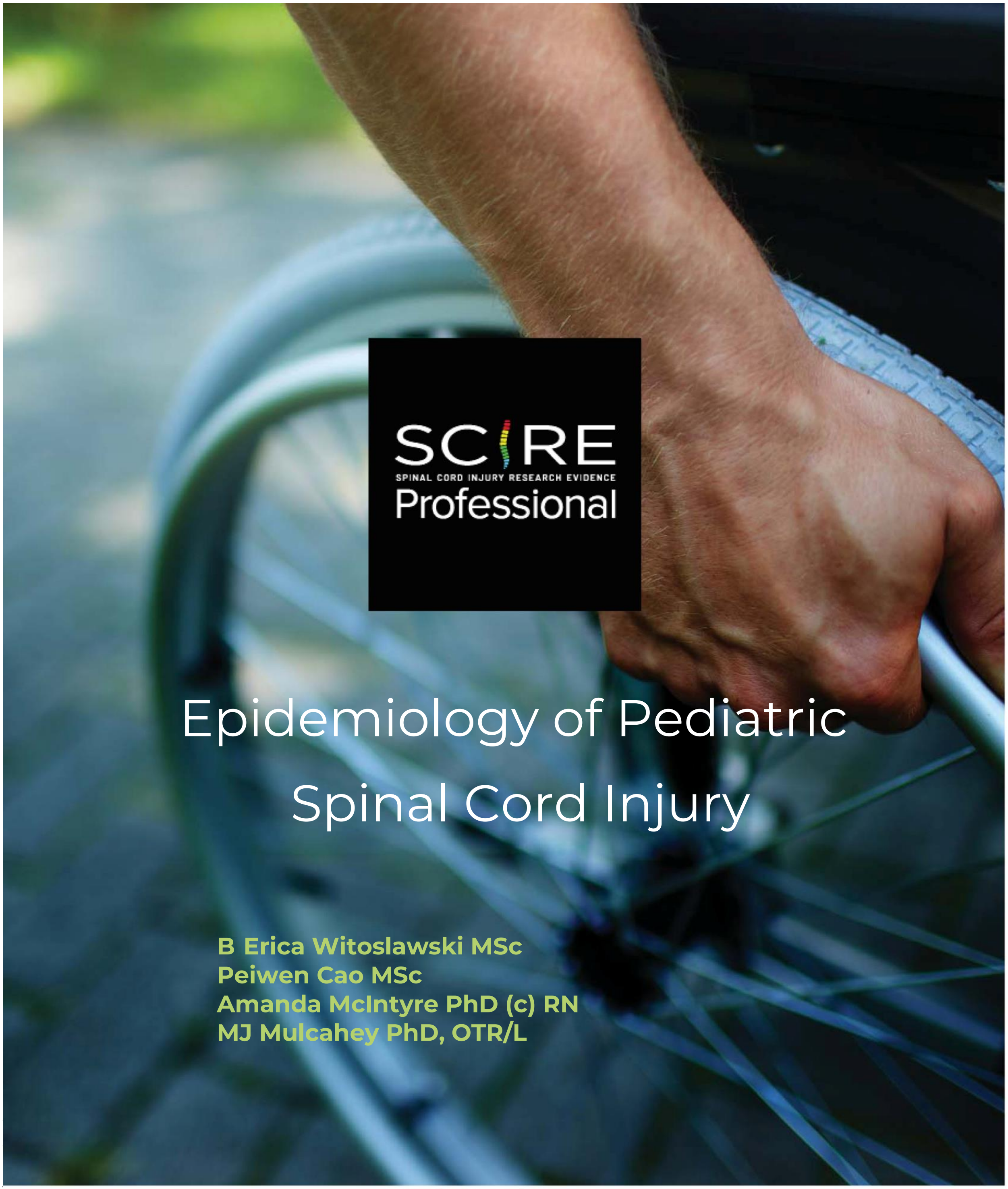

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Epidemiology of Pediatric Spinal Cord Injury

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1.0 Introduction

As defined by the CDC, epidemiology is the, “Study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problem,” (Centers for Disease Control and Prevention, 2012). Distribution as it pertains to epidemiology can be broken down into frequency (i.e., the number of health events in a population), prevalence (i.e., the relationship of the number of health events to the size of the population), and incidence of health events in a population (i.e., pattern, the occurrence of health-related events by time, place, and person). Incidence and prevalence related to pediatric spinal cord injury (SCI) will be discussed further in this chapter. The determinants of the epidemiology of pediatric SCI, causes and other factors that influence the occurrence of disease and other health-related events (etiology) will also be examined. While SCI in the pediatric population is relatively rare, it carries significant psychological and physiological consequences (Kokoska et al., 2001).

The National Institute of Neurological Disorders and Stroke (NINDS) (2021) categorizes SCI etiology based on presence of iatrogenic elements (whether a condition is caused by a physician or medication). Subsequently, NINDS common data elements (CDEs) break SCI into traumatic and non-traumatic injuries. Traumatic injuries include sports/leisure activity injuries, assault, transport, fall, birth injuries, and other injuries with traumatic causes. Non-traumatic injuries consist of those congenital or genetic in etiology, vascular in etiology, infectious in etiology, degenerative, tumor, or other non-traumatic spinal cord dysfunction (National Institute of Neurological Disorders and Stroke, 2021). This chapter is organized based on the NINDS CDEs and will also touch on the incidence and prevalence of pediatric SCI in places across the globe.

2.0 Traumatic Etiologies

2.1 Iatrogenic

While there are many potential causes of SCI, some are more common than others in pediatrics. As previously mentioned, iatrogenic SCI is the result of surgical or medical treatment by a physician (Krishnan & Kasthuri, 2005). According to DeVivo and Vogel (2004), surgical complications account for a significantly greater proportion of SCIs in adolescents (13 – 21 years of age) than in adults. In addition, as suggested by Smith et al. (2017), iatrogenic causes are only second to transport incidents in causing traumatic SCI in teenagers. While SCI caused by spinal deformity surgery is uncommon in the pediatric population, it is well documented. It is a rare complication after lower extremity surgery in children with skeletal dysplasia and thoracic kyphosis (Pruszczynski et al., 2015).

The mid-thoracic spinal cord is most vulnerable to vascular injury (Youlo et al., 2013). With vascular insults to the spinal cord being documented as a cause for SCI, injuries above the level of instrumentation are rare. In some instances, chest compressions needed to resuscitate an unconscious person may lead to unintended SCI. Samson et al. (2012) described one such case in which a 4-month-old male experienced an episode of asystole and left ventricle fibrillation following a heart transplant. This episode led to the child undergoing 10 minutes of chest compressions. The child was later found to be a paraplegic with radiological imaging showing he had experienced subdural hematoma and hemorrhagic medullary contusion from T4 – T10 with subarachnoid hemorrhaging from T10 – S2. While instances such as this do occur in children, they are relatively rare. Although there are some documented cases of medical treatment leading to SCI, more information on potential causes and severity is needed to fully understand iatrogenic SCI in children.

2.2 Sports/Leisure

With some pediatric-aged individuals being heavily involved in sports and other extracurricular activities, it is not surprising that sports and leisure activities contribute to SCI in the pediatric population. SCI due to sports and leisure activities can be caused by accidents in all sports, such as diving injuries, football injuries, bicycle crashes, all-terrain vehicle incidents (ATVs), and activities involving trampolines (Babcock et al., 2018; Canosa-Hermida et al., 2019; Hwang et al., 2003). ATV-related incidents can lead to serious injuries, sometimes causing SCI resulting in paraplegia and quadriplegia (Mangano et al., 2006; Sneed et al., 1986). An important contributor to ATV injuries is the lack of helmet use. In fact, the majority of individuals suffering injury via ATV crash were not wearing a protective helmet (Carr et al., 2004). Although rare, sledding is another leisure activity that can lead to life altering SCI and vertebral fracture (Noffsinger et al., 2008).

Like football, rugby, and other contact sports, hockey is a game in which intentional contact with other players can cause injury (Brown et al., 2001). In some unusual instances, hockey contact has led to ligamentous injury of the cervical spine, causing tetraplegia in children. When it comes to hockey, injuries of the spine have shown to be most common in younger children (≤14 years old) (Polites et al., 2014). The trampoline is another apparatus that has produced significant injuries in the pediatric population. Spinal injuries associated with the trampoline generally lead to cervical and thoracic fractures, and more infrequently, paraplegia. SCI is most commonly associated with jumping on the trampoline and landing improperly (i.e., jumping into a foam pit or the hitting head, as opposed to falling off the trampoline) (Furnival et al., 1999; Kasmire et al., 2016).

In general, as it relates to sports and recreational activities, research has found that children with this type of trauma have increased odds of cervical spine injury if they had focal neurologic findings, had complaints of neck pain, were injured diving, or sustained axial loading impacts (Babcock et al., 2018). Sports and leisure-related SCI has been seen in individuals ages 0 – 18 years; however, it is most common in teenagers (Baker et al., 1999; Canosa-Hermida et al., 2019; Cirak et al., 2004; DeVivo & Vogel, 2004; Finch & Barnes, 1998; Sneed et al., 1986). Findings have also indicated that SCI is much more likely to be neurologically complete in younger persons (DeVivo & Vogel, 2004). Insult caused by sports can also lead to contiguous and noncontiguous multilevel SCI in children (Mortazavi et al., 2011). Moreover, as in the instance of other traumatic SCI etiology like transport and falls, some instances of

SCI due to sports/leisure accidents saw spinal cord without radiological abnormality (SCIWORA) (Carroll et al., 2015).

Research has found that the mechanism of the neural injury likely relates to the inherent elasticity of the adolescent spine, which allows self-reducing yet significant intersegmental displacements when subjected to flexion, extension, and distraction forces. This makes the spinal cord vulnerable to injury even though the vertebral column is spared from disruption. This vulnerability is most evident in children younger than 8 years of age (Pang & Pollack, 1989). In fact, pediatric SCI is a very distinct injury profile, as anatomical and biomechanical features distinguish the younger immature spine from older adolescents with a more mature, adult-like spine. This means that while less likely to experience SCI, younger children have a higher incidence of neurological injury and higher frequency of SCIWORA and upper cervical spine injury (Hamilton & Myles, 1992). Examples of this phenomena can be seen in individuals doing the back bend motion during dance class, causing pediatric thoracic SCIWORA (Ren et al., 2017). Based on the above information, it appears that SCI in sport and leisure activities is predominantly the result of impact from contact with other individuals or surfaces. Knowing this, precautions can be taken to protect the pediatric population from severe injuries in the future.

2.3 Assault

Assault is another fairly common traumatic cause of spinal cord in injury in children, leading most often to paraplegia (Costacurta et al., 2010). Common violent causes of SCI include but are not limited to gun shots, knifings, fights, war, and child abuse. Studies have found that violent etiologies, predominantly gunshots, account for a disproportionate share of SCIs in preteens and teens, as well as African American and Hispanic males (Apple et al., 1995; DeVivo & Vogel, 2004). Firearm injuries are most commonly associated with thoracic spine injuries (Chu et al., 2016). Despite the low occurrence, dog attacks can cause SCI in children as well. In Kumar and colleagues' (2017) study examining neurosurgical sequelae of domestic dog attacks in children, it was found that 1 out of 124 participants experienced SCI.

Child-abuse is another unfortunate violent cause of SCI in the pediatric population. Infants and toddlers have been known to acquire cervical SCI as the result of physical abuse (Feldman et al., 2008). Children who are below 2 years of age, female, and non-white are more likely to sustain SCI caused by abuse; in addition, the thoracic and lumbar spine is at an increased risk of injury (Jauregui et al., 2019).

It should be noted that SCI etiology in the pediatric population can vary across different countries based on cultural and socioeconomic factors. For example, in some African countries where hunting is commonly practiced, SCI inflicted by hunting equipment such as bows and arrows may be more prevalent compared to that in Western society (van Adrichem et al., 2019). van Adrichem et al. (2019) reported a case in Tanzania, in which a teenage bird-hunter experienced an arrowhead wound to the neck, causing an incomplete and penetrating SCI, which resulted in paraplegia.

