JOURNAL OF NEUROTRAUMA 28:1515–1524 (August 2011)

DOI: 10.1089/neu.2009.1153

Spinal Cord Injury in the Pediatric Population: A Systematic Review of the Literature

Stefan Parent,[1–3] Jean-Marc Mac-Thiong,[1–3] Marjolaine Roy-Beaudry,[1] Jose Felix Sosa,[1] and Hubert Labelle[1,2]

Abstract

Spinal Cord Injury (SCI) in the pediatric population is relatively rare but carries significant psychological and physiological consequences. An interdisciplinary group of experts composed of medical and surgical specialists treating patients with SCI formulated the following questions: 1) What is the epidemiology of pediatric spinal cord injury and fractures?; 2) Are there unique features of pediatric SCI which distinguish the pediatric SCI population from adult SCI?; 3) Is there evidence to support the use of neuroprotective approaches, including hypothermia and steroids, in the treatment of pediatric SCI?

A systematic review of the literature using multiple databases was undertaken to evaluate these three specific questions. A search strategy composed of specific search terms (Spinal Cord Injury, Paraplegia, Quadriplegia, tetraplegia, lapbelt injuries, seatbelt injuries, cervical spine injuries and Pediatrics) returned over 220 abstracts that were evaluated and by two observers. Relevant abstracts were then evaluated and papers were graded using the Downs and Black method. A table of evidence was then presented to a panel of experts using a modified Delphi approach and the following recommendation was then formulated using a consensus approach: *Pediatric patients with traumatic SCI have different mechanisms of injury and have a better neurological recovery potential when compared to adults. Patients with SCI before their adolescent growth spurt have a high likelihood of developing scoliosis. Because of these differences, traumatic SCI should be highly suspected in the presence of abnormal neck or neurological exam, a high-risk mechanism of injury or a distracting injury even in the absence of radiological anomaly.*

Key words: adolescents; children; spinal cord injury; systematic review

Introduction

Spinal cord injury (SCI) before the age of 15 years is a relatively rare occurrence, but it can have important psychological and physiological consequences. Although the exact frequency is unknown, it represents < 4% of the overall incidence of SCI annually (National Spinal Cord Injury Statistical Center, 2004). The mechanism of injury, the male: female ratio, and the level of injury are different than in the adult population. The incidence increases rapidly with age, with > 30% of injuries occurring between the ages of 17 and 23, and 53% occurring between the ages of 16 and 30. The rate of recovery following SCI in the pediatric population is also thought to be faster.

This systematic review of the literature was undertaken to evaluate three specific questions: 1) What is the epidemiology of pediatric SCI and fractures; 2) Are there unique features of pediatric SCI that distinguish the pediatric SCI population from the adult SCI population; and 3) Is there evidence to support the use of neuroprotective approaches, including hypothermia and steroids, in the treatment of pediatric SCI. The systematic review approach was chosen to review the evidence surrounding these aspects of pediatric SCI because of the paucity (or nonexistence) of good randomized controlled trials for this particular problem.

Methods

A systematic review of the literature of three online databases (EMBASE, Medline, and the Cochrane database) was performed for articles matching the search criteria through June 2009. The search strategy was: ("Spinal Cord Injury" OR "Paraplegia" OR "Quadriplegia" OR "tetraplegia" OR "lapbelt injuries" OR "seatbelt injuries" OR "cervical spine injuries") AND "Pediatrics" (All mapped to subject heading, including all subheadings, and searched as keywords). This returned a total of 220 abstracts. The search was then limited to English language abstracts and human-subject studies.

[1]Research Center, Hôpital Ste-Justine, Montreal, Quebec, Canada.
[2]Department of Surgery, University of Montreal, Quebec, Canada.
[3]Research Center, Hôpital Sacré-Coeur de Montréal, Quebec, Canada.

Table 1. Evidentiary table

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Apple et al., 1995; USA	*Clinical Pediatrics*	SCI in youth	Retrospective review	M/F 60/28; 3–15 yrs old mean 12.7; SCI with traumatic etiologies	Patients charts were reviewed. Relevant data were collected and compared	Patient demographics, neurological characteristics, functional recovery, associated injuries and medical complications, management	16,0	Mode level of bony injury was C2 in pre-teens, C4 in teens, and C4–C5 in adults. Scoliosis developed far more frequently in children, particularly pre-teens (23%), than in adults (5%) $p=0.01$. Violent etiologies, predominantly gunshots, accounted for a disproportionate share of injuries to pre-teens (19%) and African-Americans (28%), as compared with adults (12%) and Caucasians (7%). The percentage of females decreases as age increases, and vehicular accidents are the most frequent cause of SCI overall. Fixation and laminectomy were used in similar proportions among all ages. Teens received significantly more fusions ($n=44$; 74,6%) than did the other groups (x2[2]=6.6,$p<0.4$). No significant differences among the three age categories in the use of halo vests or traction.
Baker et al., 1999; USA	*American Journal of Emergency Medicine*	Evaluation of pediatric cervical spine injuries.	Retrospective review	Median age 9, 57% M; patients <18 discharged from hospital for CSI	Patients record with an ICD-9 code for cervical spine injury were reviewed. Relevant data was collected and compared. Cervical spine injury were divided in two categories : radiographically evident cervical spine injury and SCIWORA	Patient demographics, cost of radiographs, mechanisms of injury	16,5	Sports-related injuries were the most common. Forty patients had RESCI and 32 had SCIWORA. Forty-nine (80%) of all the patients had abnormal findings on neck examination, and six (16%) of the RECSI group had abnormal neurological findings ($p<0.05$). Lateral radiographs had a sensitivity for CSI of 79%; a three-view radiographic series had a sensitivity of 94%. All patients with CSI who were clinically asymptomatic had both a high-risk injury mechanism and a distracting injury.
Bosch et al.,2002; USA	*Spine*	Pediatric SCIWORA: the absence of occult instability and lack of indication for bracing.	Retrospective review	M/F 66%/34%, mean age 10.7; SCI without fracture or dislocation	Patients records with an ICD-9 code 952.xx for cervicel spine injury were reviewed. Relevant data were collected in a database and analyzed.	Patient demographics, analysis of MRI, Torg ratio, recurrent and bracing SCIWORA, outcome and prognosis	19,0	A total of 189 patients were diagnosed with SCIWORA at our institution over the 35-year review period. These patients differed from those reported in the literature with respect to a higher incidence, older age, less involved neurological injury, and more low-energy mechanisms, such as sports injuries and falls. There were no cases of a patient with SCIWORA who deteriorated and developed a permanent neurological deficit after having either recovered or plateaued from an initial SCIWORA. All recurrent SCIWORA patients recovered to normal neurological function. Bracing did not demonstrate any benefit in preventing these minor recurrent SCIWORAs.
Brown et al., 2001; USA	*Journal of Pediatric Surgery*	Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center	Retrospective review	M/F 1.6:1; mean age10.3 +/- 5.2 years, cervical spine injuries	Patients' charts were reviewed. Relevant data were collected and compared	Patient demographics, mechanisms and types of injury, treatment	15,0	A high index of suspicion for SCIWORA is essential when evaluating adolescents with neck trauma associated with sporting injuries or abuse. The most common mechanism of injury was motor vehicle related (52%), followed by sporting injuries (27%). Football injuries accounted for 29% of all sports-related injuries. Sixty-eight percent of all children sustained injuries to C1–C4; 25% to C5– C7; and 7% to both. SCIWORA occurred in 38%. Five patients had complete cord lesions involving the lower cervical spine (C4–C7); four of these were motor vehicle related, and all four patients died. Isolated cervical spine injuries occurred in 43%, whereas 38% had associated closed head injuries (CHI). The overall mortality rate was 18.5%, most commonly motor vehicle related (95%), occurring in younger children (mean and median age 5 years) and associated with upper cervical spine injuries (74%) and CHI (89%). C1 dislocations occurred in younger children (mean age, 6.6 years), most often as a result of motor vehicle related trauma (especially pedestrians) and were associated with the highest injury severity score (ISS), longest length of stay (LOS), most CHIs, and the highest mortality rate (50%). Cervical spine fractures with or without SCI occurred most commonly as a result of falls and dives. Sporting injuries occurred almost exclusively in adolescent boys (mean age, 13.8 years) and were isolated injuries associated with a relatively low ISS and shorter LOS. Interestingly, 75% of sporting injuries showed SCIWORA, and all infants suffering from child abuse had SCIWORA.

