	0 (0)	2 (1)	4 (1)
	Bilateral facet fracture or dislocation	1 (4)	1 (1)	6 (2)
	Ligamentous injury without fracture	0 (0)	7 (5)	12 (3)
	Multilevel subaxial vertebral body fractures other than burst	1 (4)	0 (0)	14 (4)
	Multilevel vertebral body burst fractures	0 (0)	1 (1)	10 (3)
	Single-level disc injury	0 (0)	0 (0)	4 (1)
	Single-level teardrop fracture	0 (0)	0 (0)	5 (1)
	Single-level vertebral body fracture, other	0 (0)	2 (1)	11 (3)
	Single-level burst fracture	1 (4)	0 (0)	16 (4)
	Single-level compression fracture	0 (0)	1 (1)	39 (10)
	Single-level subluxation, without fracture	1 (4)	3 (2)	5 (1)
	Unilateral facet fracture or dislocation	1 (4)	1 (1)	10 (3)
	Clinically insignificant injury C3–C7[c]	1 (4)	6 (4)	62 (17)
SCIWORA	SCIWORA[d]	1 (4)	7 (5)	60 (16)

[a] Fracture of both pedicles or pars interarticularis of the axis vertebra (C2).
[b] Fracture involving the anterior and posterior arches of the atlas vertebra (C1).
[c] Includes occipital condyle fractures, lateral mass fractures, laminar fractures, spinous process fractures, transverse process fractures, and unilateral pedicle fractures without subluxation.
[d] Patients experiencing more than transient neurologic symptoms but with normal cervical plain radiographs, computed tomography, and MRI.

TABLE 3 Mechanisms of Injury Relative to Level of Injury[a]

Mechanism of Injury	Axial, *N* (Row %), *N* = 244	Subaxial, *N* (Row %), *N* = 228	SCIWORA, *N* (Row %), *N* = 68
Occupant in MVC	85 (56)	66 (43)	1 (1)
Fall down stairs or from standing, walking, or running	14 (40)	14 (40)	7 (20)
Diving injury	3 (9)	29 (83)	3 (9)
Fall from elevation	42 (56)	26 (35)	7 (9)
Other motorized transport crash (eg, ATV, motorcycle)	7 (39)	10 (56)	1 (6)
Bike or other nonmotorized transport (eg, go-cart, scooter, wagon) collision or fall	13 (45)	12 (41)	4 (14)
Bike or other nonmotorized rider struck by moving vehicle	13 (81)	2 (13)	1 (6)
Pedestrian struck by moving vehicle	23 (61)	13 (34)	2 (5)
Blunt injury to the head or neck	10 (63)	5 (31)	1 (6)
Sports injury	15 (17)	40 (44)	35 (39)
Other	19 (53)	11 (31)	6 (17)

[a] Fisher's exact test for an association between mechanism and level of injury $P < .01$.

collars were rarely used as the sole treatment of CSI.

Of the 540 patients with CSI, 128 (24%) received corticosteroid treatment. Corticosteroid administration varied by site, ranging from 8% to 50%. Although we are unable to determine from our data the indications for administration, the regimen followed, and whether it affected neurologic outcome, we do know that corticosteroids were administered at high rates to patients who had focal neurologic deficits at presentation (56%), cervical cord abnormalities on MRI (53%), and ultimately

TABLE 4 Neurologic Outcomes for Children With CSI

	Age <2, N = 27, (%)	Age 2–7, N = 140, (%)	Age 8–15, N = 373, (%)
Outcome			
Death during hospitalization	7 (26)	22 (16)	11 (3)
Normal	10 (37)	84 (60)	292 (78)
Persistent neurologic deficit	10 (37)	34 (24)	70 (19)

poor neurologic outcomes (death, 30%; persistent neurologic deficit, 43%).

Special Populations

Certain genetic conditions are associated with cervical spine abnormalities, particularly Down syndrome.[16] In our cohort, 6 children with Down syndrome sustained CSIs, and their ages ranged from 1 to 8 years. Falling caused 4 of the 6 injuries; the other 2 were caused by other mechanisms. Injuries to these children included C1–2 subluxation (3), hangman's fracture (1), os odontoideum (1), and single-level subaxial subluxation without fracture (1). Four had persistent deficits after injury, but none died.

