Childs Nerv Syst (2011) 27:1095–1100
DOI 10.1007/s00381-010-1348-y

ORIGINAL PAPER

Pediatric multilevel spine injuries: an institutional experience

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Received: 5 November 2010 / Accepted: 15 November 2010 / Published online: 26 November 2010

Abstract
Object Spinal column trauma is relatively uncommon in the pediatric population, representing 1–2% of all pediatric fractures. However, pediatric spinal injury at more than one level is not uncommon. The purpose of this study was to evaluate the mechanisms and patterns of the injury and factors affecting management and outcomes of pediatric multilevel spine injuries.
Patients and methods Patients with pediatric spine injury (183) were retrospectively reviewed. Patients (28 boys, 20 girls; mean age 12.8 years; range 3 to 16 years) identified with multilevel spinal injuries were 48 (26.2%): 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. Of the 48 patients, 30 (62.5%) were at contiguous levels and 18 (37.5%) were at noncontiguous. A total of 126 injured vertebrae were diagnosed. The cervical region alone was most frequently (31.2%) involved, and the thoracic region alone was the least frequently involved (12.5%). Overall, 73% of patients were neurologically intact, 4.1% had incomplete spinal cord injury (SCI), and 8.3% had complete SCI. Treatment was conservative in 36 (75%) patients. Surgical treatments were done in 12 patients (25%). Postoperatively, one patient (16.6%) with initial neurologic deficit improved. The overall mortality rate was 6.2%.
Conclusions Multilevel spine injuries are most common in children between 9 and 16 years of age and are mainly located in the cervical region. The rostral injury was most often responsible for the neurologic deficit. The treatment of multilevel spine injuries should follow the same principles as single level injury, stability and neurologic symptoms indicate the appropriate treatment.

Keywords Children · Spinal cord injury · Multiple spine injury · Spinal fracture

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Introduction

Spinal column trauma is relatively uncommon in pediatric trauma patient [1–4]. Spine fractures in children represent 1–2% of all pediatric fractures, and most of these injuries involve the cervical spine. Multilevel spine injuries have been documented 6–23.8% of adult patients with spinal trauma [1, 3–5]. However, the reported incidence of multilevel spine injury ranges from 6% to 50% in pediatric patients with spine injury [3, 4]. The differences in the spinal injury incidence rate and the injury profile noted for the pediatric population can be partially explained by certain anatomical and biomechanical factors. Incomplete ossification, a different vertebral configuration, the head's relative proportion to the body, and ligamentous laxity account for a different injury pattern compared with that of adults. The immature intervertebral discs are more resistant to trauma than immature bones and transmit high energy to adjacent levels causing multilevel involvement [1]. Awareness of multilevel spine injuries and associated neurological patterns is important for the proper initial management of pediatric patients.

Previously, very few studies on pediatric spinal injury have been published. Carreon et al. [2] reviewed 137 cases retrospectively showing the incidence of cord injury being 20% with higher frequencies in younger children, potential for neurologic recovery was good, young children having a higher risk for death than older children, no predominance of cervical injuries in the young child, and the incidence of SCIWORA being low.

Previous work of our group on pediatric subaxial cervical spine injuries in 2006 reported on mechanisms, patterns, management, and outcome of 51 patients showing these injuries being most common in ages 9–16 years and occurring mostly at C5–7, and mostly being conservatively treated. This report indicated multilevel injury as common [6]. A subsequent report from our group in 2007 on the pediatric thoracolumbar and sacral injuries showed that thoracic and lumbar injuries, again being most common in children older than the age of 9 years, had a good potential for recovery. The majority of them were like the subaxial group treated conservatively. The report showed multilevel injuries as common and warranting imaging evaluation of the entire spinal column [7]. Therefore, studying pediatric multilevel spine injuries seemed needed. To our knowledge, multilevel pediatric spine injuries have not previously been reported in detail. The purpose of this study was to analyze the diagnostic and therapeutic approach of pediatric patients with multiple spinal injuries with special attention to their outcome. So this report highlights the cause, distribution, and types of injury and functional outcome.

Patients and methods

All pediatric trauma admissions through our Level I trauma service between 1996 and 2005 were reviewed, retrospectively. All patients 16 years and younger with multilevel spinal trauma were included in the study. Patients with missile, brachial plexus, or peripheral nerve injuries were excluded from the study.