While tragic, violent, assault-based SCI in children may inevitably occur. It's important to be aware of the trends in order to prevent and create systemic change to avoid the causes of violent SCI.

2.4 Transport

Transportation, or automotive accidents – either being a passenger during an automotive crash or a pedestrian hit by a vehicle – is one of the most common causes of traumatic SCI in children (Anissipour et al., 2017; Astur et al., 2013; Carreon et al., 2004; Dauleac et al., 2019; German et al., 2007; Leonard et al., 2007; Mulligan et al., 2007; Odetola & Gebremariam, 2016; Vander Have et al., 2009). Compared to older children, younger children are more likely to experience SCI, especially severe injuries, as a result of transport accidents (Brown & Bilston, 2009; Eleraky et al., 2000; Finch & Barnes, 1998; Khanna & El-Khoury, 2007; Nadarajah et al., 2018; Zuckerbraun et al., 2004). SCI due to motor vehicle accidents most frequently impact the cervical spine region (Carreon et al., 2004; Chan et al., 2013; Eleraky et al., 2000; Hoy & Cole, 1993; Mortazavi et al., 2011; Pieretti-Vanmarcke et al., 2009; Polk-Williams et al., 2008; Poorman et al., 2019; Ribeiro da Silva, Linhares, Cacho Rodrigues, Monteiro, Santos Carvalho, Negrao, et al., 2016; Turgut et al., 1996). Among pediatric patients with cervical SCI, insult to the upper cervical spine occur most frequently, and children between age 0 -9 years seem to be at the highest risk (Babu et al., 2016; Bilston & Brown, 2007; Boese et al., 2015; Knox et al., 2014; Leonard et al., 2014; Meyer et al., 2005; Mohseni et al., 2011; Nitecki & Moir, 1994; Poorman et al., 2019).

The extent of SCI due to transport incident varies between neurologically complete and incomplete injury, with serious injury even leading to paraplegia and permanent deficits (Brown et al., 2001; Carreon et al., 2004; Dogan et al., 2006; Ruge et al., 1988; Santschi et al., 2005; Trigylidas et al., 2011). In addition, some incidences of SCI due to vehicular accident saw spinal cord without radiological abnormality (SCIWORA) (Brauge et al., 2020; Finch & Barnes, 1998; Kim et al., 2016). Improperly restrained children involved in motor vehicle collisions are at higher risk of sustaining SCI (Achildi et al., 2007). Furthermore, studies have indicated that injury patterns may be affected by the child's age and the type of restraint used at the time of collision. For example, Zuckerbraun and colleagues' (2004) work, revealed younger children had an increased incidence of permanent cord deficit compared to older children, even when they wore restraint devices. In addition, upon evaluating 11 cases of pediatric trauma caused by automotive air-bag deployments during low-speed collisions, Marshall et al. (1998) found that cervical spine trauma occurred in older children traveling restrained, improperly restrained, or unrestrained in the vehicle's front passenger seat.

2.5 Falls

Falls are another common causative factor SCI in children. Early research indicated that pediatric syndrome of traumatic myelopathy without demonstrable vertebral injury was due to falls landing in the hyperflexion and hyperextension position. The onset of such an injury can be either immediate or delayed, and the lesion may be either complete or incomplete (Cheshire, 1977). One study looked into the cause of

SCI due to falls in children. Participants were divided into two groups based on age: children between ages 0-12 and adolescents between ages 13-18. It was revealed that falls were the predominant cause of injury in the group of children 0-12 years of age, and falls from height were the common cause in adolescents aged 13-18 years. Overall, in the group of older children, falling from a height yielded more severe injuries (Babu et al., 2016). Falls of less than five feet have been shown to cause cervical vertebral fracture and cervical SCI in young children under 6 years of age (Schwartz et al., 1997). Furthermore, children with asymptomatic or myelopathic atlantoaxial instability (loss of stability in the bones in the upper spine or neck under the base of the skull) secondary to os odontoideum (i.e., anatomic anomaly of the upper cervical spine) are at a greater risk for acute SCI even after minor traumatic injury such as injury caused by a fall (Zhang et al., 2015). While fall-related traumatic SCI may have pervasive physical and health consequences, its prevalence in the pediatric population is relatively low (Mukhida et al., 2006).

Overall, existing research has contributed to some valuable insight into the etiology of fall-related SCI. Future research could look more into the etiology of falls leading to SCI, in order to better understand the mechanism of injury, and how to better treat and prevent such injuries.

2.6 Other Sources of Traumatic SCI

Other sources of traumatic SCI include blunt trauma and birth injuries. Cases of birth-related SCI often present clinical features such as difficult delivery, absent respiration, flaccid paralysis, sensory level, and neurogenic bladder (Adams et al., 1988). Furthermore, in Adams and colleagues' (1988) study reviewing the medical records of eight neonates with birth-related SCI, myelography results revealed that seven participants had swollen cords, and one experienced cord atrophy. These situations are unusual with abnormal presentations – either cephalic, breech or face presentations (MacKinnon et al., 1993; Vialle et al., 2008). Birth injuries were elaborated upon by Ruggieri, Smárason, & Pike (1999). Their research concluded that spinal cord lesions were mostly cervical and thoraco-lumbar. More males were affected by lesions than females. Additionally, the incidence of preterm delivery, multiple pregnancy, breech presentation, forceps delivery, and caesarean delivery were higher than average. Forceps delivery was associated with cervical lesions (Ruggieri et al., 1999).

With regard to blunt trauma injuries, studies have found that the lower cervical spine is the most common site of cervical spine injury (CSI) in children, with fractures being the most common type of injury. CSI is uncommon among children aged 8 years or younger (Viccellio et al., 2001). General blunt trauma is often comprised of injuries from motor vehicle accidents, sports injuries and assaults – these etiologies are more commonly discussed and have been mentioned above. Poly-trauma is another injury mechanism associated with spinal injury. Research tackling this etiology has shown similar findings to that of singular-trauma patients. For instance, in their study, Hofbauer et al. (2012) observed that younger children (age 0-9 years) were more likely to sustain injuries to the upper spine region, whereas injuries to the lumbar region only occurred in adolescents.

3.0 Non-traumatic Etiologies

Other SCI etiologies consist of non-traumatic causes, including congenital or genetic (e.g., spinal bifida), degenerative, tumor (both benign and malignant), vascular (e.g., ischemia, hemorrhagic, malformations), and infectious (e.g., bacterial, viral) etiologies. Of the non-traumatic causes, congenital anomaly, or structural or functional abnormalities that occur to the fetus (also known as birth defects) (World Health Organization, 2021), are most frequent in children under 4 years of age (Lee et al., 2009). Tumors are the most commonly explored non-traumatic cause of SCI in the pediatric population. Metastatic spinal cord compression (MSCC) is caused by the breakdown or compression of vertebral bodies containing metastatic disease. In some rare cases, MSCC can be caused by a tumor growing directly into the vertebral column (National Collaborating Centre for Cancer, 2008). The leading cause of MSCC in children is extra-medullary tumors, in particular neuroblastoma, followed by Ewing sarcomas, as well as other sarcomas and lymphomas (De Martino et al., 2019; Lewis et al., 1986). In individuals under 18 years of age, systemic cancer can lead to spinal cord disease. Patients with spinal cord disease could also face metastatic spinal cord compression, treatment-related transverse myelopathies, or anterior spinal artery stroke (Lewis et al., 1986). While congenital issues are a common cause of SCI in younger children, tumors become a more dominant cause as age increases. Furthermore, thoracic cord level of injury is most frequent in these cases (Lee et al., 2009).

Another common non-traumatic SCI etiology is viruses, with acute flaccid myelitis (AFM) being the primary source of insult (Galvin et al., 2013; Smith et al., 2017). AFM is triggered by certain infections—predominantly viral—that attack and cause damage to the spinal cord. These viruses, known as enteroviruses, are common infections that everyone acquires over time, but only result in spinal cord damages in a very small proportion of the population (University of Minnesota Masonic Children's Hospital, 2018). Acute flaccid myelitis presents with asymmetrical limb weakness and spinal cord MRI primarily show grey matter involvement (Sarmast et al., 2019). AFM tends to affect older children and is slightly more prevalent in males than in females (Messacar et al., 2016). When it comes to AFM, there are no reported ethnic and racial predispositions or links to vaccination-status. Additionally, affected patients are predominantly healthy, with asthma being the most common underlying illness. In some cases, patients with AFM are immunocompromised, battling organ transplants, chronic lymphocytic leukemia, immune deficiency syndrome, diabetes mellitus, and lupus—among others (Messacar et al., 2016).

As mentioned previously, in some instances, vascular complications can cause SCI. A few cases of SCI are thought to have arisen from spontaneous spinal epidural hematoma (SSEH) (Lo, 2010). Spinal epidural hematomas are very rare—accounting for less than 1% of all spinal canal space—occupying lesions. Spontaneous spinal epidural hematomas refer to blood within the epidural space without known traumatic or iatrogenic cause, and have an estimated incidence of 0.1 in 100,000 per year (Figueroa & DeVine, 2017). In certain cases, cavernous vascular malformations (clusters of irregularly small blood vessels and larger, stretched-out, thin-walled blood vessels filled with blood, located in the brain or spine) were the origin of SSEH (Figueroa, & DeVine, 2017). Like SSEH, cavernous vascular malformation is not commonly seen in pediatric patients (Lo, 2010). Although a diagnosis of non-traumatic SCI can be daunting, little can be done to prevent such an occurrence. It is essential for children of all ages to enjoy their youth and live life to the fullest, as there truly is no predictor (outside of congenital instances) that any one child will experience non-traumatic SCI.

4.0 Incidence and Prevalence

Understanding the incidence and prevalence of pediatric SCI can facilitate the development and implementation of prevention and intervention programs. In this section, we review the current work on the subject of pediatric SCI incidence and prevalence across the globe.

Recent work by New et al. (2019) mapped the epidemiology of traumatic SCI and non-traumatic spinal cord dysfunction (SCDys) in the pediatric population globally through systematically reviewing the relevant literature originated from fourteen countries. The study found that the median traumatic SCI incidence rates globally were, 5.4/million population/year in Asia, East; 9.9/million population/year in Australia, 3.3/million population/year in Western Europe, and 13.2 million population/year in North America (High Income). The median non-traumatic SCDys incidence rates were, 6.5/million population/year in Australia, 6.2/million population/year in Western Europe, and 2.1/million population/year in North America (High Income). Traumatic SCI was predominantly due to land transport, falls, and sport/recreation, while non-traumatic SCI was mostly caused by tumors and inflammatory/autoimmune causes (New et al., 2019).

4.1 Australia and Asia

Research has also examined incidence and prevalence of spinal cord-related issues in specific geographic regions. For instance, Galvin et al. (2013) investigated the incidence of spinal cord dysfunction (SCD) in children in Australia. The study revealed an average incidence rate of 3.8 and 6.5 per million children younger than 15 years for traumatic SCD and non-traumatic SCD, respectively, during the study period. Two studies looked at the incidence of pediatric SCI in Asia. In their recent study, Gutierrez et al. (2019) reviewed the Department of Defense Trauma Registry for pediatric encounters in Iraq and Afghanistan from January 2007 to January 2016, and found that 1% of patients experienced cervical spine fracture. Of those with cervical spine fracture, 17% had documented SCI. Furthermore, the median age of subject with CSI was 9.5 years of age and 63.9% were male. Most injuries were due to explosions. Another study by Chien et al. (2012) investigated the incidence and risk factors of pediatric SCI in Taiwan through reviews of a nationwide cohort of 8.7 million children under the age of 18. It found the incidence rates of cervical, thoracic, lumbar, and other SCI were 4.06, 0.34, 0.75, and 0.85 per 100,000 person-years, respectively. Male children were significantly more likely to have SCI than females in all SCI groups. In addition, young adults and teenagers were significantly more likely to have cervical SCI than pre-school age children. The authors also noted that children in families of lower socio-economic status were significantly more likely to have SCI (Chien et al., 2012).