In addition to Down syndrome, 4 children had conditions associated with cervical spine abnormalities (mucopolysaccharidosis, 1; history of SCIWORA, 1; and achondrodysplasia, 2). Seventeen children had isolated congenital anomalies of their cervical spine that may have predisposed them to injury, 11 of whom had an os odontoideum.

DISCUSSION

We have compiled one of the largest, most detailed descriptions of CSI in children, which allowed us to explore the relationship between CSI and age, mechanism of injury, comorbid injuries, interventions, and outcomes. Our study demonstrates clear age-related differences in pediatric CSI and a transition at

TABLE 5 Neurologic Outcomes, Comorbid Substantial Head Injuries, and Associated Cervical Cord Abnormalities on MRI Stratified by Injury Classification[a]

Level	Injury Classification	N	Cord Injury on MRI, %	Substantial Head Injury, %[b]	Neurologic Outcome, %		
					Normal	Persistent Deficit	Death
Axial	Injuries involving C1–2	244	22	23	62	24	14
	C1 arch fracture	10	10	0	90	10	0
	Atlanto-axial rotatory subluxation	55	9	5	89	11	0
	Cord injury	10	100	30	40	50	10
	C1–2 dislocation	10	40	70	10	50	40
	C1–2 subluxation	5	20	20	40	40	20
	C2 synchondrosis fracture	15	7	23	73	13	13
	C2 vertebral body fracture, other	7	14	43	43	14	43
	Hangman's fracture	16	38	7	63	38	0
	Jefferson fracture without ligamentous injury	2	0	0	100	0	0
	Ligamentous injury C1–2 without fracture	10	10	44	40	50	10
	Atlanto-occipital dislocation	30	27	45	7	40	53
	Os odontoideum	11	36	0	82	18	0
	Type I odontoid fracture	2	50	0	100	0	0
	Type II odontoid fracture	22	23	41	59	18	23
	Type III odontoid fracture	12	17	0	92	8	0
	Clinically insignificant injury C1–C2	27	11	33	74	22	4
Subaxial	Injuries involving C3–7	228	19	14	75	23	3
	Cord injury	6	100	0	17	83	0
	Bilateral facet fracture or dislocation	8	38	13	38	63	0
	Ligamentous injury without fracture	19	16	22	74	21	5
	Multilevel subaxial vertebral body fractures other than burst	15	53	7	60	40	0
	Multilevel vertebral body burst fractures	11	55	9	45	55	0
	Single-level disc injury	4	0	0	100	0	0
	Single-level teardrop fracture	5	0	0	80	20	0
	Single-level vertebral body fracture, other	13	23	31	62	23	15
	Single-level burst fracture	17	47	6	65	35	0
	Single-level compression fracture	40	5	5	88	13	0
	Single-level subluxation, without fracture	9	0	0	89	0	11
	Unilateral facet fracture or dislocation	12	17	17	83	8	8
	Clinically insignificant injury C3–C7	69	3	23	84	14	1
SCIWORA	SCIWORA	68	0	5	94	6	0
Overall		540	18	17	71	21	7

[a] All are row percentages (ie, percentage of those with a particular injury classification).

[b] Ten patients with missing head injury information were excluded when percentages were calculated.

midchildhood from axial to subaxial CSI. Furthermore, we show that these differences are independently related to mechanism of injury as well as age. Finally, we report injury-specific outcomes and establish that multiple factors influence outcomes for children with CSI, including age, injury pattern, associated cervical cord injury on MRI, and comorbid injuries.

TABLE 6 Adjusted Odds Ratios of Death Versus Normal Outcome, or Persistent Neurologic Deficit Versus Normal Outcome, From a Generalized Logistic Regression Model[a]

Characteristic	Odds Ratio (95% Confidence Interval)	
	Death During Hospitalization	Persistent Neurologic Deficit
Cervical cord injury (vs. no cervical cord injury)	5.4 (1.9–15.4)	17.8 (9.5–33.4)
Axial (vs. subaxial)	4.7 (1.5–14.7)	0.9 (0.5–1.8)
Age (1-y increase)	0.8 (0.8–0.9)	1.0 (0.9–1.0)
Substantial head injury	20.3 (7.3–56.4)	9.9 (4.7–21.0)
Substantial face injury	1.7 (0.4–8.3)	0.8 (0.2–3.7)
Substantial neck injury	16.6 (4.8–57.5)	4.1 (1.4–12.3)
Substantial torso injury	4.5 (1.4–14.3)	2.3 (0.9–5.8)
Substantial extremity injury	1.1 (0.3–4.0)	2.7 (1.1–6.5)

[a] *N* = 464 after 68 SCIWORA patients and 8 patients with missing data about substantial comorbidities were excluded.