(*continued*)

Table 1. (Continued)

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Carr et al., 2004; USA	*Neurosurgery*	Neurological injury and death in ATV crashes in West Virginia: a 10-year retrospective review.	Retrospective review	80% male, average age 27.3; trauma registry data	Patients' charts were reviewed. Relevant data were collected and compared	Patients' demographics, type of injuries, helmet status, safety legislation	16,0	Eighty percent of victims were male, with an average age of 27.3 years. Only 22% of all patients were wearing helmets. Alcohol and/or drugs were involved in almost 50% of all incidents. Fifty-five of 238 patients sustained spinal axis injuries; only five were wearing helmets. One-third of victims (75 of 238 victims) were in the pediatric population, and only 21% were wearing helmets. Only 15% of victims <16 years of age were wearing helmets. There were a total of eight deaths; only one patient was wearing a helmet. **Conclusion**: In the United States, ATVs caused an estimated 240 deaths/yr between 1990 and 1994, which increased to 357 deaths/yr between 1995 and 2000. Brain and spine injuries occurred in 80% of fatal crashes. West Virginia has a fatality rate approximately eight times the national rate. Helmets reduce the risk of head injury by 64%, but only 21 states have helmet laws
Carreon et al., 2004;USA	*Journal of Spinal Disorders & Techniques*	Pediatric spine fractures: a review of 137 hospital admissions.	Retrospective review	M/F 52%/48%, mean age 12 y; spine injuries	Patients' charts were reviewed. Relevant data were collected and compared. Divided into three age groups: 0–9, 10–14 and 15–17 years old.	Patients' demographics, mechanisms and level of injuries, type of neurological injury	17,0	There were 36 patients aged 0–9, 49 aged 10–14, and 52 aged 15–17. Spine injury incidence increased with age ($p<0.001$). Motor vehicular accidents were the most common cause in this series. Injuries were 36% cervical, 34% thoracic, 29% lumbar, 34% multilevel contiguous, and 7% multilevel noncontiguous involvement. Nineteen percent had SCI. Thirteen of 21 had complete neurological injuries and all 3 incomplete injuries improved. Cord injury was more common in the 0–9 age group ($p=0.01$). Four of five patients with SCIWORA were in the 0–9 age group and had complete neurological injuries. Young children with cervical injuries were more likely to die than older children ($p<0.001$). Fifty-three percent had associated injuries. Eighteen percent underwent decompression, fusion, and instrumentation. Two patients developed scoliosis. The complication rate in surgical patients was higher than in patients treated nonsurgically ($p=0.006$) and in polytrauma patients. This may be related to the severity of the initial injury.
Cirak et al., 2004;USA	*Journal of Pediatric Surgery*	Spinal injuries in children	Retrospective review	2/3 were boys, mean age 9.48; spinal trauma diagnoses	Patients' charts were reviewed (ICD-9-CM 805-806.9,839-839.9; 847.0-847.9;952.0-952.9). Relevant data were collected and compared	Patients demographics, spinal column divided into five regions are compared by demographic data, mechanism of injury, level of injuries	16,5	The most common overall mechanism of injury was motor vehicle crash (MVC; 29%) and ranked highest for infants. Falls ranked highest for ages 2–9 years. Sports ranked highest in the 10–14 year age group. Paravertebral soft tissue injuries were present in 68%. The most common injury level was the high cervical spine (O–C4). The incidence of SCIWORA was 6%. Traumatic brain injury (37%) was the most common associated injury. Overall mortality rate was 4% in this urban catchment. Differences in injury severity and distributions of mechanisms of injury between age groups were highly significant ($p<0.01$). The distribution of levels of paravertebral soft tissue injuries and distribution of levels of isolated vertebral column injuries are not significantly different between age groups.
Cvijanovich et al., 2001;USA	*Pediatrics*	A population-based assessment of pediatric ATV injuries.	Retrospective review	M/F 2.1:1 and 2.7:1, average age 11.2; external cause of injury code for ATV	Patients record with an ICD-9 code for CSI were reviewed. Relevant data were collected and compared.	Patient demographics, ATV-related injury types, riding position	17,0	In 1996, 268 emergency room visits by children involved an all-terrain vehicle. Boys were twice as commonly injured as girls (male:female ratio: 2.1:1), and skin and orthopedic injuries were most frequent. The median ER charge was $368, and ER charges for these patients totaled $138, 000. From 1992 to 1996, 130 children were hospitalized as a result of injuries sustained during ATV use, with median charges of $4240 per admission. Male to female ratio was 2.7:1, and the average age was 11.2 +/- 3.6 years. Mean injury severity score was 8.0 +/- 6.0, and median length of stay was 2 days (range: 0–43 days). Orthopedic injuries were most frequent, but 25% ($n=32$) of children sustained traumatic brain or spinal cord injury. Most children (94%) were discharged from the hospital, but eight children died as a result of their injuries. Utah regulations prohibit children who are <8 years of age from driving an ATV and advise against carrying passengers on ATVs. However, 25% ($n=15$) of all injured children who were<8 were driving the ATV when injured, and 15% ($n=60$) of injured children were passengers on ATVs. Four of the eight fatally injured children were <8 years of age, and all were driving the ATV at the time of the crash. Finally, the estimated injury rate per 100 registered ATVs is significantly higher for children than for adults (3.41 vs 1.71).