All types of spinal injuries were included: minor injuries such as posterior element fractures, tear drop fractures, ligament injuries as well as severe compression fractures, burst fractures, and fracture dislocations. These injuries were classified as contiguous when more than one adjacent vertebra was involved, and as noncontiguous if there was preservation of at least one uninjured vertebral column between the injuries.

In all patients, we evaluated the level and pattern of injury, diagnosis, frequency of neurological compromise, associated injuries, imaging findings, and outcomes. Neurological function was graded according to the American Spinal Injury Association (ASIA)-modified Frankel classification. Follow-up assessment included clinical evaluation and 3- and 6-month radiographic studies (mean follow-up duration 7.5 months, range 3–40 months).

Diagnostic imaging studies, including plain cervical (anteroposterior, lateral, and swimmer's), thoracic, lumbar (anteroposterior and lateral) X-ray films and computerized tomography (CT) scans, were obtained in all patients. If the presence of a fracture was uncertain or if a patient had a spinal cord injury (SCI), magnetic resonance imaging (MRI) was obtained (23 patients [47.9%]).

Results

A total of 183 cases with pediatric spine injury were identified using our trauma registry. Among them, 48 (26.2%) patients with multilevel spinal injuries with and without SCI were treated (28 boys, 20 girls; mean age 12.8 years; range 3–16 years). Of the 48 patients with multilevel spine injuries, 30(62.5%) were at contiguous levels and 18 (37.5%) were at noncontiguous. Of these patients, 7 (14.5%) were between 3 and 9 years of age, and 41 (85.5 %) with multilevel spine injuries were between 9 and 16 years of age. 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%). Of the cases involving MVAs, 72% were unrestrained at the time of the accident (18 patients). For incidence, radiological diagnosis, neurological assessment, and treatment, see Table 1.

Table 1 Distribution of 48 patients with multilevel spine injuries according to involved level

Level of injury	# of Contiguous spine injuries (%)	# of Noncontiguous spine injuries (%)	Total (%)
Cervical	10(20.1)	5(11.1)	15(31.2)
Cervical + thoracic	1(2.0)	2(4.2)	3(6.2)
Cervical + lumbar	–	2(4.2)	2(4.2)
Thoracic	4(8.2)	2(4.2)	6(12.6)
Thoracic + lumbar	7(16.8)	4(6.2)	11(23.0)
Lumbar	8(16.6)	2(4.2)	10(20.8)
Cervical + thoracic + lumbar	–	1(2.1)	1(2.1)
Total	30(63.7)	18(36.3)	48(100)

In the 48 multilevel pediatric spine injury, the patients had, a total of 126 injured vertebrae (mean injury; 2.62, range; 2–6 injuries). The greatest number was found in the cervical region with 38 (30.1%) injured vertebrae. A number of 35 (27.7%) injured vertebrae were seen in the thoracic region and 34 (27.1%) in the lumbar region, whereas at the thoracolumbar junction, 19 (15.1%) injured vertebrae occurred.

On admission, a majority of the patients (73%) were neurologically intact. Among six patients with neurological deficits, two (4.1%) had incomplete neurological injuries (all patients were at contiguous levels), and four (8.3%) had a complete SCI (all patients were at noncontiguous levels). Neurological status (according to the ASIA-modified Frankel classification) could not be evaluated in seven patients (14.6%) with severe head injury. Many patients had other associated injuries, including head and facial trauma (37.5%), multisystem trauma (14.5%), and orthopedic injuries (4.1%); of the patients with cervical multilevel spine injuries, eight patients had head and facial injuries, and one patient had multisystem trauma associated with spleen injury. Of the patient with thoracic and/or lumbar multilevel spine injuries, ten patients had head and facial injury, six patients had visceral organ injuries such as spleen, liver, and pneumothorax, and two patients had an orthopedic injury.

Of the 48 patients, 15 patients (31.2%) suffered multilevel spinal fracture only at cervical levels, three patients (6.2%) at cervical and thoracic levels, two patients (4.2%) at cervical and lumbar levels, six patients (12.5%) in the thoracic region, 11 patients (23%) in the thoracic and lumbar region, ten patients (20.8%) in the lumbar region, and one patient (2.1%) in the cervicothoracolumbar region. Distribution of multilevel spine injuries according to the involved levels is summarized in Table 2.

Of the 36 (75%) patients treated nonsurgically, three (8.3/6.25%) wore a halo vest, six (16.7/12.5%) wore a rigid cervical orthosis, 16 (44/33%) wore a thoracolumbosacral orthosis (TLSO), three (8.3/6.25%) patients with cervical and thoracolumbar injuries wore both a rigid cervical orthosis and a TLSO for a mean of 8–12 weeks, and 8 (22/16.7%) patients with bed rest and gradual resumption of activities. All patients underwent follow-up evaluation with CT scanning or dynamic flexion–extension X-ray films 12 weeks postinjury. None of the conservatively treated patients needed surgical intervention in the follow-up period for nonunion or instability or for complication.