4.2 Europe

More extensive research has been conducted on SCI incidence and prevalence in children in Europe. In their study examining the medical records of 56 children with cervical spine injury (CSI) at a Level 1 trauma center, a group of researchers from Austria found that 54% of the patients with CSI were aged 8 years or younger, and 46% were between the ages of 9 to 16. In addition, it was revealed that injuries of the upper cervical spine were more prevalent in younger patients, whereas injuries of the lower level were more prevalent among older patients (Platzer et al., 2007).

Augutis and Levi (2003) examined the incidence of pediatric SCI among children 0-15 years of age in Sweden between 1985 and 1996 through analyzing the data from population registers, County Habilitation Centers, as well as from informal sources. The incidence was estimated to be 4.6/million children/year, and 2.4/million children/year, excluding prehospital fatalities. Among survivors of incidents leading to SCI, sports-related injuries were the most common cause of injury – making up 43% of SCI etiology (Augutis & Levi, 2003). A UK-based study looked at the prevalence of spinal injury within the pediatric trauma population. Of the 19,538 children included in the UK Trauma Audit & Research Network Database from 1989 to 2000, the study found that 0.56% experienced SCI, and 0.15% sustained SCIWORA. Cord injury. It was also revealed that children under the age of eight were at higher risk of experiencing SCIWORA compared to older children (Martin et al., 2004).

In Finland, a review of the National Hospital Discharge Register including all spinal and spinal cord injuries in children under 18 years of age treated in hospitals between 1997 and 2006 was conducted. The proportions of cervical, thoracic, and lumbar spine injuries varied with age. The review found that 64% of spinal injuries in children below 8 years of age were cervical, while in the older children lumbar (42%) and thoracic spine injuries (33%) were more common. The incidence of spinal cord injuries averaged 1.9 per 10 children (Puisto et al., 2010).

Finally, Augutis et al. (2006) assessed the incidence of pediatric SCI in 19 European countries based on the survey responses from health professionals working with individuals with pediatric SCI (children between ages 0-14 years). Conclusive results were only identified for Portugal and Sweden, with the incidence of pediatric SCI (fatal injuries included) established, that is 27 children/million children/year and 4.6 children/million children/year experiencing SCI, respectively. For the other 17 countries, the estimated incidence of pediatric SCI (nonfatal injuries) varied from 0.9 to 21.2 children/million children/year (Augutis et al., 2006).

4.3 United States

The incidence and prevalence of pediatric SCI in in the United States, have received considerable attention from researchers. Piatt and Imperato (2018) looked into the trends in population-based incidences of SCI in children (between ages 0-14) and adolescents (between ages 15-17) by reviewing the Kids' Inpatient Database (KID) for 1997, 2000, 2003, 2006, 2009 and 2012; the denominator of the proportions for this analysis was taken from U.S. Census data. It was revealed that the annual population-based incidences of hospitalization for spinal injury and SCI trended downward from 1997 to 2012 for both children and adolescents in the United States. The review also indicated motor vehicle crashes were the most common injury mechanism for both children and adolescents, but penetrating injuries and sport injuries were more commonly linked to SCI (Piatt & Imperato, 2018). Data from KID was unitized in several other studies to explore the incidence and prevalence of pediatric-SCI in the U.S. One review of trauma cases from 2003 through 2012 queried the KID, putting the focus on CSI cases. The study demonstrated that the incidence of cervical spine injury significantly increased since 2003 (2.39% in 2003 vs 3.12% in 2012, respectively) (Poorman et al., 2019). Likewise, Shin and colleagues' (2016) review of the KID from 2000 to 2012 for pediatric CSI (PCSI) admissions found the overall prevalence of traumatic PCSI during those years was 2.07%. In line with the findings from Piatt and Imperato's (2018) work, Shin et al. (2016) identified transportation accidents as the most common cause of PCSI, accounting for 57.51% of all injury causes.

Another study by Piatt (2015) looked into admissions for spinal fracture without or with SCI) spinal dislocation, and SCIWORA in the KID and the National Trauma Data Bank (NTDB) registry during 2009. The study showed a nationwide pediatric SCI incidence rate of 24 per 1 million, with variations across regions. In addition, it was revealed that Back patients were more likely to experience severe injuries than patients of other races (Piatt, 2015). Vitale et al. (2006) analyzed data from 1997 and 2000 from the same databases, and suggested that the overall incidence of pediatric SCI in the United States was 1.99 cases per 100,000 children. In addition, significant differences in the annual incidence rate of pediatric SCI were found between patient populations stratified by race and sex. For example, African Americans (1.53 cases/100,000 children) exhibit a significantly higher rate of pediatric SCI than Native Americans (1.00), Hispanics (0.87), and Asians (0.36). Furthermore, males (2.79) were more than twice as likely to experience SCI as females (1.15) (Vitale et al., 2006).

Additional review of the NTDB from January 2002 through December 2006 were conducted to identify pediatric patients suffering from blunt trauma. Of pediatric blunt trauma patients, 1.3% sustained CSI. In stratified age groups, the incidence of CSI was 0.4% in infants/toddlers, 0.4% in preschool/young children, 0.8% in preadolescents, and 2.6% in adolescents (Mohseni et al., 2011). Another review of children with CSI entered in the National Pediatric Trauma Registry was carried out during a 10-year period by Patel et al.(2001), in which the researchers found an overall pediatric CSI incidence rate of 1.5%.

Research has also been conducted to examine the incidence of pediatric SCI in specific states or regions in the United States. In one study, Saunders et al. (2015) identified children and adolescents (0-21 years) who experienced SCI between 1998 and 2012 through the South Carolina CSI Surveillance Registry, and found an overall age-adjusted incidence rate of 26.9 per million population, with a trend toward decreasing incidence of pediatric SCI over the years. In northern Manhattan, pediatric deaths and hospital admissions secondary to neurological trauma were accounted for in the Northern Manhattan Injury Surveillance System from 1983 to 1992 and linked to census counts to compute incidence rates. Of neurological injuries, spinal cord and peripheral nerve injuries were relatively rare (5%) compared to head injuries (95%) (Durkin et al., 1998). An earlier study by Kewalramani et al. (1980) looked into acute spinal-cord lesions in children, aged 1 to 15 years. The study investigated injuries that occurred between 1970 and 1971 in 18 Northern California counties and used U.S. Census data as the denominator for incidence proportions. The investigation revealed that, in northern California, the incidence of acute spinal cord lesions in children/adolescents was 18.2 per million population. Males, especially those between ages 10-15, were found to be most at risk for such injuries (Kewalramani et al., 1980).

5.0 Conclusion

This chapter reviewed the etiology, incidence and prevalence of pediatric SCI. Not surprisingly, the majority of studies on the incidence, prevalence, and etiology of pediatric SCI have been conducted in Europe and North America, highlighting the need for more research in non-Western countries. Based on the findings from existing literature, our review suggests that both traumatic and non-traumatic SCI is relatively rare across the globe. In terms of the etiology of pediatric SCI, transport accidents are the most common cause for traumatic SCI in children, and acute flaccid myelitis is the most common cause for non-traumatic SCI in this population. Furthermore, regardless of etiology, males are more likely than females to suffer serious injury, and younger children are more likely to experience injury to the cervical spine than older children and adolescents. Studies also indicate that there may be a connection between race and SCI incidence. These may have important implications for the treatment and prevention of pediatric SCI. Studying the epidemiology of pediatric SCI allows researchers and clinicians to better understand injury trends over the years, and enables them to develop new safety measures and guidelines to protect children involved in sports, riding in vehicles, and living in potentially unsafe home environments. While not all SCI is avoidable, it is crucial for the public and health professionals to take necessary precautions to minimize the risks and mitigate the impact of pediatric SCI.

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7.0 Evidence Table

Table 1. Studies on Etiology of Pediatric SCI

Author, Year **Country** **Research Design** **Total Sample size** **Level of Evidence**	**Method**	**Results**
Costacurta et al. (2010) Brazil Case Series N=106 Level of evidence: 4	Reviewed cases of 106 patients 16 years of age or younger who were admitted with SCI to a Brazilian Rehabilitation Medical Center between April 2002 and June 2008	1. 67 boys (63.2%) and the mean age of 8.6 years. In all, 50.9% of the SCI have traumatic etiology. 2. The most frequent causes were gunshot 42.6%, traffic accident 38.9%, diving 9.3% and fall 3.7%. 3. Non-traumatic etiologies corresponded to 49.1% of the total patients - tumor (36.5%) and infection (19.2%) were the most frequent cause of spinal injuries. 4. Average time between SCI event and arrival at the rehabilitation medical center was 27 months. 5. Majority of patients were paraplegic (76.4%)
Kumar et al. (2017) USA Case Series N=124 Level of evidence: 4	Reviewed retrospectively all children requiring neurosurgical consultation for dog bite at a regional Level 1 pediatric trauma center over a 15-year period	1. 17 children (13.7%) incurred injuries requiring neurosurgical consultation. 2. 53% of victims were female. 3. The mean age at the time of attack was 30 months. 4. Twelve (71%) of the attacks were perpetrated by the family pet, and 13 (76%) occurred at the patient's home. 5. Spinal fracture with complete spinal cord injury in 1 child.
van Adrichem et al. (2019) Tanzania Case Study N=1 Level of evidence: 5	Reviewed the case of a 17-year-old male bird hunter admitted to Kilimanjaro Christian Medical Centre (KCMC) in northern Tanzania with a penetrating neck injury	1. Hunter received an arrowhead to neck wound while hunting. 2. Resulted in incomplete spinal cord injury.
Feldman et al. (2008) USA Case Series N=5 Level of evidence: 4	Reviewed 5 cases of infants and toddlers who sustained cervical spinal cord injury as the result of child abuse	1. Five infants and toddlers who sustained cervical spinal cord injury as the result of child abuse, 4 children had spinal cord injury without (or with minimal) radiological abnormality. 2. The 3 children presenting to our hospital with cord injury represent 1% of the estimated cases of inflicted head injury seen during a 23-year period.
Jauregui et al. (2019) USA N=5 Case Series Level of evidence: 4	Reviewed the cases of 5 infants and toddlers who sustained cervical spinal cord injury as the result of child abuse are described	1. Most common type of abuse was physical. 2. Abused patients were more likely to be below 2 years of age, female, and nonwhite. 3. Abused patients also presented with an increased risk of thoracic and lumbar vertebral column fractures.
Apple et al. (1995) USA Case Series N=1770 Level of evidence: 4	Reviewed a database of 1,770 traumatic SCI patients	1. Violent etiologies, predominantly gunshots, accounted for a disproportionate share of injuries to preteens (19%) and African-Americans (28%), as compared with adults (12%) and Caucasians (7%)