(*continued*)

Table 1. (Continued)

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Dare et al., 2002 ;USA	*Journal of Neurosurgery*	MRI correlation in pediatric SCIWORA.	Retrospective review; case series	M/F 17/3; three children between 3 and 8 years of age (mean 4.7), 17 patients between 9 and 17 years (mean 13.3); SCI	Patients' charts were reviewed. Relevant data were collected and compared	Patient demographics, cause of injury, neurological presentation, MRI and outcome	15,0	Neurological syndromes on presentation were complete (Frankel grade A) in two patients (10%), severe partial (Frankel grade C) in one patient (5%), and mild partial (Frankel grade D) in 17 patients (85%). Partial neurological deficits resolved in 14 (78%) of 18 patients within 72 h and lasted >72 h in four patients (22%). MRI was performed in both patients presenting with complete injuries and in 17 of 18 patients presenting with partial neurological deficits. The studies were obtained within 24 h in 17 patients (85%). Neuroimaging revealed spinal cord swelling at the cervical level in one of the children with complete injury and cord edema with associated hemorrhage at cervical and thoracic levels in the other. Neural and extraneural elements were shown to be normal in all 17 patients with partial injuries who underwent MRI, including in the four patients with partial motor deficits lasting >72 h.
Davis et al., 1993; USA	*AJNR: American Journal of Neuroradiology*	Spinal injuries in children: role of MRI	Retrospective review; case series	M/F 10/5 $n=15$; age 12 h–17years; MRI evaluation of acute/subacute spinal injury	Patients charts were reviewed. Relevant data were collected and compared	Patient demographics, MRI, CT and radiographic findings	14,0	Children may have extensive cord contusion and/or infarction with minor, remote, or no fracture dislocation. Because both hemorrhagic and nonhemorrhagic cord lesions found on MRI were associated with significant, persistent cord deficits, the authors conclude that MRI provides a practical tool for diagnosis/prognosis in children with acute/subacute spinal injury. On MRI, of seven children with spinal cord neurological deficits, four had hemorrhagic contusions, one had nonhemorrhagic contusion, one had extensive infarction, and one revealed a normal cord. All had persistent deficits on hospital discharge. Eight without cord neurological deficit revealed no cord lesions on MRI; this group included two with epidural hematoma, four with ligamentous disruption, and two with bone compression.
Dearolf et al., 1990;USA	*Journal of Pediatric Orthopedics*	Scoliosis in pediatric spinal cord-injured patients.	Retrospective review	M/F 111/44; average age F 16 years M 17 years. Average curve preadolescent 32.2 degrees; SCI	Patients' charts were reviewed. Relevant data were collected and compared. Divided into two groups; those injured before and those injured after the adolescent growth spurt.	Patient demographics, radiographs, bracing and surgery for scoliosis	14,0	Patients were divided into two groups: those injured before and those injured after the adolescent growth spurt. Scoliosis developed in 97 and 52%, respectively. Bracing was effective in delaying progression in the pre-adolescent group. The progressive paralytic spinal deformity did not appear to be related to the level of injury. The older patient is at much less risk for paralytic scoliosis, but still requires routine examination.
DeVivo and Vogel, 2004; USA	*Journal of Spinal Cord Medicine*	Epidemiology of spinal cord injury in children and adolescents.	Retrospective review	Males 83% in 16 and 21 years of age; 51% among those aged 0–5 years; SCI	Patients' charts were reviewed. Relevant data were collected and compared. Divided into five groups: 0–5, 6–12, 13–15, 16–21, and 22+years old)	Patients' demographics, SCIWORA, etiology and injury level	13,5	Significant differences across age groups in every descriptive characteristic ($p<0.0001$). Incidence of complete lesions in relationship to the presence or absence of SCIWORA is significant for preschoolers ($p=0.0525$) and older adolescents ($p=0.0497$). Sports caused more SCI among males than among females who were at least 13 years of age ($p<0.0001$). Among persons who were at least 13 years of age, both vehicular crashes and sports caused a greater proportion of SCI in whites than in either African-Americans or Hispanics ($p<0.0001$). Etiology of SCI over time is significant for all (6–12 yo $p=0.0278$, 13–15 yo $p=0.0017$, 16–21 yo $p<0.0001$, 22+yo $p<0.0001$) except 0–5 yo ($p=0.3670$).
Dickman et al.,1991; USA	*Journal of Spinal Disorders*	Pediatric SCIWORA: report of 26 cases and review of the literature	Retrospective review	M/F 3:1; $n=159$; 16% with SCIWORA; spinal trauma	Patients' charts were reviewed. Relevant data were collected and compared	Patient demographics, SCIWORA, mechanism of injury, neurological presentation, radiological evaluation, treatment, outcome	13,5	As with other types of spinal cord injuries, the severity of neurological injury was the most important predictor of outcome. Patients with complete neurological deficits from SCIWORA had a poor prognosis for recovery of neurological function. Of these, 26 children (16%) sustained SCIWORA. The mechanism of injury, its severity, and the prognosis for recovery were related to the patient's age. In young children, SCIWORA accounted for 32% of all spinal injuries and tended to be severe; 70% were complete injuries. In older children, SCIWORA accounted for only 12% of the spinal injuries, was rarely associated with a complete injury, and had an excellent prognosis for complete recovery of neurological function.