Of the 48 patients, 12 (25%) patients had at least one unstable injury associated with and without neurological deficits and required surgical intervention. Six (50%) patients had an unstable injury associated with a second stable spine injury. Six (50%) other patients with multilevel injuries required surgical stabilization of both unstable injuries. An anterior approach was performed in six (50%) patients. Of these, three (50%) had a fracture dislocation, one (16.6%) had a ligamentous injury, one (16.6%) had an odontoid fracture (type II), and one (16.6%) had a burst fracture in the lumbar level. The posterior approach was performed in five (41.6%) patients. Of these, three (60%) were in cervical level, one (20%) was thoracic, and one (20%) was at the thoracolumbar junction. One (8.4%) patient with an L-1 burst fracture and T6–7 fracture and dislocation underwent a posterior approach to correct the fracture dislocation, followed by an anterior approach to correct the L-1 burst fracture. The age range of surgically treated patients was 3–16 years. All patients with cervical injuries wore a Miami J or a Philadelphia collar; other patients with thoracic and lumbar injuries wore a TLSO for 8–12 weeks after surgery.

Solid arthrodesis was demonstrated in all 11 patients who underwent fusion procedures and were available for follow-up evaluation (mean duration 14.9 months, range 6–40 months). Of the conservatively treated patients, 31 were available for follow-up, three were lost to follow-up, and two died. Only one patient developed slight kyphoscoliosis at follow-up. The patient—a 14-year-old girl with noncontiguous multilevel spinal injuries, a compression fracture at L-3, and a wedge fracture at L-1, and no neurological deficit at admission—was treated nonsurgically. This patient did not require surgical intervention for her deformity. There were no surgery-related deaths or complications.

The neurological condition of all 35 patients who were intact on admission and available for follow-up review remained stable. Of the two patients with an incomplete neurological deficit on admission who were available for follow-up, one improved by one neurological grade (from ASIA grades D to E), whereas one remained unchanged. Of the four patients with complete neurological deficits, one died after admission, and the other three remained unchanged at follow-up.

Nine patients with complete SCI or severe head injuries were transferred to a rehabilitation center. The mean duration of hospital stay was 9 days (range 2– 83 days). Long hospital stays reflected concomitant injuries or severe neurological deficits. One patient with a complete SCI died 12 days postadmission due to head injury. Two other patients also died of a concomitant severe head injury. The overall mortality rate was 6.2%.

Discussion

The spine in children differs from that of adults in numerous respects. Certain anatomical features in children

Table 2 Summary of characteristics in 12 pediatric patients who underwent surgery for multilevel injuries

Case no.	Age (years)/sex	Mechanism	Associated injury	Primary level of injury	Secondary level of injury	Preop neurol status (grade)[a]	Treatment	Postop neurol status (grade)[a]	Follow-up (months)
1	3/F	MVA	Head	C1–2 dislo	C6–7 fx and dislo	Complete (A)	Occ–T3 post stabil	Complete (A)	10
2	8/M	MVA	None	C1–2 dislo	Occ–C1 dislo	Intact (E)	Occ–C2 post stabil	Intact (E)	7
3	8/M	MVA	Multisystem injury	C6–7 fx and dislo	C1–4 post element fx	Complete (A)	Occ–T1 post stabil C1–2 laminectomy for subdural hemorrhage	Died	12 days postadmission
4	11/M	Fall	None	C4 compression fx	C4–5 subluxation	Intact (E)	Ant fusion C3–5 stabil	Intact (E)	35
5	14/F	MVA	None	L1 burst fracture	C1–2 ligament injury	Intact (E)	T12–L2 post stabil conservative for C1–2 lig injury	Intact (E)	12
6	15/M	Sport	None	C3–4 fx and dislo	C4–5 fx and dislo	Incomplete (B)	Ant fusion C3–5 stabil.	Incomplete (B)	40
7	15/M	Sport	None	C4–5 fx and dislo	C5–7 ligament injury	Incomplete (D)	Ant fusion C4–6 stabil	Intact (E)	24
8	15/M	Sport	Multisystem injury	T6 burst fracture	T5 lamina fx, T7–8 comp fx and L1 wedge fx	Complete (A)	T3–L2 post stabil	Complete (A)	14
9	16/M	Sport	None	Odontoid (type II) fracture	C7 post element fx	Intact (E)	Anterior odontoid screw fixation	Intact (E)	6
10	16/F	MVA	Multisystem injury	L1 burst fracture	T5–6 compression fx	Intact (E)	L1 corpectomy T12–L2 stabil	Intact (E)	13
11	16/F	MVA	None	C2–3 fx and dislo	T1–4 transverse process fracture	Intact (E)	Ant. fusion C2–3 stabil	Intact (E)	8
12	16/F	Sport	None	T6–7 fx and dislo	L1 burst fracture	Complete (A)	T5–9 post stabil and L1 corpectomy T12–L2 ant stabil	Complete (A)	10