Chu et al. (2016) USA Case Series N=8317 Level of evidence: 4	Reviewed the National Trauma Databank (2007-2010) to identify patients with mandibular fractures	1. There were statistically significant lower rates of associated CSI in pediatric patients than adults (3.5% *versus* 7.3%, $P < 0.01$). 2. Predictors of associated CSI in mandible fractures for both adults and children were older age, lower Glasgow Coma Scale, thoracic injuries, firearm or motor vehicle accident mechanisms, and symphyseal fractures. 3. In the pediatric cohort, body, ramus, and subcondylar fractures were significantly associated with CSI.
Adams et al. (1988) Canada Case Series N=8 Level of evidence: 4	Reviewed of cases of 8 neonates who presented with the clinical features of spinal cord injury	1. Most cases involved difficult delivery, absent respiration, flaccid paralysis, sensory level, and neurogenic bladder. 2. Myelography revealed that 7 patients had the early changes of swollen cord and 1 patient had the late changes of cord atrophy.
Vialle et al. (2008) France Case Series N=9 Level of evidence: 4	Reviewed medical charts of nine patients identified by a questionnaire sent to the members of the French Society of Paediatric Orthopaedics (SOFOP)	1. Fetal presentation was cephalic in three cases, a breech presentation in four cases, and a face presentation in two cases.
Polk-Williams et al. (2008) USA N=95,654 Case Series Level of evidence: 4	Reviewed the National Trauma Data Bank (NTDB) for the period January 2001 to December 2005 for patients younger than 3 years of age with a blunt CSI	1. Most patients with a CSI were injured in motor vehicle crash (MVC) (66%) or falls (15%). 2. Injured patients without CSI were also most likely to be injured in a MVC (32%) or via a fall (27%). 3. MVCs remained the most common mechanism of injury, whether cord-injured, column-injured, or both. Similarly, falls remained the second most common cause of all 3 types of c-spine injury. 4. Slightly fewer than half of CSI patients with a cord injury sustained such injuries in an MVC (45.6%), whereas significantly more than half of both column-injured patients and column and cord-injured patients sustained their injuries in an MVC (69.1% and 64.7%, respectively). 5. An assault was more likely to cause an isolated cord injury than an isolated column injury or a column injury with cord injury.
Babu et al. (2016) India Case Series N=84 Level of evidence: 4	Retrospectively reviewed 84 consecutive pediatric spine injuries treated at an institute from January 2002 to December 2011	1. The mean age was 14.7 years. 2. There were 18 patients (21%) in group A (0-12 years) and 66 patients (79%) in group B (13-18 years). 3. Overall, injury was more common in boys (ratio of 6:1). 4. Trivial fall was the predominant cause in group A and fall from height in group B. There were 30 children (36%) with injuries of the upper cervical spine, 53 (63%) with injuries of the lower cervical spine and 1 patient (1%) with a combined injury of upper cervical spine and thoracic spine. 5. Overall, 22% of the group A children and 67% of the group B patients had more severe injuries

Cheshire (1977) USA Case Series N=3 Level of evidence: 4	Reviewed 3 case histories	1. The majority of children the spinal paralysis is complete and this would appear to be particularly true in those children in whom the onset of the paralysis is immediate.
Zhang et al. (2015) China Case Series N=6 Level of evidence: 4	Reviewed retrospectively 6 pediatric patients with os odontoideum who suffered acute traumatic cervical cord injury between 2012 and 2013	1. There were 2 male and 4 female subjects ranging in age from 4 to 18 years (mean 11.8 years). 2. In children aged 4 - 18, Falls were the most common injury (n = 5), followed by a minor motor vehicle accident (n = 1) 3. Asymptomatic or myelopathic atlantoaxial instability secondary to os odontoideum ahead of fall. 4. Atlantoaxial instability and cord compression were presented in all cases with dynamic cervical lateral radiographs and magnetic resonance imaging. 5. Most patients presented with spinal cord thinning and hyperintensity on T2-weighted sequences in magnetic resonance imaging. 6. Two patients were classified as ASIA B, 1 as ASIA C, and 3 as ASIA D category on admission.
Schwartz et al. (1997) USA Case Series N=8 Level of evidence: 4	Reviewed retrospectively the medical records of children younger than 6 years old with the diagnosis of cervical vertebral fracture or cervical spinal cord injury after a fall of less than 5 feet. Data from medical records over an average time span of 11 years at four large children's hospitals were compiled.	1. Children ranged in age from 9 to 68 months. 2. Three had rotary subluxation of C1, and three had subluxation of C1-C2. 3. One of the children in the latter group also had an odontoid fracture. 4. Two children had a fracture of C2. 5. All the children had limited range of motion of the neck or neck pain.
Mukhida et al. (2006) Nepal Case Series N=352 Level of evidence: 4	Reviewed clinical records of patients <or=18 years who presented to Tribhuvan University Teaching Hospital between April 1, 2001 and April 1, 2004 with acute neurological trauma and were admitted to hospital	1. Spinal injuries were relatively rare (4%) compared to head injuries (96%). 2. Falls were the most common cause of injuries (61%).
Cirak et al. (2004) USA Case Series N=206 Level of evidence: 4	Reviewed retrospectively all children younger than 14 years with TSI, treated at a level I pediatric trauma center between 1991 and 2002 (n = 406, 4% total registry)	1. Mean age was 9.48 ± 3.81 years. 2. The most common overall mechanism of injury was motor vehicle crash (MVC; 29%) and ranked highest for infants. 3. Falls ranked highest for ages 2 to 9 years. 4. Sports ranked highest in the 10 to 14 year age group. 5. Paravertebral soft tissue injuries were 68%. 6. The most common injury level was the high cervical spine (O-C4). 7. The incidence of spinal cord injury without radiologic abnormality (SCIWORA) was 6%

Canosa-Hermida et al. (2019) Spain Case Series N=68 Level of evidence: 4	Reviewed data from the internal registry of the Spinal Cord Injury Unit and the patient's medical records, between March 1988 and December 2014	1. The mean age was 14.4 years (median: 16). 2. Only 25% were younger than 15. 3. Male patients accounted for 73.5% of the total. 4. Main cause of injury was traffic accidents (60.3%; n = 41), being higher (77.8%) in children ≤ 10 years. 5. Other etiologies included falls (19.1%), diving accidents (16.2%) and other causes (4.4%)
Ruge et al. (1988) USA Case Series N=71 Level of evidence: 4	Reviewed clinical data from 71 children aged 12 years or younger of 2598 spinal cord-injured patients admitted to the authors' institutions from June, 1972, to June, 1986	1. The 47 children with traumatic spinal cord injury averaged 6.9 years of age and included 20 girls (43%). 2. 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%). 3. Ten children (21.3%) had spinal cord injury without radiographic abnormality (SCIWORA), whereas 27 (57%) had evidence of neurological injury. 4. Complete neurological injury was seen in 19% of all traumatic pediatric spinal cord injuries and in 40% of those with SCIWORA.
German et al. (2007) USA Case Series N=73 Level of evidence: 4	Reviewed retrospectively the University of New Mexico Hospital trauma registry of data compiled over a 7-year period	1. 53 children (73%) had sustained neurological injuries. 2. Among these 53 children, 64% sustained isolated head injuries, 15% isolated spine injuries, 9.4% combined spine and head injuries, 2% combined peripheral nerve, spine, and head injuries, 4% isolated peripheral nerve injuries, and 5.6% concussive events. 3. In 53.4% of patients with neurological injuries the results of computed tomography (CT) examination were abnormal
Turgut et al. (1996) Turkey Case Series N=82 Level of evidence: 4	Reviewed 82 children with spinal cord and/or vertebral column injury treated in department between 1968 and 1993	1. The cause of pediatric injuries differed from that of adult injuries in that falls were the most common causative factor (56%) followed by vehicular accidents (23%). 2. The most frequent level of spinal injury was in the cervical region (57%, 47 patients) followed by the lumbar region (16.5%, 13 patients). 3. 18% of the patients had complete injury and the overall mortality rate was 3.6%. 4. 11 children (13%) had spinal cord injury without radiographic abnormality (SCIWORA), whereas 39 (47%) had evidence of neurological injury
Galvin et al. (2013) Australia Case Series N=103 Level of evidence: 4	Reviewed consecutive admissions with SCD using the International Classification of Diseases and Related Health Problems, 10th Edition, Australian Modification. Potential cases admitted to RCH between January 1, 2000, and June 30, 2010, were identified and the RCH Trauma Registry was cross-checked to	1. Most patients (n = 68, 66%) had a non-traumatic SCD and were male (n = 68, 66%). 2. Of the 68 patients who sustained non-traumatic spinal injuries, the majority (n = 40, 59%) were a result of neoplasm or transverse myelitis (n = 15, 22%) or other diseases of the spinal cord (n = 12, 18%). 3. 35 children were admitted after traumatic injury and more than half of these (n = 19, 54%) were involved in motor vehicle accidents, followed by sporting injuries (n = 8, 23%), falls from height (n = 7, 20%) and assault (n = 1, 3%).

	improve accuracy of case attainment	
Viccellio et al. (2001) USA Observational N=3065 Level of evidence: 5	A prospective, multicenter study to evaluate pediatric blunt trauma victims	1. 30 patients (0.98%) sustained a CSI. 2. Included in the study were 88 children who were younger than 2, 817 who were between 2 and 8, and 2160 who were 8 to 17. 3. Fractures of the lower cervical vertebrae (C5-C7) accounted for 45.9% of pediatric CSIs. 4. No case of spinal cord injury without radiographic abnormality was reported in any child in this study, although 22 cases were reported in adults. 5. Only 4 of the 30 injured children were younger than 9 years, and none was younger than 2 years.
Mangano et al. (2006) USA Case Series N=185 Level of evidence: 4	Reviewed retrospective data obtained in all patients admitted to the St. Louis Children's Hospital between 1993 and 2003.	1. Sixty-two patients (33.5%) suffered neurological injuries 2. There were 42 male and 20 female patients whose age ranged from 2 to 17 years. 3. Most common injuries included skull fracture (37 cases) and closed head injury (30 cases). 4. There were 39 cases of intracranial hemorrhage and 11 of spinal fracture. 5. 2 patients had sustained spinal cord injury, and three procedures were performed for spinal decompression or stabilization.
Sneed et al. (1986) USA Case Series N=5 Level of evidence: 4	Reviewed 5 reports of all-terrain vehicle accidents in childhood from the US Consumer Product Safety Committee	1. Age range of victims was from 7 to 18 years. 2. Of the five cases of spinal cord injury, three resulted in quadriplegia and two in paraplegia.
Noffsinger et al. (2008) USA Case Series N=181 Level of evidence: 4	Reviewed of 181 children with sledding related-trauma at a Midwest pediatric level I trauma center and affiliated urgent care centers from 2006 – 2007	1. A 15-year-old boy sledding head first on a body board when his head struck the bumper of a trailer. 2. He sustained vertebral body compression fractures of cervical vertebrae 4–7 and spinal cord injury. 3. The most frequent mechanism of injury was collision with an object or a person.
Polites et al. (2014) USA Case Series N=155 Level of evidence: 4	Reviewed cases of children under 18 years of age who presented to our institution from July 1997 to July 2013 with injuries sustained while participating in ice hockey	1. Injuries to the spine were most common in younger children (≤14 years old) and girls, 2. Most injuries resulted from intentional contact.
Furnival et al. (1999) USA Case Series N=724 Level of evidence: 4	Reviewed retrospectively medical records of all PTI patients presenting to the pediatric ED from November 1990 through November 1997	1. Spinal injuries were common (12%), including 7 patients with cervical or thoracic fractures, and 1 with C7 paraplegia. 2. Fractures were more frequently associated with falls off the trampoline, whereas spinal injuries more frequently occurred on the trampoline. 3. The annual number of PTI nearly tripled during the study period, from 51 in 1991 to a peak of 148 in 1996.