(*continued*)

Table 1. (Continued)

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Frank et al., 2002;USA	*Spine*	The efficacy of MRI in pediatric cervical spine clearance.	Retrospective review	Preprotocol group : 7.2 mean age, M/F 35/16; post-protocol group: 7.2 mean age, M/F 37/14; cervical spine injuries	Patients' charts were reviewed. Relevant data were collected and separated in two groups; pre-protocol group (without MRI), post-protocol group (MRI)	Patient demographics, mechanisms of injury, outcome pre- and post- protocol, cost-efficiency	15,0	Fifty-one patients in each group met the inclusion criteria. In the preprotocol group, 19 patients underwent MRI at an average of 6.8 days after admission. In the postprotocol group, 31 MRIs were performed at an average of 2.5 days from admission. Time to cervical spine clearance decreased from 5.1 days in the pre-protocol group to 3.2 days in the post-protocol group ($p=0.003$). The average intensive care unit stay decreased from 9.2 days in the pre-protocol group to 7.3 days in the post-protocol group ($p=0.122$). The average hospital stay decreased from 20.1 days in the pre-protocol group to 15.5 days in the post-protocol group ($p=0.106$). Factoring charges for MRI, intensive care unit beds, and hospital beds, savings of $7,700 per patient were estimated.
Garland et al.,1988; USA	*Clinical Orthopaedics & Related Research*	Spinal cord insults and heterotopic ossification in the pediatric population.	Retrospective review; case series	15 developed HO , M/F 12/3 average age 8.5 years; spinal cord insult	Patients' charts were reviewed. Relevant data were collected and compared	Patients' demographics, HO characteristics of patients with spinal cord insult	15,0	Incidence of neurogenic heterotopic ossification was 3.3% in 152 patients. Consequently, the authors conclude from this series and from the literature review that neurogenic heterotopic ossification is uncommon in the pediatric SCI population.
Garton and Hammer, 2008; USA	*Neurosurgery*	Detection of pediatric cervical spine injury.	Retrospective review	33<8 yrs, 157 age 8–18 yrs; cervical spinal injury	Patients' charts were reviewed (ICD-9-CM 805,806,839,847,905, 907 categories). Relevant data were collected and compared	Physical findings, radiographic means of detection, and location of injury. Sensitivity of plain radiographs and diagnostic yield from additional radiographic studies	14,5	Of 239 patients, 190 had true injuries and adequate medical records; of these, 187 had adequate radiology records. Patients without radiographic abnormality were excluded. In 34 children younger than 8 years, National Emergency X-Radiography Utilization Study criteria missed two injuries (sensitivity, 94%), with 76% of injuries occurring from occiput–C2. In 158 children >8 years, National Emergency X-Radiography Utilization Study criteria identified all injured patients (sensitivity, 100%), with 25% of injuries occurring from occiput–C2. For children <8 years, plain-film sensitivity was 75% and combination plain-film/occiput–C3 CT scan had a sensitivity of 94%, whereas combination plain-film and flexion-extension views had 81% sensitivity. In patients >8 years, the sensitivities were 93%, 97%, and 94%, respectively.
Hamilton and Myles, 1992; Canada	*Journal of Neurosurgery*	Pediatric spinal injury: review of 61 deaths.	Retrospective review	M/F 35/26, average age 11.3; traumatic death in pediatric patient associated with spinal injury	Patients' charts were reviewed. Relevant data were collected and compared.	Patient demographics, injury profile, outcome	14,5	This group represented 28% of the total pediatric spine-injured population and 45% of the total pediatric spinal cord-injured group studied. The ratio of pediatric to adult spinal injury mortality was 2.5:1. Of the 61 children, 54 (89%) died at the accident scene. Thirty patients underwent a complete autopsy, 19 of whom had an Abbreviated Injury Scale Grade 6 injury (maximum score, untreatable). SCI was found to be the cause of death in only eight children and was associated with injury to the high cervical cord and cardiorespiratory arrest. These children typically sustained severe multiple traumas.
Hamilton and Myles, 1992; Canada	*Journal of Neurosurgery*	Pediatric spinal injury: review of 174 hospital admissions.	Retrospective review	M/F 115(66%)/59 (34%); mean age 14 years; pediatric patient associated with spinal injury	Patients' charts were reviewed. Relevant data were collected and compared. Divided into three age groups: 0–9, 10–14, and 15–17 years.	Patient demographics, injury profile, treatment, outcome	16,0	The etiology of injury varied according to patient age ($p<0.005$). The difference in injury pattern among the age groups was statistically significant ($p<0.005$). The difference in incidence of SCIWORA among the age groups was statistically significant ($p<0.005$). The difference in the number with severe physiologically incomplete neurological injury among the different age groups was statistically significant ($p=0.002$). Patients with complete cord injuries showed little improvement, whereas patients with incomplete injuries generally fared much better, with 74% showing significant improvement and 59% experiencing a complete recovery of neurological functions
Kannisto et al., 1998; Finland	*Spinal Cord*	Comparison of health-related quality of life (HRQL) in three subgroups of SCI patients.	Observational study	Group 1 (had pediatric SCI);31.3 years; M/F 25/11 Group 2 (newly injured) 35,3 years; M/F 25/6 Group 3 (chronic SCI) 35,2 years M/F 27/7	HRQL questionnaire analysis with three subgroups. Group 1: sustained a SCI in childhood and were adults at the time of examination. Group 2:newly injured patients at the beginning of acute rehab. Group 3: chronic SCI	Patient demographics, HRQL score analysis	15,5	There is a significant difference ($p<0.05$) among all subgroups in HRQL score. Average importance weights of the dimensions of moving ($p<0.0002$) and working ($p<0.002$) differed significantly in the three subgroups. Patients with pediatric SCI assigned the lowest importance for moving ($p<0.05$). The newly injured patients highly valued working capability ($p<0.05$). The tetraplegic patients estimated their HRQL significantly lower than patients with incomplete paraplegia. Of the three subgroups studied, those with pediatric SCI were well adjusted on the basis of anamnestic information and scored high on HRQL when compared with the other two subgroups. Patients injured in childhood expressed better performance in physical functions than patients who had sustained their injury in adulthood. The subgroups did not differ in psychological functions.

(*continued*)

Table 1. (Continued)