fx Fracture, *dislo* dislocation, *post* posterior, *comp* compression, *ant* anterior, *stabil* stabilization

[a] Neurological status classified as ASIA grades A to E

that influence the radiographic appearance of the spine, as well as the type of fracture, include an increased cartilage–bone ratio, the presence of secondary ossification centers, and soft-tissue hyperelasticity. The vertebral apophyses are secondary centers of ossification that develop in the cartilaginous end-plates at the superior and inferior surfaces of the vertebral bodies. As in other parts of the body, the child's spine has a more elastic periosteal and surrounding soft tissue envelope compared to adults, resulting in a greater potential for bony healing and remodeling. Furthermore, the increased water content of the nucleus pulposus in an immature intervertebral disk allows it to resist external stresses and deformation to a greater degree than the adult spine [1]. Finally, excessive vertebral segment motion or instability may exist after a spinal injury secondary to the underlying presence of normal ligamentous laxity and underdevelopment of the paraspinous musculature, which do not provide maximum support until puberty [8]. Maturation of cranial and cervical bony morphology after the age of 8 years leads to more adult-like patterns of cervical spinal injury after trauma. During the later stages of development, the facet joints become more vertically oriented and the decreasing ratio of head-to-torso size moves the center of the cervical spine down to the C5 to C6 level. By the time a child reaches 11 to 12 years of age, injuries to the cervical and thoracolumbar spine resemble those seen in the adult population.

Young children seem to sustain more cervical spine injuries, whereas adolescents tend to sustain more thoracic and lumbar injuries [2, 3, 6, 7]. Furthermore, the incidence of multilevel spinal involvement reported in the literature ranges from 6% to 50% in children [2, 3]. In the present study, 48 (26.2%) patients had injuries involving more than one segment of the spine. Of the 48 patients, 30 (62.5%) were at contiguous levels and 18 (37.5%) were at noncontiguous levels. As demonstrated in our findings, most of the patients with multilevel spine injuries (85.5%) were between 9 and 16 years of age. Only 14.5% of the patients in this study with such injuries were younger than 9. Nevertheless, flexibility of the spine may not be the only explanation. The dissipation of the energy of a trauma-producing force through a smaller body, or the amount of that force,or more than one force being applied to the spine may explain the high incidence of multilevel involvement [2].

In the patients in the present study, the cervical region was most affected (31.2%), followed by the thoracic and lumbar (23%), lumbar (20.8%), thoracic(12.5%), cervical and thoracic (6.2%), cervical and lumbar (4.2%), and cervicothoracolumbar regions (2.1%). Thus with 126 total injured vertebrae, the cervical spine was affected slightly more (30.1%) than the other regions.

There is no consensus among authors on the definition of multiple injuries of the spine. Multilevel injuries were classified as ‘contiguous’ when more than two adjacent vertebrae were involved, and as ‘noncontiguous’ if there were preservation of at least one uninjured articulation between the injuries. In this study, we classified vertebrae as contiguous when more than one adjacent vertebra were involved, and as noncontiguous if there was preservation of at least one uninjured vertebra between the injuries.

The most common mechanisms of subaxial injury were MVAs (52%) and sports-related accidents (18.7%). These results are similar to data that we reported more than a decade ago in a patient series in which 52% of injuries were caused by MVAs and 14 were sports-related accidents [3]. It is alarming that 72% of our patients involved in MVAs were unrestrained.We recently found that MVAs accounted for 57.3% of sports-related accidents for 21.3% of pediatric thoracolumbar and sacral spine injuries [7].