In our study there were clear differences in the level and patterns of CSI related to age. Axial spine injuries peaked between the ages of 2 and 3 years and then decreased significantly between the ages of 8 and 9 years. This finding supports the results of smaller studies and a query of the National Trauma Database, which found that upper CSIs, defined as occiput to C4, occurred more often in children <2 years.[5,10] In contrast to Mohseni et al,[10]

TABLE 7 Interventions[a] for Cervical Spine Injuries in Children

Level	Injury classification	None, *N* (Row %)	Soft Collar, *N* (Row %)	Rigid Collar, *N* (Row %)	Brace, *N* (Row %)	Traction, *N* (Row %)	Halo, *N* (Row %)	Internal Fixation, *N* (Row %)
Axial	Injuries involving C1–2	39 (16)	12 (5)	82 (34)	3 (1)	14 (6)	56 (23)	38 (16)
	C1 arch fracture	1 (10)	2 (20)	6 (60)	0 (0)	0 (0)	0 (0)	1 (10)
	AARS	6 (11)	4 (7)	20 (36)	0 (0)	14 (25)	9 (16)	2 (4)
	Cord injury	0 (0)	1 (10)	8 (80)	0 (0)	0 (0)	1 (10)	0 (0)
	C1–2 dislocation	4 (40)	0 (0)	2 (20)	0 (0)	0 (0)	1 (10)	3 (30)
	C1–2 subluxation	1 (20)	1 (20)	1 (20)	0 (0)	0 (0)	0 (0)	2 (40)
	C2 synchondrosis fracture	1 (7)	0 (0)	3 (20)	1 (7)	0 (0)	8 (53)	2 (13)
	C2 vertebral body fracture, other	3 (43)	0 (0)	3 (43)	0 (0)	0 (0)	1 (14)	0 (0)
	Hangman's fracture	2 (13)	0 (0)	4 (25)	0 (0)	0 (0)	8 (50)	2 (13)
	Jefferson fracture without ligamentous injury	0 (0)	0 (0)	1 (50)	0 (0)	0 (0)	1 (50)	0 (0)
	Ligamentous injury C1–2 without fracture	2 (20)	0 (0)	8 (80)	0 (0)	0 (0)	0 (0)	0 (0)
	Atlanto-occipital dislocation	11 (37)	0 (0)	3 (10)	0 (0)	0 (0)	5 (17)	11 (37)
	Os odontoideum	0 (0)	1 (9)	2 (18)	0 (0)	0 (0)	1 (9)	7 (64)
	Type I odontoid fracture	0 (0)	0 (0)	1 (50)	0 (0)	0 (0)	0 (0)	1 (50)
	Type II odontoid fracture	3 (14)	0 (0)	3 (14)	0 (0)	0 (0)	10 (45)	6 (27)
	Type III odontoid fracture	0 (0)	0 (0)	1 (8)	0 (0)	0 (0)	10 (83)	1 (8)
	Clinically insignificant injury C1–2	5 (19)	3 (11)	16 (59)	2 (7)	0 (0)	1 (4)	0 (0)
Subaxial	Injuries involving C3–7	29 (13)	14 (6)	109 (48)	8 (4)	0 (0)	21 (9)	47 (21)
	Cord injury	2 (33)	0 (0)	2 (33)	0 (0)	0 (0)	0 (0)	2 (33)
	Bilateral facet fracture or dislocation	0 (0)	0 (0)	1 (13)	0 (0)	0 (0)	1 (13)	6 (75)
	Ligamentous injury without fracture	3 (16)	1 (5)	10 (53)	1 (5)	0 (0)	0 (0)	4 (21)
	Multilevel subaxial vertebral body fractures other than burst	1 (7)	0 (0)	7 (47)	1 (7)	0 (0)	3 (20)	3 (20)
	Multilevel vertebral body burst fractures	0 (0)	0 (0)	4 (36)	1 (9)	0 (0)	2 (18)	4 (36)
	Single-level disc injury	1 (25)	0 (0)	3 (75)	0 (0)	0 (0)	0 (0)	0 (0)
	Single-level teardrop fracture	0 (0)	0 (0)	1 (20)	0 (0)	0 (0)	2 (40)	2 (40)
	Single-level vertebral body fracture, other	3 (23)	0 (0)	6 (46)	0 (0)	0 (0)	1 (8)	3 (23)
	Single-level burst fracture	1 (6)	1 (6)	4 (24)	1 (6)	0 (0)	5 (29)	5 (29)
	Single-level compression fracture	3 (8)	4 (10)	18 (45)	2 (5)	0 (0)	4 (10)	9 (23)
	Single-level subluxation, without fracture	2 (22)	0 (0)	4 (44)	0 (0)	0 (0)	1 (11)	2 (22)
	Unilateral facet fracture or dislocation	0 (0)	0 (0)	3 (25)	0 (0)	0 (0)	2 (17)	7 (58)
	Clinically insignificant injury C3–7	13 (19)	8 (12)	46 (67)	2 (3)	0 (0)	0 (0)	0 (0)
SCIWORA	SCIWORA	18 (26)	7 (10)	32 (47)	11 (16)	0 (0)	0 (0)	0 (0)