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Kewalramani et al.,1980; USA	*Paraplegia*	Acute spinal-cord lesions in a pediatric population: epidemiological and clinical features.	Retrospective review	Incidence higher in males, aged 1–15 years; SCI	Patients' records with an ICD-8 code for CSI were reviewed. Relevant data were collected and compared.	Incidence, mechanism of injury, autopsy, clinical and radiological findings	11,0	The incidence cases represent 9.4% of the total of 619 persons with SCI. Children in the general population at greatest risk were males. Almost 66% of the cases were motor vehicule collisions.
Mangano et al., 2006; USA	*Journal of Neurosurgery*	Pediatric neurosurgical injuries associated with ATV accidents: a 10-year experience at St. Louis Children's Hospital	Retrospective review	M/F 130/55; median age 12.3 y; pediatric cases involving ATV-related accidents	Patients' charts were reviewed. Relevant data were collected and compared	Patient demographics, neurological injuries	14,0	The overall RR of CNS injury was calculated for drivers ($p=0.003$) and passengers ($p=0.003$). Sixty-two patients (33.5%) had neurological injuries; there were 42 male and 20 female patients whose ages ranged from 2 to 17 years. The most common injuries included skull fracture (37 cases) and closed head injury (30 cases). There were 39 cases of intracranial hemorrhage and 11 of spinal fracture. A total of 15 types of neurosurgical procedures were performed: six craniotomies for hematoma drainage, five craniotomies for elevation of depressed fractures, two procedures to allow placement of an intracranial pressure monitor, one to allow placement of an external ventricular drain, and one to allow the insertion of a ventriculoperitoneal shunt. Two patients had sustained SCI, and three procedures were performed for spinal decompression or stabilization. The duration of hospital stay ranged from 1 to 143 days (mean 6.6 days). Fifty-seven patients (30.8%) were eventually discharged from the hospital, three (1.6%) were transferred to another hospital, two (1.1%) died, and 123 (66.4%) required inpatient rehabilitation.
Marshall et al., 1998; USA	*AJNR: American Journal of Neuroradiology*	Air bag-related deaths and serious injuries in children: injury patterns and imaging findings	Case series	No description, pediatric trauma from automotive air-bag deployments	Patients' charts were reviewed. Relevant data were collected and compared	Patients' demographics, autopsy and imaging study	12,0	The cause of death or serious injury in every case was the direct result of neurological injury. Injury patterns differed according to the child's age and type of restraint used at the time of collision. Crush injury to the skull predominated in infant victims traveling in rear-facing child safety seats, and both cranial and cervical spine trauma occurred in older children traveling restrained, improperly restrained, or unrestrained in the vehicle's front passenger seat.
Osenbach and Menezes, 1992;USA	*Neurosurgery*	Pediatric spinal cord and vertebral column injury	Retrospective review	M/F 110/69; mean age 10.2 years; pediatric spinal injuries	Patients' charts were reviewed. Relevant data were collected and compared. Divided into two age groups: 0–8 and 9–16 years.	Patient demographics, cause of injury, type of injury, neurological injury	13,5	The cause, distribution, type of injury, and severity of neurological injury varied with age. Neurological outcome was dependent upon the severity of the initial neurological injury. Children with complete or severe incomplete myelopathy uniformly remained with severe neurological dysfunction; children with mild to moderate injuries recovered normal or nearly normal neurological function. Surgical versus nonoperative management had no bearing on neurological outcome. 12% of the children with severe SCI developed post-traumatic spinal deformity. We conclude that spinal injury patterns differ between pre-adolescent children and adolescents. Most injuries can be successfully managed with nonoperative therapy. Prognosis is primarily correlated with the severity of the initial neurological insult. Finally, children with severe SCI must have close, long-term follow-up to monitor the development of post-traumatic spinal deformity.
Patel et al., 2001; USA	*Journal of Pediatric Surgery*	Pediatric cervical spine injuries: defining the disease.	Retrospective review	Mean age 11 + /- 5 years, 61% were boys; children with cervical spine injury	Patients' records with an ICD-9 code for CSI were reviewed. Relevant data were collected and compared.	Patients' demographics, mortality, presence or absence of bony injury, level of cervical spine injury, and presence of neurological deficit.	15,0	From a database of 75,172 injured children, 1,098 were identified with cervical spine injury, overall incidence 1.5%. Fractures of the upper spine were more common than those of the lower cervical spine ($p<0.001$). Dislocations were five times more common in the upper than in the lower spine ($p<0.001$). Nine-hundred-and- eight children (83%) had bony spine injury. Distribution of bony injury among upper cervical spine, lower cervical spine, or both was 52%, 28%, and 7%, respectively. The remaining 13% comprised unspecified levels of injury. Upper cervical spine injuries were prevalent among all age groups (42%, age ≤8; 58%, age >8), whereas lower spine injuries predominated in older children (85%, age >8). One third of children in the study group had neurological injury, and half of these had no radiographic evidence of bony injury. Ninety-four children (24%) had a complete SCI, and the remaining 76% had an incomplete SCI. One-hundred-and-eleven children (23%) with upper spine injury died compared with 11 children (4%) with lower spine injury. Mortality rate was highest (48%) in those with atlanto-occipital dislocation.

(*continued*)

Table 1. (Continued)

