Pediatric spinal injury: the very young

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Maturity of the spine and spine-supporting structures is an important variable distinguishing spinal cord injuries in children from those in adults. Clinical data are presented from 71 children aged 12 years or younger who constituted 2.7% of 2598 spinal cord-injured patients admitted to the authors' institutions from June, 1972, to June, 1986. The 47 children with traumatic spinal cord injury averaged 6.9 years of age and included 20 girls (43%). The etiology of the pediatric injuries differed from that of adult injuries in that falls were the most common causative factor (38%) followed by automobile-related injuries (20%). Ten children (21.3%) had spinal cord injury without radiographic abnormality (SCIWORA), whereas 27 (57%) had evidence of neurological injury. Complete neurological injury was seen in 19% of all traumatic pediatric spinal cord injuries and in 40% of those with SCIWORA. The most frequent level of spinal injury was C-2 (27%, 15 cases) followed by T-10 (13%, seven cases). Upon statistical examination of the data, a subpopulation of children aged 3 years or younger emerged. These very young children had a significant difference in level of injury, requirement for surgical stability, and sex distribution compared to 4- to 12-year-old children.

KEY WORDS: spinal cord injury, pediatric spine, spinal stabilization, bone maturation, infant, child

Spinal column injury in the child constitutes 0.65% to 9.47% of all cases of spinal cord injury (SCI) and is fundamentally different from its adult counterpart.2,4,5,9,11,15-20,26,28-30,34,37,39,43-45,49,57 The differences seen in pediatric SCI include: disproportionate involvement of the upper cervical spine and upper thoracic spine,2,23,25,26,36,42,45,46,52 a high frequency of spinal cord injury without radiographic abnormality (SCIWORA), often associated with a poor neurological outcome,3,10,13,14,22,33,37,39,44 paucity of bone fracture lines and avulsion chips (involvement of cartilaginous endplates instead),4,5,16,22,26,42 high susceptibility to a delayed onset of neurological deficit,39,58 and a higher proportion of complete neurological injuries.8,26,30,38

Many theories exist to explain these reported differences between the adult and pediatric SCI populations. Pediatric SCI's are caused by different mechanisms than adult SCI's, even when injury at birth8,29,32 is excluded. Pedestrian-related motor-vehicle accidents (MVA) or falls comprise the most frequent etiology of pediatric SCI as opposed to passenger-related MVA in adults.2,7,9,10,21,25,27,30,31,36,39,56,57 Anatomical and biomechanical differences certainly exist between the adult and pediatric spine. Those differences that may play a role in SCI include the following: the infant's head is a disproportionally large mass and exposes the spine to different inertial forces,20,46,47,56 facets are shallowly angulated and the vertebral bodies are wedge-shaped, predisposing the spine to greater mobility,6,12,17,20,23-25,29,45,48,53,56 and the fulcrum of neck motion occurs much higher in the child that in the adult.5,6,12,17,40,41 Finally, maturation per se not only of the spinal cord and its vasculature but also of the paraspinal musculature, ligaments, and bone structure is an important variable.1,14,20,33,42,47,52,56 Unfortunately the only variable that is easily monitored is bone development. Roentgenographic examination reveals that most of the neural arches close and the dens synchondrosis starts to fuse by 3 years of age. Roentgenographically, by 8 years of age the pediatric spine has most of the adult characteristics.6,17,56

Based on roentgenographic evidence of maturation, it is hypothesized that the young child (< 3 years old) represents a unique subpopulation of those with pediatric SCI. This study was undertaken to not only test this hypothesis, but also to characterize our population of spinal cord-injured children.

Clinical Material and Methods

The records of 71 children aged 12 years or younger who were admitted to the Children's Memorial Hospital
TABLE 1

Neurological status in 47 children with traumatic spinal cord injury

<table>
<thead>
<tr>
<th>Neurological Status</th>
<th>Cases</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>neurological injury</td>
<td>27</td>
<td>57</td>
</tr>
<tr>
<td>complete</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>incomplete</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>transient</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>brachial plexus</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>intact</td>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>total cases</td>
<td>47</td>
<td>100</td>
</tr>
</tbody>
</table>

Falls accounted for 38% of these pediatric SCI's (18 cases). The children fell from heights ranging from a standing position to four stories. Automobile-related injuries accounted for 20% of the SCI's (nine cases); 56% of these were as pedestrians (five cases). The remainder of the injuries were caused by gunshot wounds (13%, six cases), sports (13%, six cases), delivery at birth (4%, two cases), and other (13%, six cases).