[a] When multiple interventions were given, the highest level of intervention is reported.

we found that the incidence of subaxial CSI increases in school-age children which corresponds with the developmental maturation of the pediatric cervical spine. At this age, the synchondroses have fused, and the fulcrum of motion of the cervical spine has shifted caudally. Also, multilevel injuries were uncommon in our study, particularly in children <8 years old. Others[2,4,17] have shown that multilevel injuries occur in children, although the reported injury rate varies widely, from 6% to 50%. Injury patterns in children, once they have reached the age of 12, more closely resemble those of adults, making the inclusion of a substantial percentage of younger patients important in describing the epidemiology and treatment of CSI in children.[10]

Mechanisms of injury were related to both age and level of injury, a fact that influences the distribution of CSIs seen in our cohort. For children <2 years old, by far the most common cause of CSI is MVCs, both in this study and in others.[8,18,19] This probably occurs because infants and toddlers are unrestrained or restrained improperly. As children mature and begin to participate in organized sporting activities, the mechanisms for CSI become more diverse, with falls, pedestrian injuries, injuries related to other forms of motorized transport, and sports injuries becoming more prevalent, an observation that corresponds with the recent review of the National Trauma Data Bank.[20]

After we adjusted for age, level of injury was independently associated with the mechanism of injury. MVCs more commonly result in axial injury, probably as a function of the biomechanical forces exerted on the cervical spine (eg, high-speed acceleration and deceleration). The greater frequency of axial injuries seen among children hit by motor vehicles also illustrates this point. Sports-related CSI most commonly affected the subaxial region in our cohort. SCIWORA was also frequently associated with sports. As compared with MVCs, sports and recreation injuries involve different biomechanics (eg, lower velocity and axial load) that probably influence the observed injury patterns. Diving, which often produces axial load biomechanics, resulted predominantly in subaxial injury.

We found that 2% of the cohort had conditions that predispose to CSI, particularly Down syndrome and os odontoideum. There are guidelines for CSI screening in children with Down syndrome, and they recommend staged screening, particularly for children involved in sports.[21] However, isolated congenital vertebral anomalies may be discovered only on evaluation for CSI. Once identified, children with vertebral anomalies such as os odontoideum should be referred to a pediatric spine specialist for additional evaluation and potential internal fixation when instability is present.[22]

Previous investigators[5] have reported overall mortality rates for CSI in children to be as high as 27%, with 66% of surviving children having persistent neurologic deficit. Neurologic deficits (21%) and death (7%) were less common in our study and varied by age group, with younger children being the most severely affected. Poor outcomes were associated with age, injury to the axial region, associated cervical cord abnormalities on MRI, and comorbid injuries. These findings are supported by a pediatric autopsy study, which showed that the pediatric cervical spine could withstand significant forces before fracture and instability occurs. As a result, young children either die of catastrophic axial CSI or survive the initial injury with minor fractures.[23] In contrast, older children have more developed musculature, the synchondroses have closed, and the fulcrum of motion has moved away from the upper cervical spine. Catastrophic injuries in this patient group were more likely to produce a persistent neurologic deficit.