Author/Year/ Country	Journal	Title	Study design				Downs and Black score	Results (list main outcomes first, provide the results for each outcome and p-value):
			Type	Population	Treatment	Outcome measure	Mean	
Pollack et al.,1988; USA	*Journal of Neurosurgery*	Recurrent SCIWORA in children.	Retrospective review; case series	Aged from 1.5 to 14 years; 6M. 2F; SCIWORA patient	Patients' charts were reviewed. Relevant data were collected and compared	Patients' demographics, recurrent SCIWORA, outcome	13,5	The children most susceptible to re-injury were those who sustained mild or transient neurological deficits from an initial cord injury and who rapidly resumed normal activities. Radiographically occult spinal instability resulting from the initial injury to the vertebral and paravertebral soft tissues presumably made these children vulnerable to recurrent SCI, often from otherwise insignificant trauma. During the last 21 months, 12 additional children have been managed with a more stringent protocol combining neck immobilization in a rigid cervical brace for 3 months and restriction of both contact and non-contact sports, together with a major emphasis on patient compliance. With this new protocol, no recurrent cord injuries have been documented.
Ruge et al., 1988; USA	*Journal of Neurosurgery*	Pediatric spinal injury: the very young.	Retrospective review	M/F 27/20, average age 6.9 years; SCI	Patients' charts were reviewed. Relevant data were collected and compared. Divided into two age groups: 0–3, 4–12 years	Patients' demographics, neurological status, radiographic features	13,5	Upon statistical examination of the data, a subpopulation of children aged ≤3 years emerged. These very young children had a significant difference in level of injury ($p=0.0012$), requirement for surgical stability ($p=0.0046$), and sex distribution ($p=0.095$) compared to 4- to 12-year-old children.SCIWORA is more frequent in 4–12 year group than in the 0–3 year group ($p=0.0165$). The etiology of the pediatric injuries differed from that of adult injuries in that falls were the most common causative factor (38%) followed by automobile-related injuries (20%). Ten children (21.3%) had SCIWORA, whereas 27 (57%) had evidence of neurological injury. Complete neurological injury was seen in 19% of all traumatic pediatric SCI and in 40% of those with SCIWORA. The most frequent level of spinal injury was C-2 (27%, 15 cases) followed by T-10 (13%, 7 cases).
Scarrow et al., 1999; USA	*Pediatric Neurosurgery*	Cervical spine evaluation in obtunded or comatose pediatric trauma patients: A pilot study.	Experimental	M/F 11/6; mean age 5.6 years; 41% of severely brain-injured patients; suspected SCI	Flexion-extension maneuvers of the cervical spine with SSEP monitoring	Patients' demographics, SSEP monitoring, outcome	15,5	Fifteen patients were evaluated with this protocol. Two patients had movement on flexion-extension of the cervical spine and five had SSEP changes. Three patients had an MRI with only one showing injury. Five patients had residual hemiparesis. Evaluation of the cervical spine in obtunded or comatose pediatric trauma patients can be done safely with flexion-extension under fluoroscopy and SSEP monitoring. Further prospective studies are required to determine the efficacy of SSEP monitoring for cervical spine clearance in this select population.
Schwartz et al.,1997; USA	*Annals of Emergency Medicine*	Pediatric cervical spine injury sustained in falls from low heights.[erratum appears in *Ann Emerg Med* 1998 31,141].	Retrospective review; case series	M/F 7/1; mean age 47 months; cervical vertebral fracture or cervical SCI after a fall of <5 feet	Patients record with an ICD-9 code for CSI were reviewed. Relevant data was collected and compared.	Patients demographics, mechanisms of injuries	12,0	We identified eight children who sustained cervical spine injury after a fall of<5 feet. These children ranged in age from 9 to 68 months. Three had rotary subluxation of C1, and three had subluxation of C1–C2. One of the children in the latter group also had an odontoid fracture. Two children had a fracture of C2. All the children had limited range of motion of the neck or neck pain.
Sledge et al., 2001 ;USA	*Journal of Pediatric Orthopedics*	Use of MRI in evaluating injuries to the pediatric thoracolumbar spine.	Retrospective review; case series	M/F 12/7; age range 8–15 years; pediatric thoracolumbar injuries associated with a neurological deficit	Patients' charts were reviewed. Relevant data (MRI within 24 h of injury) were collected and compared	Patient demographics, imaging comparison, outcomes	14,0	After retrospectively reviewing 19 pediatric thoracolumbar fractures associated with neurological deficits from three level 1 trauma centers, we conclude that MRI is the imaging modality of choice in these patients because it can accurately classify injury to bones and ligaments and because the cord patterns as determined by MRI have predictive value.
Sun et al.,2000; USA	*Journal of Neurosurgery*	Spectrum of occipito-atlantoaxial injury in young children.	Retrospective review; case series	Mean age 3.5+/-0.54; trauma-related abnormalities of the Oc–C2 region	Patients' charts were reviewed. Relevant data (MRI after sustaining trauma) were collected and compared	Patient demographics, radiological evaluation, injury classification	17,0	Analysis of plain radiographs revealed that a novel interspinous C1–2:C2–3 ratio criteria of ≥2.5 was predictive of tectorial membrane abnormalities on MRI, with 87% sensitivity and 100% specificity. In patients with tectorial membrane abnormalities who underwent immobilization alone, interim platybasia was demonstrated on follow-up MRI.
Turgut et al., 1996; Turkey	*European Spine Journal*	Spinal injuries in the pediatric age group: a review of 82 cases of spinal cord and vertebral column injuries	Retrospective review	M/F 55/27; M median age 12 years, F median age 11.4 years; pediatric spinal injuries	Patients' charts were reviewed. Relevant data were collected and compared. Divided into two age groups: 0–9 and 10–16 years.	Patient demographics, cause of injury, level of injury, neurological injury, radiographic abnormalities	14,5	In our series, 18% of the patients had complete injury and the overall mortality rate was 3.6%. Eleven children (13%) had SCIWORA, whereas 39 (47%) had evidence of neurological injury. Although the spinal injury patterns differed between children and adolescents, the outcome was found to be predominantly affected by the type of neurological injury ($p<0.05$).
Wang et al.,2004; USA	*Spine*	High rates of neurological improvement following severe traumatic pediatric SCI.	Retrospective review; case series	M/F 26/4; mean age 7 years; SCI with neurological deficit	Patients' charts were reviewed. Relevant data were collected and compared	Patient demographics, injury patterns, neurological recovery	15,5	Factors found to be associated with neurological improvement were younger age ($p=0.04$), SCIWORA ($p=0.02$), and some neurological function at presentation ($p=0.07$). Methyl prednisolone administration ($p=0.31$), non-cervical injuries ($p=0.46$), and particular fracture type ($p=0.36$) were not found to be associated with neurological improvement.

Case reports of <10 patients were excluded. The abstracts were then read by title and relevant abstracts were reviewed. Full-length articles of interest were then obtained. All articles were then reviewed according to the method of Downs and Black (1998) by two independent reviewers. A total of 48 articles were kept at the end of this process and reviewed, and an evidentiary table was prepared (Table 1). A modified Delphi approach was used in which the questions were submitted to a panel of experts. After careful review of the resulting evidence in the form of evidentiary tables, a recommendation was submitted to a panel of experts and agreement among the panel members was noted. The members of the panel could modify the recommendations until a consensus was obtained.

The recommendation that emerged from this process is as follows:

> Pediatric patients with traumatic SCI have different mechanisms of injury and have a better neurological recovery potential than adults. Patients with SCI before their adolescent growth spurt have a high likelihood of developing scoliosis. Because of these differences, traumatic SCI should be highly suspected in the presence of abnormal neck or neurological examination, a high-risk mechanism of injury, or a distracting injury, even in the absence of anomaly on plain radiographs.

Data Compilation

The following data were compiled in an evidentiary table: study design, population, treatment or therapeutic measure, outcome measure, study purpose, and key results. The evidentiary table was then used to answer the three study questions.

Results

What is the epidemiology of pediatric spinal cord injury fractures?

A total of five retrospective studies were used to answer this question. Pediatric SCI is relatively rare. In a large retrospective study of the National Pediatric Trauma Registry over a 10-year period, the overall incidence of cervical spine injuries was 1.5% (Patel et al., 2001) In another study, 88 pediatric patients were identified based on the analysis of a database of 1,770 traumatic SCI patients (5%) (Apple et al., 1995). The level of injury differed based on the age category, with C2 lesions occurring in the pre-teen groups, C4 lesions occurring in the teen group, and C4–C5 lesions occurring in the adult group (Apple et al., 1995). In this series, violent etiologies (especially gunshots) accounted for a significant proportion of the pre-teen injuries (19%) compared to adults (12%).