To test the hypothesis of radiographic maturity, our sample was then divided into two groups: those 3 years of age or younger and those 4 to 12 years of age. Fisher's exact test of statistical significance was performed with respect to: level of injury (C-2 vs. others); complete neurological injury compared with incomplete/ intact function; subluxation alone compared with fractures and subluxation; surgical compared with nonsurgical stabilization; anatomical involvement compared with SCIWORA; neurological injury compared with bone injury alone; and male compared with female.

Results

Neurological Status

Fifty-seven percent (27 cases) had evidence of neurological injury (Table 1). Nine (19%) of 47 patients had complete neurological injuries. Five children had transient weakness or paresthesias. Two of these children complained of a burning dysesthesia of the upper extremities. Two children had brachial plexus injury with evidence of spinal column injury. Of the 10 children with SCIWORA, four had complete neurological deficits.

Radiographic Features

Evidence of radiographic abnormality was found in 79% of the children (37 cases). There were three children (6%) with subluxation only and 34 children (72%) with a total of 55 fractures with or without subluxation. The distribution of fractures according to vertebral level is given in Fig. 2. The most common level of involvement was C-2 (27%, 15 cases) followed by T-10 (13%, seven cases). In the cervical spine there was only one fracture below C-3. Ten children (21%) had SCIWORA.
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Statistical Results

The distribution and statistical significance of grouping our sample into those 0 to 3 years of age and those 4 to 12 years of age is given in Table 2. Assuming an unbiased sampling per age group, the probability that the variables tested would have distributed in the proportions they showed in each of the two age groups was calculated using Fisher's exact test. A high degree of statistical significance (p < 0.01) was found between the two age groups with regard to sex, level of injury, and the requirement for surgical stabilization. There was a moderate degree of significance (p = 0.016) between the two age groups when separated by the presence of SCIWORA.

Discussion

Many of the attributes of the pediatric spine which cause it to respond differently to trauma than the adult spine have recently been identified. However, some of the unresolved issues in pediatric SCI include: the prevalence of pediatric cases within the entire population of SCI's, the mechanism of injury, the SCIWORA rate and significance, the factors determining extent of injury, and the influence of neural, soft-tissue, and bone maturation.

The variety of age groups defined as "pediatric" has resulted in a reported range of incidence from 0.65% to 9.47% of all SCI's. This present study excluded children 13 years of age and older for two reasons. First, a review of our age/frequency distribution (Fig. 1) revealed a dramatic increase in frequency of SCI at age 13 years. The reasons for this are unclear but are due in part to the more "adult-like" environment this age group is exposed to. We believe our referral pattern does not bias the age distribution nor the presence of complete lesions, but these may be a factor. Second, although the pediatric spine has most of the adult roentgenographic features by the age of 8 years, occasionally more juvenile features persist until 11 or 12 years of age (JR Ruge, G Sinson, DG McLone, in preparation). Other series of similar age groups have reported SCI rates from 1% to 4%. In terms of etiology, the pediatric SCI differed from the adult SCI in that falls were the most common cause of injury in the children. Several other series agree. In our series, most of the children with SCI's as a result of MVA were pedestrians.

The SCIWORA phenomenon occurs more often in the pediatric age group than in other age groups. Although elderly people often develop SCI without evidence of fractures, usually spondylolytic changes are evident on roentgenographic studies. Otherwise, SCIWORA is rare in adults and constitutes a syndrome unique to the pediatric population. Pang and Wilberger recently reported their experience with pediatric SCIWORA and reviewed the literature. They found that 24 (66.7%) of the children up to 16 years who had nonpenetrating SCI had SCIWORA. Furthermore, they believed this to be associated with a poor prognosis, as 55% of the patients with SCIWORA had complete neurological injuries. Interestingly, 52% of the children with SCIWORA had a delayed onset of symptoms. Some series have reported similar high percentages of SCIWORA as did Pang and Wilberger: Melzak and Burke each had a 55% incidence of SCIWORA (16 of 29 cases), Hachen had 44% (eight of 18 cases), Andrews and Jung had 47% (seven of 15 cases).
The dens synchondrosis, the wedge-shaped vertebral bodies, the epiphyseal plates, the pseudosubluxation of C2–3, and the shallow angulation of the facets are depicted in transition from their appearance in infants (left) to the normal adult spine (right). See also the cover illustration.

FIG. 3. Diagram showing the normal maturation of the spine. The dens synchondrosis, the wedge-shaped vertebral bodies, the epiphyseal plates, the pseudosubluxation of C2–3, and the shallow angulation of the facets are depicted in transition from their appearance in infants (left) to the normal adult spine (right). See also the cover illustration.