In our study, many children underwent surgical stabilization (halo placement or internal fixation), illustrating the need for prompt recognition and classification of CSI. Catastrophic axial injuries in children (eg, atlanto-occipital dislocation) involve ligamentous disruption, necessitating internal fixation. External fixation with halo immobilization was performed in most children with type II or type III odontoid fractures and synchondrosis fractures, a finding that is consistent with the experience of other authors.[24] In older adults, however, odontoid fractures are more commonly treated with internal fixation because both the nonunion rates and mortality for halo placement in this patient population are substantially higher.[25] Not surprisingly, clinically insignificant injuries, SCIWORA, and AARS were the largest categories of injury treated by rigid collar alone. Only 2 children in these treatment categories, both with AARS, underwent internal fixation. The treatment of these injuries was consistent with the recommendations of most authors.[26–28]

Corticosteroids were frequently administered in our cohort, and use varied by site. Children treated with corticosteroids had worse outcomes, but it is unclear how these outcomes are related to the administration of corticosteroids, because clinicians may have selectively treated those with poorer prognosis. Use of corticosteroids remains controversial, with most current guidelines recommending against administration.[29,30]

This study has several limitations resulting chiefly from its retrospective nature and the lack of availability of neuroimaging for independent review. Classification of injuries was based on radiologic reports and spine surgeon consultation notes. However, when insufficient details were present to describe the injury, we gathered additional information from the medical record. We excluded children if sufficient detail did not exist to classify their CSIs, and despite the multicenter nature of the study, we were still able to identify only 27 children <2 years old with CSI. Nevertheless, in this study we describe in substantial detail a very large cohort of children who have sustained CSIs.

CONCLUSIONS

We demonstrated the high degree of variability of injury patterns, treatments, and outcomes of CSIs in children. Our findings relate these differences to both mechanism of injury and age. The high degree of morbidity and frequent need for surgical treatment associated with these injuries underscore the need for prompt recognition of CSI in children. Future prospective investigations are needed to develop evidence-based protocols for evaluation and treatment of children with these potentially devastating injuries.

ACKNOWLEDGMENTS

Participating centers and investigators were as follows: Lise E. Nigrovic, MD, MPH, Boston Children's Hospital (Boston, MA); Elizabeth Powell, MD, Chicago Memorial/Northwestern (Chicago, IL); Curt Stankovic, MD, Prashant Mahajan, MD, MPH, Children's Hospital of Michigan (Detroit, MI); Aaron Donoghue, MD, MSCE, Children's Hospital of Philadelphia (Philadelphia, PA); Kathleen Brown, MD, Children's National Medical Center (Washington, District of Columbia); Scott D. Reeves, MD, Cincinnati Children's Hospital Medical Center (Cincinnati, OH); John D. Hoyle Jr, MD, DeVos Children's Hospital/Spectrum Health (Grand Rapids, MI); Dominic Borgialli, DO, MPH, Hurley Medical Center (Flint, MI); Jennifer Anders, MD, Johns Hopkins Medical Center (Baltimore, MD); Greg Rebella, MD, Medical College of Wisconsin and Children's Hospital of Wisconsin (Milwaukee, WI); Kathleen Adelgais, MD, Primary Children's Medical Center (Salt Lake City, UT); Kathleen Lillis, MD, State University of New York, Buffalo (Buffalo, NY); Nathan Kuppermann, MD, MPH, Emily Kim, MPH, UC Davis Medical Center (Sacramento, CA); Getachew Teshome, MD, MPH, University of Maryland (Baltimore, MD); Alexander J. Rogers, MD, University of Michigan (Ann Arbor, MI); Lynn Babcock, MD, MS, University of Rochester Medical Center (Rochester, NY); Julie C. Leonard, MD, MPH, David M. Jaffe, MD, Jeffrey R. Leonard, MD, Washington University and St Louis Children's Hospital (St. Louis, MO); Cody Olsen, MS, Richard Holubkov, PhD, J. Michael Dean, MD, MBA, Data Coordinating Center, University of Utah (Salt Lake City, UT).