		4. PTI patients were 53% female, with a median age of 7 years; 37% were <6 years of age. 5. Privately owned trampolines accounted for 99% of PTI. Most injuries (66%) occurred on the trampoline, 28% resulted from falls off, and 4% from imaginative mechanisms. 6. One hundred eleven patients (15%) suffered severe injury (1990 Abbreviated Injury Scale value >/=3), usually of an extremity (89 out of 111). Fractures occurred in 324 patients (45%).
Kasmire et al. (2016) USA Case Series N=8263 Level of evidence: 4	Reviewed data on trampoline injuries from the National Electronic Injury Surveillance System from 2010 to 2014	1. TPIs resulting in hospital admission included open leg fractures (*n* = 4), a skull fracture (*n* = 1), and cervical spine fractures with spinal cord injury (*n* = 2). 2. Both patients with spinal cord injuries (ages 17 and 20 years old) sustained the injury performing a flip, with 1 landing on his head on a bar and the other jumping into a foam pit.
Babcock et al. (2018) USA Case Series N=176 Level of evidence: 4	A secondary analysis of a multicenter retrospective case-control study involving children younger than 16 years who presented to emergency departments after blunt trauma and underwent cervical spine radiography	1. Children with sport and recreational activity–related trauma had increased odds of cervical spine injury if they had focal neurologic findings (odds ratio [OR], 5.7; 95% confidence interval [CI], 3.5–9.4), had complaints of neck pain (OR, 3.1; 95% CI, 1.9–5.0), were injured diving (OR, 43.5; 95% CI, 5.9–321.3), or sustained axial loading impacts (OR, 2.2; 95% CI, 1.3–3.5). 2. Football (22%), diving (20%), and bicycle crashes (11%) were the leading activities associated with cervical spine injury.
Kokoska et al. (2001) USA Case Series N=408 Level of evidence: 4	Reviewed the National Pediatric Trauma Registry between April 1994 and March 1999 and identified (by ICD-9 criteria) all cases of blunt trauma victims with cervical fractures, dislocations, and spinal cord injuries without radiographic abnormality (SCIWORA)	1. INCIDENCE of spinal cord injury is relatively low (1% to 2%) among pediatric trauma victims, 60% to 80% of all pediatric vertebral injuries are in the cervical (C) spine. 2. Data were sorted by International Classification of Diseases, 9th revision, Clinical Modification (ICD · 9 · CM) diagnosis as follows: fractures (805.00 to 805.19, 806.00 to 806.19), dislocations (839.00 to 839.18), and spinal cord injury without radiographic abnormality (SCIWORA; 952.00 to 952.09).
Baker et al. (1999) USA Case Series N=72 Level of evidence: 4	Reviewed retrospectively patients who were diagnosed with CSI	1. 72 children, ages from 1 month to 15 years (median age, 9 yrs), were included in the study. 2. Sports-related injuries were the most common. 3. Forty patients had RESCI and 32 had SCIWORA.
DeVivo & Vogel (2004) USA Case Series N=35,080 Level of evidence: 4	Reviewed persons with SCI enrolled in either the Shriners Hospitals for Children SCI database or the National SCI Statistical Center database from 1973 through 2002	1. Among children and adolescents (under the age of 22), the proportion of SCI due to motor vehicle crashes was higher than in adults (22+ years). 2. Sports, violence, and medical or surgical complications also accounted for a significantly greater proportion of SCI in teenagers (13–21 years) than in adults.

		3. Violence has become the leading cause of SCI among African American and Hispanic teenage males (1 3–21 years). 4. SCI was much more likely to be neurologically complete in younger persons.
Astur et al. (2013) USA Case Series N=14 Level of evidence: 4	Reviewed cases of patients ranging in age from newborn to sixteen years old who had a diagnosis of atlanto-occipital dislocation from 1991 through 2011	1. Half of the patients were male, and the mean age at the time of the accident was 5.2 years (range, one to ten years). 2. A motor-vehicle accident was the mechanism of injury for all patients: eleven were injured while riding in an automobile, two patients were struck by an automobile, and one fell from an all-terrain vehicle. 3. Five of the eleven patients who were injured while riding in an automobile had been unrestrained and were ejected from the vehicle.
Nadarajah et al. (2018) USA Case Series N=587,084 Level of evidence: 4	Reviewed and analyzed the data sets of the Healthcare Cost and Utilization Project (HCUP) Kids' Inpatient Database (KID) from 2000-2012	1. Of our study population, 0.8% had a documented diagnosis of spinal cord injury (SCI). 2. The most common documented external cause of injury code was motor vehicle accidents, representing roughly half of all cases in patients 0-9 years-old ($p = 0.001$). 3. PSCI due to sports as an external cause of injury was more prevalent in patients 10-17 years old, and was especially prevalent in the 10-13 year-old age category in which sports-related PSCI reached a high of 25.6%. 4. Risk factors for traumatic PSCI after a sports-related external cause included being of older age, male, and white.
Ribeiro da Silva et al. (2016) Portugal Case Series N=75 Level of evidence: 4	Reviewed clinical records of pediatric trauma patients admitted to a level 1 trauma center between 1991 and 2009	1. Patients were stratified by age into two groups: group A with patients aged eight or less, and group B with patients from nine to 16 years, based on previous studies, with group A representing patients with younger. immature spine, and group B the ones closer to the adult. 2. Lesions resulted mostly from motor-vehicle crashes in both groups ($p < 0.001$), but other mechanisms of injuries were also observed as: pedestrian, falls, and sports or leisure-related injuries (including jumps into shallow water) (Fig. 1). 3. Patients of group A were mostly injured in car or motorcycle crashes, whereas patients of group B were more often injured in car accidents, during sports or leisure activities.
Poorman et al. (2019) USA Case Series N=11,196 Level of evidence: 4	Reviewed the Kids' Inpatient Database (KID) for trauma cases from 2003 to 2012	1. Most common etiology was motor vehicle accidents (50.5%). 2. Infants and children frequently fractured at C2 (closed: 43.1%, 32.9%); adolescents and young adults frequently fractured at C7 (closed: 23.9%, 26.5%). 3. Upper cervical SCI was less common (5.8%) than lower cervical SCI (10.9%).

		4. Lower cervical unspecified-SCI, anterior cord syndrome, and other specified SCIs significantly decreased since 2003. 5. Predictors of SCI included sports injury and CCI.
Leonard et al. (2014) USA Case Series N=540 Level of evidence: 4	5-year retrospective review of children <16 years old with CSIs at 17 Pediatric Emergency Care Applied Research Network hospitals	1. CSI level was associated with both age and mechanism of injury. 2. For children <2 and 2 to 7 years old, motor vehicle crash (MVC) was the most common injury mechanism (56%, 37%). 3. Children in these age groups more commonly injured the axial (occiput–C2) region (74%, 78%). 4. 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). 5. CSIs often necessitated surgical intervention (axial, 39%; subaxial, 30%) and often resulted in neurologic deficits (21%) and death (7%)
Dogan et al. (2006) USA Case Series N=51 Level of evidence: 4	Reviewed patients with sub-axial cervical spine injuries retrospectively	1. Motor vehicle accidents (MVAs) were the most common cause of injury. 2. Overall, 12% presented with a dislocation, 63% with a fracture, 19% with a fracture–dislocation, and 6% with a ligamentous injury. 3. The most frequently injured level was C6–7 (33%); C3–4 (6%) was least frequently involved. 4. Sixty-four percent of patients were neurologically intact, 16% had incomplete spinal cord injuries (SCIs), 14% had complete SCIs, and three patients (6%) died after admission and before assessment.
Eleraky et al. (2000) USA Case Series N=102 Level of evidence: 4	Retrospective clinical study of 102 cases of pediatric cervical spine injuries treated in the last decade	1. Patients were divided into two age groups-birth to 9 years (Group I) and 10 to 16 years of age (Group 2). 2. Motor vehicle accidents were the most common cause of injury, and 40% were associated with head injury. 3. Patients in the younger-age group (Group 1) sustained more neurological injuries than the older patients in Group 2, and most injuries were in the upper cervical spine. 4. Of the 38 children in Group 1, in 39% a subluxation was present and in 29% a fracture or fracture/subluxation was demonstrated. 5. Of the patients in Group 2, 80% had sustained fractures or fracture/subluxations. 6. Vertebral fractures were the most common radiological findings (32%)
Finch and Barnes (1998) New Zealand Case Series N=32 Level of evidence: 4	Population-based study of pediatric cervical spine trauma in the Auckland region over 7 years starting in March 1989	1. 32 children younger than 15 years of age who had sustained a fracture, dislocation, or major ligamentous injury to the cervical spine including SCIWORA. 2. 21 patients were injured during sport or recreational activities and 11 in motor vehicle accidents. 3. Children in the younger age group were mostly injured in motor vehicle accidents, whereas older children were more often injured during sport or recreation ($p < 0.001$).

Carr et al. (2004) USA Case Series N=238 Level of evidence: 4	Retrospectively reviewed cases of patients who were admitted to the Jon Michael Moore Trauma Center at the West Virginia University School of Medicine after all-terrain vehicle crashes, between January 1991 and December 2000	1. One-third of victims (75 of 238 victims) were in the pediatric population, and only 21% were wearing helmets. 2. Only 15% of victims less than 16 years of age were wearing helmets.
Knox et al. (2014) USA Case Series N=206 Level of evidence: 4	Reviewed all patients treated for spinal injury at a single large level I pediatric trauma center between 2003 and 2011	1. 57 patients were between 0 and 3 years of age and 149 were between 4 and 9 years old. 2. Although motor vehicle collision was the most common cause of injury in both the groups, non-accidental trauma was responsible for 19% of spine trauma among patients aged 0 to 3 years. 3. Cervical spine injuries were much more common in the youngest patients (*P*<0.05) with injuries primarily in the upper cervical spine.
Santschi et al. (2005) Canada Case Series N=8 Level of evidence: 4	Reviewed case of injuries sustained by 8 children, including 2 sets of twins, in 3 different motor vehicle crashes	1. All children were rear seat passengers wearing lap or 3-point restraints. 2. All had abdominal lap-belt ecchymosis and multiple abdominal injuries due to the common mechanism of seat-belt compression with hyperflexion and distraction during deceleration. 3. 5 of the children had lumbar spine fractures and 4 remained permanently paraplegic.
Achildi et al. (2007) USA Case Series N=250,000 Level of evidence: 4	Reviewed current literature on lapbelt injuries, seatbelt syndrome, and pediatric SCI using PubMed	1. Approximately 250,000 patients are presently living with spinal cord injury (SCI) in the United States. 2. Approximately 20% of patients with SCI are less than 20 years old, and 15% are less than 15 years old. 3. The most common cause of pediatric SCI is a motor vehicle collision (MVC; ~ 40 %); lapbelt injuries and the seatbelt syndrome are seen more often in children involved in MVCs. 4. Children involved in MVCs who are improperly restrained are at higher risk of sustaining injuries.
Hoy and Cole (1993) Australia Case Series N=541 Level of evidence: 4	Reviewed 541 children with injuries sustained as passengers in motor vehicle accidents over a 9-year period	1. Of these, seven (1.3 per cent) had the cervical seat belt syndrome. 2. 5 children had fractures or fracture-subluxations of the proximal cervical spine, while two had injuries of the lower cervical spine.
Zuckerbraun et al. (2004) USA Case Series N=5117 Level of evidence: 4	Data on children (<18 years, 1997 to 2002) admitted to a level 1 pediatric trauma center were prospectively collected and retrospectively reviewed	1. Those with C-spine injuries caused by MVC were extracted and divided into 2 groups: young (0 to 8 years) and old (9 to 18 years). 2. 94 had C-spine injuries with a mean age of 11 ± 5 years, 66% of which were boys. 3. Among 1,124 patients who had sustained MVC there were 27 C-spine injuries (2.4% incidence), of which, 12 were less than 8 and 15 were older than 8 years.

		4. Restraint devices were utilized at least as frequently in younger children (young, 58% v. old, 43%; not significant). 5. Younger children had an increased incidence of permanent cord deficit (young, 57% v. old, 13%; P <.05) and closed head injury (young, 50% v. old, 7%; P <.05) even while wearing restraint devices, suggesting that restraint devices are inadequate or improperly used in younger patients.
Dauleac et al. (2019) France Case Series N=73 Level of evidence: 4	Retrospective review of all patients admitted to our pediatric trauma center for spine traumas that required surgical management, between 2005 and 2016	1. Mean age was 14.1 years. 2. Spinal injuries were more common in the teenage group (14–18 years). 3. The predominant etiology of spine injuries was motor vehicle collision (36%). 4. The spinal level of injury varied according to the age group: young children presented more cervical traumas (P < 0.01), while teenagers presented more lumbar traumas. 5. There were more fractures alone in the teenage group (P < 0.005), while there were more luxations alone in the school-age group (P < 0.05)
Hamilton and Myles (1992) Canada Case Series N=174 Level of evidence: 4	Method: Reviewed 174 pediatric patients	1. Spinal cord injury was present in 45% of patients. 2. The younger patients, while less likely to have spinal injury, had a higher incidence of neurological injury, in addition to a higher frequency of both spinal cord injury without radiological abnormality and upper cervical cord injury. 3. Younger patients with spinal cord injury and no radiological abnormality were more likely to have complete or severe cord injury.
Odetola and Gebremariam (2016) USA Case Series N=2317 Level of evidence: 4	Secondary analysis of a national database on injured children 0-20 years evaluated at U.S. EDs and either hospitalized or released, in 2009-2012	1. Majority (87%) of children evaluated for SCI were under 6 years of age, and boys comprised 73% of the visits. 2. Injuries were caused mainly by motor vehicle accidents, falls, non-transport-related accidents, and firearms. 3. The South census region had the most ED visits and hospitalizations.
Kim et al. (2016) Canada Case Series N=275 Level of evidence: 4	Retrospectively reviewed the cases of children with spinal injuries treated at a level 1 pediatric trauma center between 1990 and 2013	1. The mean age at admission was 12 ± 4.5 years, and the male:female ratio was 1.4:1. 2. Spinal injuries were more common in children of ages 12–16 years, with most injuries among ages 15–16 years. 3. The top 3 mechanisms of spinal injury were motor vehicle–related trauma (53%), sports (28%) and falls (13%). 4. Myelopathy occurred in 12% and SCIWORA occurred in 6%. 5. The most common spine levels injured were L2–sacrum, followed by O–C2.
Bilston and Brown (2007) Australia Case Series N=340	Reviewed all children up to age 16 who sustained spinal trauma, as defined by ICD10 codes, at 2	1. Traffic-related incidents accounted for approximately one third of all spinal trauma and half of serious injuries.