Regarding the mechanism of injury, there appeared to be two distinct mechanisms that affected younger children and adolescents. Motor vehicle accidents (MVA) usually affected younger children whereas adolescents were commonly injured during sporting activities (Brown et al., 2001). In a retrospective study of 103 consecutive cervical spine injuries treated in a single level 1 pediatric trauma center, MVA accounted for 52% of injuries followed by sports injuries (27%) of which 29% were associated with football (Brown et al., 2001) The level of injury was C1 to C4 for 68% of patients, C5 to C7 for 25%, and both in 7%. The mortality rate in this series was 18.5%, occurred in younger children (mean age 5 years), was commonly the result of an MVA (95%) and was most often associated with an upper cervical spine injury (74%). Spinal cord injury without radiological anomaly (SCIWORA) accounted for 43% of injuries. In another study using the National Pediatric Trauma Registry, (Patel et al., 2001) 17% of patients with cervical spine trauma did not show any radiological anomaly, although 50% of patients with SCI show no radiological anomaly.

Most studies report a large predominance of males compared to females (Apple et al., 1995; Bosch et al., 2002; Brown et al., 2001; Carreon et al., 2004; Cirak et al., 2004; Dickman et al., 1991; Wang et al., 2004). All-terrain vehicles (ATVs) are also responsible for a higher injury rate in children than in adults. In a retrospective study of 268 children involved in ATVs accidents, the injury rate per 100 registered ATVs was significantly higher for children (3.41) compared to adults (1.71)(Cvijanovich et al., 2001).

Are there unique features of pediatric SCI, which distinguish the pediatric SCI population from the adult SCI population?

Neurological recovery. Neurological recovery in children with SCI is thought to be better than in the adult population. Several studies have shown good neurological recovery following SCI, with incomplete lesions having the best prognosis (Dickman et al.,1991), although severe complete injuries can also improve over time. In a retrospective review of 30 patients with SCI, Wang and associates (2004) evaluated the neurological injury based on the level of neurological involvement at time of injury. Of the 20 patients with complete injury, 7 died, 7 had no neurological recovery, and 6 improved. Five of these patients eventually gained enough function to become ambulatory. In the subgroup of patients with incomplete lesions (10 patients), 8 patients had neurological improvement. Cervical dislocation had a poor prognosis for neurological recovery (Wang et al., 2004) There are no studies comparing adults and children in terms of recovery and it is therefore difficult to clearly establish if neurological recovery is significantly better in children. The evidence is therefore very slight that neurological recovery is better in the pediatric population.

Scoliosis development. Scoliosis following SCI in children is a common entity especially when the neurological insult occurs at a young age. Apple and associates (1995) showed that scoliosis developed more frequently (23%) in pre-teens (<12 years of age) than in adults (5%). In a retrospective study of 130 children who had sustained SCI between birth and the age of 21 years, Dearolf and associates (1990) showed that 97% of patients injured before the growth spurt developed scoliosis compared to 52% when the injury occurred after the growth spurt.

SCIWORA. SCIWORA remains a recognized entity in the pediatric population although the SCI is usually diagnosed with the use of MRI. In a retrospective study of all children with traumatic spinal injury in a level 1 pediatric center, the incidence of SCIWORA was 6%.(Cirak et al., 2004) In a study by Dare and associates (2002), MRI performed in 17 patients with partial injuries failed to show any neural abnormalities even when performed >72 hours after injury in patients with

motor involvement. A high index of suspicion for SCIWORA is important when evaluating patients with sports injuries or or who have been abused, as evidenced by a study by Brown and associates (2001). In this series, 75% of pediatric SCI patients with sports injuries and all patients suffering from child abuse had SCIWORA. The physical examination remains an important component of the diagnostic process, as midline cervical tenderness is the most common physical finding in children with cervical spine injury even in the absence of radiological abnormality (Baker et al., 1999).

Is there evidence to support the use of neuroprotective approaches, including hypothermia and steroids, in the treatment of pediatric SCI?

After a careful review of the available literature, there is no evidence regarding the use of neuroprotective approaches for the treatment of SCI in children.

Discussion

The epidemiological features of pediatric SCI show that these injuries are relatively uncommon and that the mechanism of injury is different depending upon the age at time of injury and compared to the adult population. Neurological recovery appears to be better than in adults (Wang et al., 2004), although large series of cases are rare and no comparative studies between adults and children have so far been undertaken. The evidence is therefore very slight that neurological recovery is better in the pediatric population.

The modified Delphi approach used in this review was done in a stepwise fashion. First, three questions were formulated by a panel of experts. These questions were used to guide the literature review and orient the selection of papers. After careful review of the evidence in the form of evidentiary tables, a recommendation was submitted to a second panel of experts and agreement among the panel members was noted. The recommendation is:

> Pediatric patients with traumatic SCI have different mechanisms of injury and have a better neurological recovery potential than adults. Patients with SCI before their adolescent growth spurt have a high likelihood of developing scoliosis. Because of these differences, traumatic SCI should be highly suspected in the presence of abnormal neck or neurological examination, a high-risk mechanism of injury, or a distracting injury, even in the absence of radiological anomaly.

Complete agreement was reached among the expert panel and this recommendation was deemed strong although the evidence available was weak. SCI in the pediatric population remains a catastrophic event and every attempt should be made at decreasing the extent and severity of the injury as well as the complications following the injury. Imaging techniques have improved greatly over the past years making it possible to identify lesions that were not easily distinguishable on plain radiographs a few decades ago. The absence of radiological anomaly does not preclude significant injury.

There was no evidence in the current literature review to support the use of neuroprotective approaches including steroids and hypothermia. The current evidence for steroid use in adults is very weak. A systematic review of the animal literature on the use of corticosteroids showed a positive benefit in only 59% of the studies (Akhtar et al., 2009).

Summary

Pediatric patients with SCI have very different characteristics from their adult counterparts. Neurological recovery seems to be better than in adults. However, patients with SCI before their adolescent growth spurt are at higher risk of developing scoliosis. This systematic review provides the elements to support the proposed guidelines through a modified Delphi approach. The proposed guidelines are meant to help diminish the impact of SCI in the pediatric population.

Author Disclosure Statement

No funds were received for the preparation of this article. Dr. Parent is chair holder of the academic chair for pediatric spinal deformities of CHU Ste-Justine (endowed chair). Dr. Parent has a consulting agreement with Deputy Spine for Education.

References

The 2004 Annual Statistical Report for the Model Spinal Cord Injury Care Systems. (2004). National Spinal Cord Injury Statistical Center. University of Alabama at Birmingham.

Akhtar, A.Z., Pippin, J.J., and Sandusky, C.B. (2009). Animal studies in spinal cord injury: a systematic review of methylprednisolone. Alternatives to laboratory animals. ATLA 37, 43–62.

Apple, D.F., Anson, C.A., Hunter, J.D., and Bell, R.B. (1995). Spinal cord injury in youth. Clinical Pediatrics 34, 90–95.

Baker, C., Kadish, H., and Schunk, J.E. (1999). Evaluation of pediatric cervical spine injuries. Am. J. Emerg. Med. 17, 230–234.