PECARN Steering Committee: N. Kuppermann, Chair; E. Alpern, D. Borgialli, K. Brown, J. Chamberlain, J. M. Dean, G. Foltin, M. Gerardi, M. Gorelick, J. Hoyle, D. Jaffe, C. Johns, K. Lillis, P. Mahajan, R. Maio, S. Miller (Deceased), D. Monroe, R. Ruddy, R. Stanley, M. Tunik, A. Walker. Maternal and Child Health Bureau/ Emergency Medical Services of Children liaisons: D. Kavanaugh, H. Park

Central Data Management and Coordinating Center: M. Dean, A. Donaldson, R. Holubkov, S. Knight, S. Zuspan

Feasibility and Budget Subcommittee: T. Singh, Chair; A. Drongowski, L. Fukushima, M. Shults, J. Suhajda, M. Tunik, S. Zuspan

Grants and Publications Subcommittee: M. Gorelick, Chair; E. Alpern, G. Foltin, R. Holubov, J. Joseph, S. Miller (Deceased), F. Moler, O. Soldes, S. Teach

Protocol Concept Review and Development Subcommittee: D. Jaffe, Chair; A. Cooper, J. M. Dean, C. Johns, R. Kanter, R. Maio, N. C. Mann, D. Monroe, K. Shaw, D. Treloar

Quality Assurance Subcommittee: R. Stanley, Chair; D. Alexander, J. Burr, M. Gerardi, R. Holubkov, K. Lillis, R. Ruddy, M. Shults, A. Walker

Safety and Regulatory Affairs Subcommittee: W. Schalick, Chair; J. Brennan, J. Burr, J. M. Dean, J. Hoyle, R. Ruddy, T. Singh, D. Snowdon, J. Wright

We thank the site PIs and research coordinators at PECARN, whose dedication and hard work made this study possible.

REFERENCES

1. Viccellio P, Simon H, Pressman BD, Shah MN, Mower WR, Hoffman JR; NEXUS Group. A prospective multicenter study of cervical spine injury in children. *Pediatrics*. 2001; 108(2). Available at: www.pediatrics.org/cgi/content/full/108/2/E20
2. Hadley MN, Zabramski JM, Browner CM, Rekate H, Sonntag VK. Pediatric spinal trauma. Review of 122 cases of spinal cord and vertebral column injuries. *J Neurosurg*. 1988;68(1):18–24
3. Garton HJ, Hammer MR. Detection of pediatric cervical spine injury. *Neurosurgery*. 2008;62(3):700–708, discussion 700–708
4. Mortazavi MM, Dogan S, Civelek E, et al. Pediatric multilevel spine injuries: an institutional experience. *Childs Nerv Syst*. 2011;27(7):1095–1100
5. Platzer P, Jaindl M, Thalhammer G, et al Cervical spine injuries in pediatric patients. *J Trauma*. 2007;62(2):389–396; discussion 394–386
6. Kokoska ER, Keller MS, Rallo MC, Weber TR. Characteristics of pediatric cervical spine injuries. *J Pediatr Surg*. 2001;36(1): 100–105
7. Akbarnia BA. Pediatric spine fractures. *Orthop Clin North Am*. 1999;30(3):521–536, x
8. Baker C, Kadish H, Schunk JE. Evaluation of pediatric cervical spine injuries. *Am J Emerg Med*. 1999;17(3):230–234