Level of evidence: 4	pediatric trauma hospitals in Sydney, Australia	2. The cervical spine was the most frequently injured region, with thoracic and lumbar spine injuries becoming more common with age. 3. The upper cervical spine was more commonly seriously injured in young children, and the lower cervical spine was involved more often in older children
Marshall et al. (1998) USA Case Series N=68 Level of evidence: 4	Retrospectively evaluated the available autopsy and imaging studies in 11 such cases not previously reported in the medical literature, in addition to three published case studies	1. As of November 1, 1997, automotive air-bag deployments occurring in low-speed collisions had resulted in the deaths of 49 children and in the serious injuries of 19 children in the United States. 2. The cause of death or serious injury in every case was the direct result of neurologic injury. 3. Injury patterns differed according to the child's age and type of restraint used at the time of collision. 4. 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.
Pieretti-Vanmarcke et al. (2009) Case Series USA N=12,537 Level of evidence: 4	Reviewed the trauma registries from 22 level I or II trauma centers were reviewed for the 10-year period (January 1995 to January 2005)	1. Of 12,537 patients younger than 3 years, CSI was identified in 83 patients (0.66%); 2. 8 had spinal cord injury
Chan et al. (2013) Canada Case Series N=365 Level of evidence: 4	Retrospective review of 365 pediatric severe trauma patients (0-17 years), defined as an Injury Severity Score (ISS)≥12, admitted to the pediatric intensive care unit (PICU)	1. Clinically significant CS injuries were identified in 5% (n ¼ 18/365) of trauma patients. 2. No CS injuries were identified in trauma patients with intentional injuries (n¼ 25), of which the vast majority were under 1 year of age, and diagnosed with shaken baby syndrome. 3. In patients with CS injuries, motor vehicle collisions were the predominant mechanism of injury, and TBI was the primary injury. 4. The incidence of CS injuries increased to 9% in severe TBI patients (n¼ 13/149).
Meyer et al. (2005) France Case Series N=831 Level of evidence: 4	Children with HSCI surviving inaugural cardiac arrest/apnea were selected for a retrospective analysis of a trauma data bank	1. 13 patients had cervical spine lesions above the C3 level with inaugural cardiac and/or respiratory arrest were identified. 2. In children with HSCI, the mean age was 4.7 F 2.9 years (range, 10 months to 8 years) and the male-to-female ratio was 1.6:1. 3. Victims sustained a witnessed high-energy distracting injury, more than 50% being pedestrian struck by vehicles and 38% being passengers of moving vehicles (vs 33% and 15%, respectively, in the rest of the population).
Nitecki and Moir (1994) USA Case Series	Uncommon traumatic cervical spine fractures and dislocations were studied in 227	1. The mean patient age was 14 years (range, 1 to 17 years), and the male:female ratio was 2.4:1 (161 boys, 66 girls).

N=227 Level of evidence: 4	consecutively treated children	2. 38 patients (17%) were under 8 years of age; 21 were boys (55%), and 17 were girls (45%). 3. The male preponderance was most marked in patients aged 9 to 17 years (male:female ratio, 2.9:1). 4. For children under 8 years of age, motor vehicle accidents were the leading cause of injury, followed by falls. 5. Among older children, sports accidents were the leading cause of injury. 6. Lower cervical spine fractures or dislocations (C-3 to C-7) affected 73% of all patients. 7. A C-7 injury was the single most common spinal injury, occurring in 22% of patients (51 patients), followed by C-2 (in 15%). 8. Children with a higher-level injury were younger than those with a lower-level injury.
Brown and Bilston (2009) Australia Case Series N=72 Level of evidence: 4	Retrospective review of data from all motor vehicle passengers aged 0–16 years treated at two major children's hospitals from 1999 to 2004 with ICD-10 codes for spinal trauma	1. Age <12 years was found to be significantly associated with serious spinal injury. 2. Compared to older children, children aged less than 12 years were more likely to sustain serious spinal injury (OR 7.1, 95% CI 1.2 to 42.9). 3. This age breakpoint may reflect the adequacy of seat belt fit, and use of adult seatbelts alone before age 12 may increase a child's risk of serious spinal injury.
Anissipour et al. (2017) USA Case Series N=21 Level of evidence: 4	Reviewed 21 patients of age 12–17 years that were treated for unilateral or bilateral facet dislocations between January 2004 and September 2014	1. The mean age at presentation was 14.9 years; (range 12–17). Male:female ratio was 15:6. 2. Mechanisms of injury included 13 motor vehicle accidents, five diving injuries, two assaults, and one fall from height.
Smith et al. (2017) Ireland Case Series N=48 Level of evidence: 4	Retrospective review of prospectively gathered data in the Patient Administration System of the National Rehabilitation Hospital of patients age 15 years or younger at the time of SCI onset	1. Since 2000, 22 children have sustained TSCI and 26 have sustained NTSCI. 2. Median (IQR) age at TSCI onset was 6.3 (4.4) years, and at NTSCI onset it was 7.3 (8.1) years. 3. Most common TSCI etiology was transportation (n = 10; 45.5%), followed by surgical complications (n = 8; 36.4%); most common injury type was complete paraplegia (n = 12; 54.5%) followed by incomplete paraplegia (n = 5; 22.7%). 4. Most common NTSCI etiology was transverse myelitis (n = 11; 42.3%) followed by vascular (n = 5; 20%); most common injury type was incomplete paraplegia (n = 17; 65.4%) followed by incomplete tetraplegia (n = 6; 24%).
Mohseni et al. (2011) USA Case Series N=240,647 Level of evidence: 4	Retrospective review of the National Trauma Data Bank was conducted for the period of January 2002 through December 2006 to identify pediatric patients admitted following blunt trauma	1. Patients were stratified into 4 developmental age groups: infants/toddlers (age 0-3 years), preschool/young children (age 4-9 years), preadolescents (age 10-13 years), and adolescents (age 14-17 years). 2. Of these, 1.3% (n = 3,035) sustained a CSI. 3. The incidence of CSI in the stratified age groups was 0.4% in infants/toddlers, 0.4% in

		preschool/young children, 0.8% in preadolescents, and 2.6% in adolescents. 4. The level of CSI (upper [C1-C4] vs lower [C5-C7]) according to the age groups was as follows: infants and toddlers, 70% vs 25%; preschool/young children, 74% vs 17%; preadolescents, 52% vs 37%; and adolescents, 40% vs 45%, respectively. 5. Motor vehicle accident as the mechanism of injury carried the highest risk for CSI (OR = 3.0; 95% CI, 2.8-3.3; P b .001)
Brown et al. (2001) USA Case Series N=103 Level of evidence: 4	Retrospective analysis of 103 consecutive C-spine injuries treated at a level 1 pediatric trauma center over a 9(1/2)-year period (January 1991 through August 2000)	1. The mean age was 10.3 ± 5.2 years, and the male-to-female ratio was 1.6:1. 2. The most common mechanism of injury was motor vehicle related (52%), followed by sporting injuries (27%). 3. Football injuries accounted for 29% of all sports-related injuries. 4. 68 percent of all children sustained injuries to C1 to C4; 25% to C5 to C7; and 7% to both. 5. Spinal cord injury without radiographic abnormality (SCIWORA) occurred in 38%. 6. 5 patients had complete cord lesions involving the lower C-spine (C4 to C7); 4 of these were motor vehicle related, and all 4 patients died. Isolated C-spine injuries occurred in 43%.
Lee et al. (2009) South Korea Case Series N=48 Level of evidence: 4	Reviewed clinical characteristics of 48 patients who experienced SCI during childhood and adolescence and who underwent rehabilitation treatment	1. Clinical characteristics were compared in patients under 4 years old (group A), 4–12 years old (group B), and 13–18 years old (group C) at SCI onset. 2. The overall male:female ratio was 3:2, with SCI due to non-traumatic causes more frequent overall. 3. Of traumatic causes of SCI, vehicle accident was the most frequent. 4. Of non-traumatic causes, congenital anomaly was most frequent in group A, but tumors became dominant as age increased. 5. Overall, thoracic cord level of injury was most frequent. SCI without radiologic abnormalities (SCIWORA) was predominant in group A, but none was observed in group C. Spinal fractures with or without subluxation accounted for >60% of group C SCI.
Mortazavi et al. (2011) USA Case Series N=183 Level of evidence: 4	Patients with pediatric spine injury (183) were retrospectively reviewed	1. 7 patients (14.5%) were between 3 and 9 years of age, and 41 patients (85.5%) were between 9 and 16 years of age. 2. 30 patients (62.5%) were at contiguous levels and 18 (37.5%) were at noncontiguous. 3. A total of 126 injured vertebrae were diagnosed. 4. The cervical region alone was most frequently (31.2%) involved, and the thoracic region alone was the least frequently involved (12.5%). 5. Overall, 73% of patients were neurologically intact, 4.1% had incomplete spinal cord injury (SCI), and 8.3% had complete SCI.

		6. The predominant mechanism of multilevel spine injury was motor vehicle accidents (MVA, 52%), followed by sports-related activities (18.7%), fall-related injuries (16.7%), and motor vehicle versus pedestrian accidents (12.6%). 7. Of the cases involving MVAs, 72% were unrestrained at the time of the accident (18 patients).
Leonard et al. (2007) Ireland Case Series N=40 Level of evidence: 4	A 10-year (1995-2004) retrospective study was undertaken of all patients treated for a spinal injury at the Department of Orthopedics, The Children's University Hospital in Dublin, Ireland	1. The patients ranged in age from 2 to 15 years (mean age 10 years). 25 of the patients were male. 2. The most common mechanism of injury was MVA (16/40). Nine were vehicle occupants, five were pedestrians and two were cyclists when they were injured. 3. The rest of the patients were injured as a result of falls (14/40) sporting injuries (7/40) and assaults (3/40).
Vander Have et al. (2009) USA Case Series N=37 Level of evidence: 4	Reviewed all pediatric patients who sustained thoracic or lumbar burst fractures at 2 institutions between 1991 and 2005	1. The mean age at the time of injury was 14.6 years (range, 6 to 18 y). 2. There were 17 male patients and 20 female patients. 3. The mechanism of injury was a motor vehicle accident in 19 children, a fall in 7, an all-terrain vehicle accident in 5, a snowmobile accident in 4, and a snow-sledding injury in 2.
Khanna and El-Khoury (2007) USA Case Series N=122 Level of evidence: 4	Reviewed patterns of common pediatric cervical spine injuries	1. While pedestrian-automobile accidents and falls are the most common etiology in young children (less than 8 years of age), older children are more often injured as passengers in motor vehicle accidents or in sports injuries, such as football, diving and wrestling. 2. Other less common causes of cervical injury include birth trauma in breech delivery and non-accidental trauma.
Lewis et al. (1986) USA Case Series N=643 Level of evidence: 4	Reviewed newly diagnosed patients with systemic cancer younger than 18 years of age during a 40-month period	1. In 4% of newly diagnosed patients with systemic cancer younger than 18 years of age (range: 3 months to 17 years) spinal cord disease developed. 2. Patients with spinal cord disease included 21 children with metastatic spinal cord compression, two with treatment-related transverse myelopathies, and one with an anterior spinal artery stroke. 3. Spinal cord disease occurred in 13 of 102 children (12%) with sarcomas, six of 82 (7%) with neuroblastomas, and four of 94 (4%) with lymphomas.
De Martino et al. (2019) Italy Case Series N=44 Level of evidence: 4	Reviewed children under 18 admitted and assessed for MSCC since 2007	1. The leading cause of MSCC was extramedullary tumors (63.6%), in particular neuroblastoma (27.2%) followed by Ewing sarcomas (15.9%).
Lo (2010) Singapore Case Series N=2	Reviewed two cases of acute spinal cord injury resulting from	1. Both cases of epidural hematoma had a cavernous vascular malformation origin.