Our study fails to support the findings of other series that the child with SCI has a higher incidence of complete neurological injury than the adult with SCI. Kewalramani and Tori reported 67 cases (69%) of complete neurological injuries in their sample of 97 pediatric SCI’s. Of the 24 nonbirth-related SCI’s reported by Burke, 22 cases (92%) had complete and two (8%) had incomplete neurological injury. In our series, 27 patients (57%) had neurological injury. Interestingly, five patients had transient neurological symptoms, two of which could be classified as the “burning hand syndrome” described by Maroon. Nine (19%) of our pediatric patients were found to have complete injuries; in comparison, 34% of our adult population had complete neurological injury. Whereas 25% of our adult patients with SCI’s were intact neurologically, 43% of our pediatric SCI patients were intact. Anderson and Schutt similarly found pediatric cases of SCI to have a more favorable extent of neurological injury. Their series of 156 pediatric patients (< 14 years) with SCI included 44 children (28%) with neurological injury: 16 (10%) with complete and 28 (18%) with incomplete neurological injuries. Our data suggest a lesser degree of neurological injury when compared to other pediatric series and with our adult population. This may be due to the comparatively young age of our patients (average 6.9 years) and the presumed lower number of high-velocity injuries.

In an attempt to explain many of the clinically significant differences between the adult and pediatric SCI’s, attention has focused on the effects of aging on the spine. The anatomical (Fig. 3) and biomechanical differences between the adult and pediatric spine are well documented. The combination of a relatively large head atop a largely cartilaginous spine with shallowly angulated facets, lax ligaments, and immature joints of Luschka contributes to produce a hypermobile spine with a different fulcrum of motion than in adults. Fractures tend to occur at the relatively weak growth plates. Ossification and fusion of the bone structures can be followed roentgenographically.

More difficult to observe and therefore less known is the relative importance of maturation of both the spinal cord and its vasculature and the paraspinal musculature and ligaments. There is indirect evidence to suggest that maturation of the vascular supply to the pediatric spinal cord is important. Choi, et al., and Ahmann, et al., have reported spinal cord infarction in as many as 8% of the children with SCI. Such vascular infarction may account for some of the reported cases of SCIWORA. The age at which full maturation of the spinal cord and intraspinal structures occurs is not known. Magnetic resonance (MR) imaging depicts the soft-tissue structures of the spine well; however, we are unaware of any MR studies of the maturation of the spine.

When does a pediatric spine change into an adult spine? Roentgenographically, by 8 years of age most of the adult spinal characteristics have been attained. Is evidence of adult patterns of bone ossification an important variable? Hill, et al., reported a significant difference in level of injury between children 8 years of age or younger compared to those 9 to 18 years of age. In their younger group the spinal injuries were located exclusively in the upper cervical spine as opposed to the older group whose injuries occurred along the entire cervical spine. Pang and Wilberger also reported that 8 years of age was significant. Not only did their findings support those of Hill, et al., but they also found that the younger age group suffered more serious neurological damage. A temporal correlation exists between radiographic evidence of maturation and the clinical manifestations of SCI; however, causation is not implied.

In this study, an attempt was made to determine statistically significant differences between very young children (< 3 years) and those older (4 to 12 years). Roentgenographically and clinically, most of the bone maturation occurs between 3 and 8 years of age; thus, we suspect that the very young child represents a distinct subpopulation of those with pediatric SCI.
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A statistically significant difference was found between the two age groups with respect to level of injury, requirement for surgical stabilization, and sex distribution. The statistical results (Table 2) indicate whether the differences in proportions are significant. Specifically, a larger proportion of the very young than of the older age group had C1–2 bone involvement. A larger proportion of the very young required surgical stabilization; however, we consider that this is biased by our proportion of the very young required surgical stabilization. Finally, a larger proportion of the very young were female. We were unable to find a statistically significant difference between the groups with regard to neurological injury, subluxation alone, and SCIWORA.

Clinical studies such as this one are limited by the small number of pediatric patients with SCI, the differences in age included in each series, and the multiple variables beyond control. An important uncontrollable variable is the age at which the adult environment encroaches on the child. A multicenter study is currently being organized in an attempt to provide further insight into the nature of the spinal cord-injured child.

Conclusions

In this series, 2.7% of all SCI patients were aged 12 years or less. High cervical spinal levels were most frequently involved; there was only one cervical fracture below C-3. Of all 47 pediatric patients with traumatic SCI, 21.3% had SCIWORA, 40% of whom had complete neurological injury. Nineteen percent of all the 47 children had complete neurological injury, which is a much smaller percentage than has generally been reported. A subpopulation of children 3 years of age or younger was identified. This group had a statistically significant difference in level of injury, requirement for surgical stabilization, and sex distribution compared to those children 4 to 12 years of age. Anatomical, biomechanical, maturational, and environmental factors all contribute to the fundamental differences between pediatric and adult types of SCI.

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References


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