9. Bohn D, Armstrong D, Becker L, Humphreys R. Cervical spine injuries in children. *J Trauma*. 1990;30(4):463–469
10. Mohseni S, Talving P, Branco BC, et al. Effect of age on cervical spine injury in pediatric population: a National Trauma Data Bank review. *J Pediatr Surg*. 2011;46(9):1771–1776
11. Brown RL, Brunn MA, Garcia VF. Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center. *J Pediatr Surg*. 2001;36(8):1107–1114
12. Hasler RM, Exadaktylos AK, Bouamra O, et al. Epidemiology and predictors of cervical spine injury in adult major trauma patients: a multicenter cohort study. *J Trauma Acute Care Surg*. 2012;72(4):975–981
13. Bilston LE, Brown J. Pediatric spinal injury type and severity are age and mechanism dependent. *Spine*. 2007;32(21):2339–2347
14. Leonard JC, Kuppermann N, Olsen C, et al; Pediatric Emergency Care Applied Research Network. Factors associated with cervical spine injury in children after blunt trauma. *Ann Emerg Med*. 2011;58(2):145–155
15. Gilbert EH, Lowenstein SR, Koziol-McLain J, Barta DC, Steiner J. Chart reviews in emergency medicine research: where are the methods? *Ann Emerg Med*. 1996;27(3):305–308
16. McKay SD, Al-Omari A, Tomlinson LA, Dormans JP. Review of cervical spine anomalies in genetic syndromes. *Spine*. 2012;37(5):E269–E277
17. Parisini P, Di Silvestre M, Greggi T. Treatment of spinal fractures in children and adolescents: long-term results in 44 patients. *Spine*. 2002;27(18):1989–1994
18. Cirak B, Ziegfeld S, Knight VM, Chang D, Avellino AM, Paidas CN. Spinal injuries in children. *J Pediatr Surg*. 2004;39(4):607–612
19. Eleraky MA, Theodore N, Adams M, Rekate HL, Sonntag VK. Pediatric cervical spine injuries: report of 102 cases and review of the literature. *J Neurosurg*. 2000;92(1 Suppl):12–17
20. Polk-Williams A, Carr BG, Blinman TA, Masiakos PT, Wiebe DJ, Nance ML. Cervical spine injury in young children: a National Trauma Data Bank review. *J Pediatr Surg*. 2008;43(9):1718–1721
21. Bull MJ; Committee on Genetics. Health supervision for children with Down syndrome. *Pediatrics*. 2011;128(2):393–406
22. Rozzelle CJ, Aarabi B, Dhall SS, et al. Os odontoideum. *Neurosurgery*. 2013;72(Suppl 2):159–169
23. Ouyang J, Zhu Q, Zhao W, Xu Y, Chen W, Zhong S. Biomechanical assessment of the pediatric cervical spine under bending and tensile loading. *Spine*. 2005;30(24):E716–E723
24. Duhem R, Tonnelle V, Vinchon M, Assaker R, Dhellemmes P. Unstable upper pediatric cervical spine injuries: report of 28 cases and review of the literature. *Childs Nerv Syst*. 2008;24(3):343–348
25. Schoenfeld AJ, Bono CM, Reichmann WM, et al. Type II odontoid fractures of the cervical spine: do treatment type and medical comorbidities affect mortality in elderly patients? *Spine*. 2011;36(11):879–885
26. Beier AD, Vachhrajani S, Bayerl SH, Aguilar CY, Lamberti-Pasculli M, Drake JM. Rotatory subluxation: experience from the Hospital for Sick Children. *J Neurosurg Pediatr*. 2012;9(2):144–148
27. Subach BR, McLaughlin MR, Albright AL, Pollack IF. Current management of pediatric atlantoaxial rotatory subluxation. *Spine*. 1998;23(20):2174–2179
28. Pang D, Li V. Atlantoaxial rotatory fixation: part 3—a prospective study of the clinical manifestation, diagnosis, management, and outcome of children with alantoaxial rotatory fixation. *Neurosurgery*. 2005;57(5):954–972, discussion 954–972
29. Stahel PF, VanderHeiden T, Finn MA. Management strategies for acute spinal cord injury: current options and future perspectives. *Curr Opin Crit Care*. 2012;18(6):651–660
30. Breslin K, Agrawal D. The use of methylprednisolone in acute spinal cord injury: a review of the evidence, controversies, and recommendations. *Pediatr Emerg Care*. 2012;28(11):1238–1245, quiz 1246–1248

(Continued from first page)

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: Supported by a grant from the Health Resources and Services Administration/Maternal and Child Health Bureau, Division of Research, Education, and Training, and the Emergency Medical Services of Children Program (H34 MC04372). The Pediatric Emergency Care Applied Research Network (PECARN) is supported by cooperative agreements U03MC00001, U03MC00003, U03MC00006, U03MC00007, and U03MC00008 from the Emergency Medical Services for Children program of the Maternal and Child Health Bureau, Health Resources and Services Administration, US Department of Health and Human Services.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

PEDIATRICS
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Cervical Spine Injury Patterns in Children

Jeffrey R. Leonard, David M. Jaffe, Nathan Kuppermann, Cody S. Olsen and Julie C. Leonard

Pediatrics 2014;133;e1179
DOI: 10.1542/peds.2013-3505 originally published online April 28, 2014;