Level of evidence: 4	spontaneous spinal epidural hematoma	2. Both spontaneous spinal epidural hematoma and intramedullary cavernous malformation are rare in children.
Messacar et al. (2016) USA Case Series N=120 Level of evidence: 4	Reviewed clinical features of the increasing cases of acute flaccid paralysis associated with anterior myelitis noted in the United States from 2012 to 2015	1. AFM predominantly affected older children (median age: 7.1 years) with a slight male predominance. 2. Despite a wide age range (5 months–73 years) reported from CDPH surveillance (which did not include age restrictions in the case definition), only 9 patients (15%) were over 21 years of age. 3. There were no identified ethnic or racial predispositions. 4. The majority of affected patients were previously healthy, with asthma being the most commonly identified underlying illness. 6 immunocompromised patients with AFM, including 2 with solid organ transplantation (cardiac, renal), 1 with chronic lymphocytic leukemia, 1 with acquired immune deficiency syndrome, 1 with diabetes mellitus type 1, and 1 on pharmacological immunosuppression with systemic lupus erythematosus, have been reported. 5. Of 37 cases with vaccine status reported from the CDPH, CHCO, and PCH cohorts, 34 (92%) had received all recommended vaccines and 3 (8%) were unvaccinated because of personal belief exemptions. 6. No common-source environmental exposures or common travel risk factors were identified.
Sarmast et al. (2019) India Case Series N=9 Level of evidence: 4	Reviewed the clinical presentation, laboratory findings, management and outcome of children with AFM	1. All cases presented with prodromal symptoms followed by acute onset asymmetrical limb weakness. 2. Maximum weakness is reached within 4 days from the day of onset. 3. Cerebrospinal fluid analysis shows that pleocytosis with viral markers for arboviruses and enteroviruses was negative. 4. Electrophysiological study revealed decreased muscle action potential in all. MRI of the spinal cord showed predominantly grey matter involvement.
Pruszczynski et al. (2015) Poland Case Series N=2 Level of evidence: 4	Retrospective review of two patients with skeletal dysplasia who had paraplegia develop after extremity surgery	1. Spinal cord injury is a rare complication after lower extremity surgery in children with skeletal dysplasia and thoracic kyphosis. 2. We encountered two patients who had this complication, from among 51 (39 from Nemours/Alfred I. duPont Hospital for Children and 12 from Seattle Children's Hospital) who underwent lower extremity surgery during an 8.5-year period (June 2004 to December 2012)
Youlo et al. (2013) USA Case Series N=2 Level of evidence: 4	Reviewed the clinical histories of 2 adolescent females undergoing posterior spinal fusion with subsequent cervical spinal cord injuries	1. Spinal cord injury is an uncommon but well-documented complication associated with spinal deformity surgery. 2. The mid-thoracic spinal cord is most vulnerable to these presumed vascular insults.

		3. Injuries above the level of instrumentation are rare. 4. 2 adolescent females undergoing posterior spinal fusion with subsequent cervical spinal cord injuries.
Samson et al. (2012) Canada N=1 Case Report Level of evidence: 5	Reviewed a case of spinal cord injury with spinal subdural hematoma after chest compressions	1. Two weeks after an infant with a hypoplastic left ventricle underwent a cardiac transplant, an episode of asystole and ventricular fibrillation of unknown origin occurred. 2. His resuscitation included a 10-minute period of chest compressions. 3. After sedation was discontinued, the patient was found to be paraplegic. 4. Spinal magnetic resonance imaging showed a subdural hematoma and a hemorrhagic medullary contusion extending from T4 to T10 with a subarachnoid hemorrhage extending from T10 to S2. 5. Adequate compression to ensure support of circulation is life-saving but pediatricians must be aware of the potential risk of spinal cord injury after chest compressions.
Boese et al. (2015) Germany Systematic Review N=114	Reviewed MEDLINE, Cochrane Central Register of Controlled Trials, and Google Scholar for studies on SCIWORA in children	1. The age distribution was homogenous, and the male-to-female ratio of 2.05:1 concurred with previously reported ratios. 2. In the very young, the sex ratio was approximately 1:1, with a male predominance in older individuals, which more closely reflects the ratio of 4.5:1 reported in adults. 3. The most common mechanisms of injury were road traffic accidents, followed by sports injuries and falls—there was an excess of road traffic accidents in the youngest and sports-related injuries in adolescents.
Brauge et al. (2020) France Case Series N=37 Level of evidence: 4	Reviewed files of 37 patients with confirmed spinal cord injury between January 1988 and June 2017	1. SCIWORA (*n* = 30), myelopathy associated with severe cranial trauma (*n* = 2), and obstetric trauma (*n* = 5). Causes comprised 17 road accidents, 11 sports accidents, 5 obstetric lesions and 4 falls.
Carroll et al. (2015) USA Systematic Review N=433	Systematic review and meta-analysis of the databases of PubMed and OvidSP	1. A total of 433 pediatric patients were identified with SCIWORA. 2. The most prevalent mechanism of injury was sports-related injury cases (39.83%) followed by fall (24.18%) and motor vehicle-related (23.18%) injuries. 3. The most common mechanism of injury was sports-related and cervical injury, which occurred more frequently than other levels.
Pang and Pollack (1989) USA N=55 Case Series Level of evidence: 4	Report of clinical profiles of 55 children with spinal cord injury without radiographic abnormalities (SCIWORA)	1. Of patients with SCIWORA, no patient had vertebral fracture or dislocation on plain films and tomographies. 2. There were ten upper cervical (C1-C4),33 lower cervical (C5-C8), and 12 thoracic cord injuries;of these,22 were complete or severe lesions and 33 were mild lesions. 3. The mechanism of the neural injury probably relates to the inherent elasticity of the juvenile spine, which permits self-reducing but

		significant intersegmental displacements when subjected to flexion, extension, and distraction forces. 4. The spinal cord is therefore vulnerable to injury even though the vertebral column is spared from disruption, and this vulnerability is most evident in children younger than 8 years. 5. All but one of the 22 children with profound neurologic injuries were younger than 8 years ($p < 0.000001$), whereas 24 of 33 children with mild injuries were older. 6. Younger children were also more likely to have sever upper cervical lesions ($p < 0.05$); lower cervical lesions were distributed evenly through the ages of 6 months to 16 years. 7. Thoracic injuries most commonly resulted from distraction or crushing. Distraction invariably involved violent forces, and crush injuries were usually caused by children being run over while lying prone, when the spinal column was acutely bowed toward the spongy abdominal and thoracic cavities.
Ren et al. (2017) China N=12 Case Series Level of evidence: 4	Retrospective case series from September 2007 to August 2016. The study was conducted at a tertiary medical center in Beijing, China (Xuanwu Hospital, China International Neuroscience Institute [China-INI], Capital Medical University)	1. 11 patients (91.7%) were younger than 8 years old. 2. The mean age of the patients was 6.6 years. 3. All patients had a clear traumatic history of severe thoracic spinal cord injury after performing back bend movements. 4. Back bend movements performed during dance practice may cause pediatric thoracic SCIWORA, particularly in children younger than 8 years old. 5. We suggest that the mechanism of primary injury is the longitudinal distraction of the thoracic spine during back bend movements, which leads to violent distraction of the spinal cord and blunt injury of nerve axons, nerve cells, and small vessels.
Trigylidas et al. (2011) Canada N=39 Case Series Level of evidence: 4	Retrospectively reviewed medical charts of 578 children with vertebral trauma at the Children's Hospital of Eastern Ontario and the Hospital for Sick Children	1. Patients with traumatic myelopathy were divided into 2 categories: 36 had radiologically evident SCI, and 3 had SCIWORA. 2. The radiologically evident population was further subdivided into those that presented with vertebral fractures (30/39; 77%) and those with other associated vertebral abnormalities (6/39; 15%). 3. Sports-related injuries (SRI) were the most frequent type of injury (51%), followed by motor vehicle accidents. (MVA; 36%) and falls (13%). The 3 SCIWORA cases were a result of 2 MVA and 1 SRI. 4. Both patients with MVA had permanent deficits and the SRI patient recovered with no long-term issues.

		5. Vertebral fractures were caused by 11 MVA, 15 SRI and 4 falls. 6. Other associated vertebral abnormalities were a result of 1 MVA, 4 SRI and 1 fall.
Mulligan et al. (2007) UK N=1 Case Report Level of evidence: 5	A case was described of a 4-year-old girl sustaining multiple injuries from blunt trauma including spinal cord injury without radiographic abnormality.	1. A 4-year-old girl was standing in front of a car when it was started and jumped forward pinning her against a wall for several seconds. 2. A child sustaining multiple injuries from blunt trauma including SCIWORA.
Carreon et al. (2004) USA N=137 Case Series Level of evidence: 4	Reviewed the cases of 137 children with spine injuries were seen over 10 years	1. There were 36 patients aged 0-9, 49 aged 10-14, and 52 aged 15-17. Spine injury incidence increased with age. 2. Motor vehicular accidents were the most common cause in this series. 3. There were 36% cervical, 34% thoracic, 29% lumbar, 34% multilevel contiguous, and 7% multilevel noncontiguous involvement. 4. 19% had spinal cord injury. 13 of 21 complete neurologic injuries and all 3 incomplete injuries improved. 5. Cord injury was more common in the 0-9 age group. 6. 4 of 5 patients with spinal cord injury without radiographic abnormality (SCIWORA) were in the 0-9 age group and had complete neurologic injuries. 7. Young children with cervical injuries were more likely to die than older children.
Hwang et al. (2003) USA Case Series N=143 Level of evidence: 4	Retrospective medical chart review of patients at an urban tertiary care pediatric facility over a 10-year period	1. Of these, 95 (66.4%) were male. 2. Median age was 3.8 years, and 30 (23.4%) of 128 had preexisting conditions. 3. Site of drowning was the pool (70.6%), the bathtub (19.0%), or natural water (10.4%). 4. The prevalence of traumatic injury was 4.9% (95% confidence interval, 0%-28%). 5. The predominant mechanism of injury was diving, and all injuries were to the cervical spine. 6. Patients with injury were more likely to be older (mean age, 13.5 vs 5.1 years; P<.001) and to have a history of diving (85.7% vs 2.2%; P<.001).