Patients with multiple injuries present a diagnostic and therapeutic problem [9]. Spinal trauma frequently is associated with concomitant systemic injuries including head, intraabdominal, and thoracic injuries and long-bone fractures [3, 7]. In the present study, associated injuries included head and facial trauma (37.5%), multisystem trauma (14.5%), and orthopedic injuries (4.1%). Head injury is the most common injury associated with spinal trauma. In our study, head injury was more commonly associated with spinal trauma than with internal organ injury and skeletal injury. Most of our patients (72%) who were injured in a MVA were known to have been unrestrained, which may explain the high number (37.5%) associated head injuries.

Pain and tenderness of the spine and/or abdomen may be an indicator of spinal injury. A patient with neurological symptoms, inability to walk, muscle spasm, and objective neurological findings was likely to have an unstable injury of the spine. The converse or lack of subjective and objective criteria, however, was no assurance that the spine was stable [5]. Wittenberg [10] concluded that when a spine fracture is accompanied by a neurologic deficit, a second fracture at another level must be excluded, and in most patients the upper fracture was responsible for the neurologic deficit. In five of six patients with neurological deficits, in five patients, the proximal injury was responsible for the neurological deficits.

Knowledge of the injury patterns and careful spine radiography in patients with severe trauma may aid in early recognition of multilevel spine injuries and possible prevention of their complications. Because these injuries occur in patients who meet the criteria for categorization as patients with multiple traumas, a complete radiographic survey of the spine must be done in the emergency room in any situation where clinical assessment is impaired. Complete spinal radiographic evaluation is recommended in the workup of patients with suspected spinal column injury, and additional imaging modalities may be necessary in those regions of the spine that are difficult to seem [9]. To help determine the extent of spinal canal impingement, thin section CT scans should be used when bone injuries are suspected or known to exist [11]. MR imaging is most useful in patients with a neurological injury, but can also be useful in establishing ligamentous injury at the craniovertebral junction [12].

The management of cervical spine injuries in the pediatric population must be individualized, and each injury should be treated according to its inherent stability. Nevertheless, therapy depends on the type, severity, and level of injury, including persistent instability, significant compression fracture of the vertebral body, a spinal kyphotic deformity of more than 15°, vertebral dislocation, ligamentous injury with facet instability, and spinal cord compression associated with progressive neurological symptoms. Extradural hematomas and herniated discs are also indications for acute surgical intervention, particularly in patients with incomplete injuries [8]. In our study, 36 patients (75%) were treated nonsurgically; of these 36 patients, 16 wore a TLSO, three wore a Halo vest, and three wore both a rigid cervical orthosis and a TLSO. However, eight patients with multilevel spine injuries were treated successfully with a short period of bed rest alone and gradual resumption of activities. Nonsurgical treatment consisting of halo vest or immobilization with a cast or orthosis or bed rest depends on the type and level of injury. Of the 12 patients treated surgically, six patients underwent an anterior approach, five patients underwent a posterior approach, and one underwent an anterior approach for an L-1 burst fracture and subsequently a posterior approach for T6–7 fracture and dislocation injury. In 11 patients, solid fusion was achieved and there was evidence of good alignment.

The development of spinal deformity after a pediatric spinal injury is directly related to the age of the patient, degree of spasticity, and level of the lesion [4]. Progressive kyphosis at the fracture site is common, especially after laminectomy and in patients with conservatively treated unstable spinal fractures [4, 13]. Only one patient in this study developed mild kyphoscoliosis who had a noncontiguous multilevel spine injury and no neurological deficits and was treated with a brace. This patient did not require surgical intervention to correct the deformity.

The prognosis of pediatric patients with multilevel spine injury depends on the presence of neurological injury and associated injuries at presentation. In our study, all neurologically intact patients remained so at follow-up evaluations. Of the two patients with an incomplete neurological deficit, one improved by one neurological grade (from ASIA grades D to E), and one remained unchanged. Of the four patients with complete neurological deficits, one died after admission, and another remained unchanged. One patient with complete SCI and multisystem trauma and two patients with severe head injuries died. The overall mortality rate was 6.2%.

Conclusions

Multilevel spine injuries are most common in children between 9 and 16 years of age and are primarily located in cervical region. The proximal injury was most often responsible for the neurological deficit. Most patients with multilevel spine injuries can be treated conservatively. The treatment of multilevel spine injuries should follow the same principles as each one separately, the stability and the neurologic symptoms indicate the appropriate treatment. Patients with multilevel spine injuries should be followed-up long-term regarding development of spinal deformity. The physician should suspect such lesions in patient with multisystem injury and should obtain detailed clinical and radiographic examination of the entire spine. Missing such an injury may result in neurologic complications.

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