Bosch, P.P., Vogt, M.T., and Ward, W.T. (2002). Pediatric spinal cord injury without radiographic abnormality (SCIWORA): the absence of occult instability and lack of indication for bracing. Spine 27, 2788–2800.

Brown, R.L., Brunn, M.A., and Garcia, V.F. (2001). Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center. J. Pediatr. Surg. 36, 1107–1114.

Carr, A.M., Bailes, J.E., Helmkamp, J.C., Rosen, C.L., and Miele, V.J. (2004). Neurological injury and death in all-terrain vehicle crashes in West Virginia: a 10-year retrospective review. Neurosurg. 54, 861–867.

Carreon, L.Y., Glassman, S.D., and Campbell, M.J. (2004). Pediatric spine fractures: a review of 137 hospital admissions. J. Spinal Dis. & Tech. 17, 477–482.

Cirak, B., Ziegfeld, S., Knight, V.M., Chang, D., Avellino, A.M., and Paidas, C.N. (2004). Spinal injuries in children. J. Pediatr. Surg. 39, 607–612.

Cvijanovich, N.Z., Cook, L.J., Mann, N.C., and Dean, J.M. (2001). A population-based assessment of pediatric all-terrain vehicle injuries. Pediatrics 108, 631–635.

Dare, A.O., Dias, M.S., and Li, V. (2002). Magnetic resonance imaging correlation in pediatric spinal cord injury without radiographic abnormality. J. Neurosurg. 97, 33–39.

Davis, P.C., Reisner, A., Hudgins, P.A., Davis, W.E., and O'Brien, M.S. (1993). Spinal injuries in children: role of MR. AJNR 14, 607–617.

Dearolf, W.W., Betz, R.R., Vogel, L.C., Levin, J., Clancy, M., and Steel, H.H. (1990). Scoliosis in pediatric spinal cord-injured patients. J. Ped. Orth. 10, 214–218.

DeVivo, M.J., and Vogel, L.C. (2004). Epidemiology of spinal cord injury in children and adolescents. J. Spinal Cord Med. 27, S4–10.

Dickman, C.A., Zabramski, J.M., Hadley, M.N., Rekate, H.L., and Sonntag, V.K. (1991). Pediatric spinal cord injury without radiographic abnormalities: report of 26 cases and review of the literature. J. Spinal Dis. 4, 296–305.

Downs, S.H., and Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J. Epid. Comm. Health 52, 377–384.

Frank, J.B., Lim, C.K., Flynn, J.M., and Dormans J.P. (2002). The efficacy of magnetic resonance imaging in pediatric cervical spine clearance. Spine 27, 1176–1179.

Garland, D.E., Shimoyama, S.T., Lugo, C., Barras, D., and Gilgoff, I. (1989). Spinal cord insults and heterotopic ossification in the pediatric population. Clin. Ortho. Rel. Res. 303–310.

Garton, H.J.L., and Hammer, M.R. (2008). Detection of pediatric cervical spine injury. Neurosurg. 62, 700–708.

Hamilton, M.G., and Myles, S.T. (1992a). Pediatric spinal injury: review of 61 deaths. J. Neurosurg. 77, 705–708.

Hamilton, M.G., and Myles, S.T. (1992b). Pediatric spinal injury: review of 174 hospital admissions. J. Neurosurg. 77, 700–704.

Kannisto, M., Merikanto, J., Alaranta, H., Hokkanen, H., and Sintonen H. (1998). Comparison of health-related quality of life in three subgroups of spinal cord injury patients. Spinal Cord 36, 193–199.

Kewalramani, L.S., Kraus, J.F., and Sterling, H.M. (1980). Acute spinal-cord lesions in a pediatric population: epidemiological and clinical features. Paraplegia. 18, 206–219.

Mangano, F.T., Menendez, J.A., Smyth, M.D., Leonard, J.R., Narayan, P., and Park, T.S. (2006). Pediatric neurosurgical injuries associated with all-terrain vehicle accidents: a 10-year experience at St. Louis Children's Hospital. J. Neurosurg. 105, 2–5.

Marshall, K.W., Koch, B.L., and Egelhoff, J.C. (1998). Air bag-related deaths and serious injuries in children: injury patterns and imaging findings. AJNR 19, 1599–1607.

Osenbach, R.K., and Menezes, A.H. (1992). Pediatric spinal cord and vertebral column injury. Neurosurg. 30, 385–390.

Patel, J.C., Tepas, J.J., Mollitt, D.L., and Pieper, P. (2001). Pediatric cervical spine injuries: defining the disease. J. Pediatr. Surg. 36, 373–376.

Pollack, I.F., Pang, D., and Sclabassi, R. (1988). Recurrent spinal cord injury without radiographic abnormalities in children. J. Neurosurg. 69, 177–182.

Ruge, J.R., Sinson, G.P., McLone, D.G., and Cerullo, L.J. (1988). Pediatric spinal injury: the very young. J. Neurosurg. 68, 25–30.

Scarrow, A.M., Levy, E.I., Resnick, D.K., Adelson, P.D., and Sclabassi, R.J. (1999). Cervical spine evaluation in obtunded or comatose pediatric trauma patients: A pilot study. Ped. Neurosurg. 30, 169–175.

Schwartz, G.R., Wright, S.W., Fein, J.A., Sugarman, J., Pasternack, J., and Salhanick, S. (1997). Pediatric cervical spine injury sustained in falls from low heights. Ann. Emerg. Med. 30, 249–252.

Sledge, J.B., Allred, D., and Hyman, J. (2001). Use of magnetic resonance imaging in evaluating injuries to the pediatric thoracolumbar spine. J. Ped. Ortho. 21, 288–293.

Sun, P.P., Poffenbarger, G.J., Durham, S., and Zimmerman, R.A. (2000). Spectrum of occipitoatlantoaxial injury in young children. J Neurosurg. 93, 28–39.

Turgut, M., Akpinar, G., Akalan, N., and Ozcan, O.E. (1996). Spinal injuries in the pediatric age group: a review of 82 cases of spinal cord and vertebral column injuries. Euro. Spine J. 5, 148–152.

Wang, M.Y., Hoh, D.J., Leary, S.P., Griffith, P., and McComb, J.G. (2004). High rates of neurological improvement following severe traumatic pediatric spinal cord injury. Spine 29, 1493–1497.

Address correspondence to:
Stefan Parent, M.D., Ph.D.
Department of Orthopaedics
Ste-Justine Hospital
Room 7904, 3175 Cote
Ste-Catherine, Montreal, Quebec, Canada H3T 1C5

E-mail: stefan.parent@montreal.ca