Table 2. Studies on the Incidence and prevalence of Pediatric SCI in Oceania

Author, Year Country Research Design Total Sample Size Level of Evidence	Population (Inclusion and exclusion criteria)	Definition of cases (nominator) and source population (denominator) used to calculate incidence	Incidence / Prevalence (By Total Number of Cases / Injury Classification)
Galvin et al. (2013) Australia Case Series N=103 Level of Evidence: 4	January 1, 2000, and June 30, 2010 SCD was identified using the International Classification of Diseases and Related Health Problems, 10th Edition, Australian Modification, diagnostic codes relating to initial onset of SCD for both traumatic and non-traumatic conditions RCH Trauma Registry was cross-checked to improve accuracy of case attainment	Non-traumatic v. traumatic cases / Total SCD cases	Most patients had a non-traumatic SCD (n = 68, 66%) n = 40, 59% result of neoplasm n = 15, 22% result of transverse myelitis n = 12, 18% result of other disease of the spinal cord Traumatic injury n = 35, 34% n = 19, 54% result of motor vehicle accidents n = 8, 23% result of sporting incidents n = 7, 20% result of falls from a height n = 1, 3% result of assault average incidence of traumatic SCD = 3.8 per million average incidence of non-traumatic SCD = 6.5 per million

Table 3. Studies on the Incidence and prevalence of Pediatric SCI in Asia

Author, Year Country Total Sample Size Level of Evidence	Population (Inclusion and exclusion criteria)	Definition of cases (nominator) and source population (denominator) used to calculate incidence	Incidence / Prevalence (In Total Sample / By Injury Classification)
Chien et al. (2012) Taiwan Case Series N=4949 Level of Evidence: 4	Children aged<18 years 11-year period Analyzed for causes, age at injury, anatomic sites, disability, and familial socio-economic factors	cervical, thoracic, lumbar, and other SCI cases / Total SCI cases SCI cases total / Children under 18 years of age	Cervical SCI 4.06 per 100,000 person-years Thoracic SCI 0.34 per 100,000 person-years Lumbar SCI 0.75 per 100,000 person-years Other SCI 0.85 per 100,000 person-years Overall SCI incidence rate is 5.99 per 100,000 person-years
Gutierrez et al. (2019) USA (Iraq and Afghanistan-based sample) Case Series N=3439 Level of Evidence: 4	January 2007 through January 2016 Department of Defense Trauma Registry for all pediatric encounters Dataset for all cervical spine fractures	CSI-related cases / Pediatric encounters Cervical spine fracture cases / CSI cases Injuries by explosion / CSI cases	CSI cases n=36, 1% Cervical spine fractures n=6, 17% 41.7%

Table 4. Studies on the Incidence and prevalence of Pediatric SCI in North America

Author, Year Country Research Design Total Sample Size Level of Evidence	Population (Inclusion and exclusion criteria)	Definition of cases (nominator) and source population (denominator) used to calculate incidence	Incidence / Prevalence (In Total Sample / By Injury Classification)
MacKinnon et al. (1993) Canada Case Series N=22 Level of Evidence: 4	Five Canadian regional neonatal tertiary care centers Time-period soon after birth SCI apparent after birth as neonate	Cases w/ lesions above the fourth cervical vertebrae / Total SCI cases Cases w/ lesions at the fourth cervical to the fourth thoracic vertebrae / Total SCI cases Cases w/ lesions at the thoracolumbar region / Total SCI cases	64% 27% 9%
Mohseni et al. (2011) USA Case Series N= 240,647 Level of Evidence: 4	January 2002 through December 2006 Pediatric patients admitted following blunt trauma Less than 18 years of age Review of National Trauma Data Bank Cervical spinal cord injury diagnoses	CSI cases stratified by age group / Total patients that meet inclusion criteria CSI level [C1-C4] vs lower [C5-C7] / CSI cases stratified by age CSI cases / Patients that meet inclusion criteria	Infants/toddlers = 0.4% Preschool/young children = 0.4% Preadolescents = 0.8% Adolescents = 2.6% Infants and toddlers, 70% vs 25% Preschool/young children, 74% vs 17% Preadolescents, 52% vs 37% Adolescents, 40% vs 45% 1.3%
Patel et al. (2001) USA Case Series N= 75,172 Level of Evidence: 4	10-year period Children with cervical spine injury in the National Pediatric Trauma Registry	CSI cases / All injured children	1.5%, n=1,098
Piatt and Imperato (2018) USA Case Series N= 75,172 Level of Evidence: 4	Discharges coded for spinal injury were extracted from the Kids' Inpatient Database 1997, 2000, 2003, 2006, 2009, and 2012	SCI cases / Child population	25 per million in 1997 and 14 per million in 2012 MVC injuries = 31.9% in children and 50% in adolescents

	Patients younger than 18 years of age		
Piatt (2015) USA Case Series N=Not Specified Level of Evidence: 4	Admissions for spinal fracture without or with spinal cord injury (SCI), spinal dislocation, and SCI without radiographic abnormality Kids' Inpatient Database (KID) and the National Trauma Data Bank (NTDB) registry During 2009 Patients younger than 21 years of age	Patients admitted to hospital for Spinal injury / Total children in population SCI cases / Total children in population Black patients with spinal injury due to firearm / Black patients with spinal injury White patients with spinal injury due to firearm / White patients with spinal injury	170 per 1 million in the population under 21 years of age 24 per 1 million 23.9% 1%
Poorman et al. (2019) USA Case Series N=11,196 Level of Evidence: 4	Kids' Inpatient Database (KID) Trauma cases from 2003 to 2012 Cervical fracture patients Patients younger than 18 years of age	Cervical fracture cases / Total trauma patients MVC cases / Total trauma cases	2003 vs 2012, 2.39% vs 3.12% 50.5%
Shin et al. (2016) USA Case Series N=Not Specified Level of Evidence: 4	KID 2000 to 2012 Using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes Patients younger than 18 years of age	Cases of traumatic pediatric CSI / Cases of PCSI PCSI cases due to transportation accidents / Traumatic PCSI cases	2.07% 57.51%
Vitale et al. (2006) USA Case Series N_{1997}=1.9 million, N_{2000}=2.5 million Level of Evidence: 4	The Kids' Inpatient Database (KID) and the National Trauma Data Bank (NTDB) Diagnosis of pediatric SCI Patients younger than 18 years of age	Cases of PedSCI in African Americans / Total cases of PedSCI Cases of PedSCI in Native Americans / Total cases of PedSCI Cases of PedSCI in Hispanics	1.53 cases/100,000 children 1.00 cases/100,000 children 0.87 cases/100,000 children 0.36 cases/100,000 children

		/ Total cases of PedSCI Cases of PedSCI in Asians / Total cases of PedSCI Cases of PedSCI in males / Total cases of PedSCI Cases of PedSCI in females / Total cases of PedSCI Total cases of PedSCI / All children	2.79 cases/100,000 children 1.15 cases/100,000 children 1.99 cases/100,000 children
Saunders et al. (2015) USA Case Series N=Not Specified Level of Evidence: 4	Children and adolescents (0-21 years) with SCI Identified through the South Carolina SCI Surveillance Registry using hospital discharge records from 1998 to 2012	Child and adolescent cases of SCI / Total number of children and adolescents	Overall age-adjusted incidence rate was 26.9 per million population
Kewalramani et al. (1980) USA (18 counties in Northern California) Case Series N=1589228 Level of Evidence: 4	Review of the diagnosis of spinal cord injury by attending physician Patients aged between 1 – 15 years of age Resident of 1 of 18 Northern California counties Between 1970 and 1971 Systematic review of records, files, reports from hospital and coroner's offices in each county and records of the State of California's Department of Health	Cases of SCI in children 1 – 15 years of age / Total number of children	Number and average annual incidence rate of acute spinal cord lesions in children in 18 Northern California counties 18.2 / million
Durkin et al. (1998) USA (Northern Manhattan) Case Series N=Not Specified Level of Evidence: 4	Pediatric deaths and hospital admissions secondary to neurological trauma Patients younger than 18 years of age Northern Manhattan Injury Surveillance System from 1983 to 1992 were linked to census counts to	Pediatric cases of neurological injuries resulting in hospitalization or death / Total number of children	Incidence of neurological injuries resulting in hospitalization or death was 155 incidents per 100,000 population per year

	compute incidence rates		

Table 5. Studies on the Incidence and prevalence of Pediatric SCI in Europe

Author, Year **Country** **Research Design** **Total Sample Size** **Level of Evidence**	**Population (Inclusion and exclusion criteria)**	**Definition of cases (nominator) and source population (denominator) used to calculate incidence**	**Incidence / Prevalence (In Total Sample / By Injury Classification)**
Hofbauer et al. (2012) Austria Case Series N=897 Level of Evidence: 4	Children aged<18 years 11-year period all pediatric patients with the diagnosis of polytrauma and associated spine injury, admitted to an urban Level I trauma center January 1992 to December 2010	Cases of patients with polytrauma and spine injury / Total severely injured children Cases of thoracic injury / Cases of patients with polytrauma and spine injury	3.12% 89%
Puisto et al. (2010) Finland Case Series N=Not Specified Level of Evidence: 4	All spinal and spinal cord injuries in children under 18 years of age Treated in hospital between 1997 and 2006 in Finland Collected from the National Hospital Discharge Register	Cases of spinal injuries / Total reference population Cases of spinal CORD injuries / Total reference population	66 per 10 of the reference population 1.9 per 10 children
Platzer et al. (2007) Austria Case Series N=56 Level of Evidence: 4	Children aged<17 years Clinical records of all pediatric trauma patients with skeletal and/or non-skeletal injuries of the spine Admitted to Level 1 trauma center Between 1980 and 2004	SCI cases in age groups / Total SCI cases	≤8 years of age - 54% 9-16 years of age - 46%
Augutis et al. (2006) Sweden Observational N=Not Specified Level of Evidence: 5	A short semi-structured questionnaire Respondents working with spinal cord injury (SCI) in 19 countries in Europe Only Portugal and Sweden established incidence of pedSCI (fatal injuries included) Children 0-14 years of age with diagnosis of spinal cord injury	Children with cases of SCI / total children Children with cases of SCI / total children Children with cases of SCI / total children	Portugal - 27 children/million children/year Sweden - 4.6 children/million children/year Other countries - varied from 0.9 to 21.2 children/million children/year (for children 0-14 years)
Martin et al. (2004) UK Case Series N=19,538 Level of Evidence: 4	Spine injured children were identified from the UK Trauma Audit & Research Network Database Between 1989 and 2000 Children under 18 years of age	Cases of children with spinal column fracture/dislocation / Total children Cases of children with SCI / Total children	2.7% suffered spinal column fracture/dislocation without cord injury SCI - 0.56% of all children; 16.5% of spine injured children

		Cases of children with SCI / Total spine injured children Cases of children with SCIWORA / Total children Cases of children with SCIWORA / Total spine injured children	SCIWORA - 0.15% of all children; 4.5% of spine injured children
Ruggieri et al. (1999) UK Observational $N_{\text{Surveys returned}}$=261, N_{Patients}=58 Level of Evidence: 5	Children with spinal cord insults (SCI) occurring in the pre-, peri-, and neonatal periods By sending questionnaires to all paediatric neurologists, paediatric urologists, and neonatologists in the UK and Ireland	Cases of children with SCI / questionnaires returned	19.54%
Augutis and Levi (2003) Sweden Case Series N=Not Specified Level of Evidence: 4	Data from population registers, County Habilitation Centers as well as from informal sources Sweden during the years 1985–1996 Children aged 0–15 years SCI diagnosis	Cases of children with SCI (including fatalities) / Total children Cases of children with SCI (not including fatalities) / Total children	4.6/million children/year 2.4/million children/year

Table 6. Studies on Incidence of Prevalence of Pediatric SCI across the Globe

Author, Year **Country** **Research Design** **Total Sample Size** **Level of Evidence**	**Population (Inclusion and exclusion criteria)**	**Definition of cases (nominator) and source population (denominator) used to calculate incidence**	**Incidence / Prevalence (In Total Sample / By Injury Classification)**
New et al. (2019) Australia Literature Review N=25	Literature search of Medline (1946–March 2017) and Embase (1974–March 2017) Relevant articles in any language regarding children with spinal cord damage included	SCI cases / Total individuals SCDys cases / Total individuals	Asia, East 5.4/million population/year; Australasia 9.9/million population/year; Western Europe 3.3/million population/year; North America, High Income 13.2 million population/year Australasia 6.5/million population/year; Western Europe 6.2/million population/year; North America, High Income 2.1/million population/year