Pediatric subaxial cervical spine injuries: origins, management, and outcome in 51 patients

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Object. In this study the authors evaluated the mechanisms and patterns of injury and the factors affecting management and outcome of pediatric subaxial cervical spine injuries (C3–7).

Methods. Fifty-one pediatric patients (38 boys and 13 girls; mean age 12.4 years, range 10 months–16 years) with subaxial cervical spine injuries were reviewed retrospectively. Motor vehicle accidents (MVAs) were the most common cause of injury. Overall, 12% presented with a dislocation, 63% with a fracture, 19% with a fracture–dislocation, and 6% with a ligamentous injury. The most frequently injured level was C6–7 (33%); C3–4 (6%) was least frequently involved. 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. Treatment was conservative in 64%: seven (13%) wore a halo vest and 26 (51%) wore a rigid cervical orthosis. Surgery was performed in the other 18 patients (36%), with the breakdown as follows: 15 (30%) underwent an anterior approach, two (4%) had posterior approaches, and one (2%) had a combined approach. Postoperatively, four patients (8%) who had a neurological deficit improved. The overall mortality rate was 8%; all deaths were related to MVAs. There were no surgery-related deaths or complications.

Conclusions. Subaxial cervical spine injuries are common in children 9 to 16 years of age, and occur principally between C-5 and C-7. Multilevel injury is more common in children 8 years of age and older than in younger children and infants. Most patients with subaxial cervical spine injuries can be treated conservatively. Both anterior and posterior approaches are safe and effective.

KEY WORDS • subaxial cervical spine • spinal cord injury • spinal fracture • children

PEDIATRIC spinal injuries constitute 1 to 10% of all cases of spinal injury.^{1,12,17,30,35} In this age group, 60 to 80% of all vertebral injuries involve the cervical spine, and the spinal cord is most frequently injured at the cervical level in all pediatric age groups.^{6,7,33} Regarding the level of injury, the upper cervical spine (above C-4) is most commonly injured in children 8 years of age and younger, whereas older children tend to be injured mainly in the lower cervical spine.¹⁷ In our two previously reported large series of pediatric cervical injuries,^{13,17} 69 to 78% of the patients 9 years of age and younger sustained upper cervical injuries (occiput–C2), whereas 70 to 73% of the patients 10 years of age and older sustained lower cervical spine injuries (C3–7).

We reviewed our experience in the last 6.5 years with subaxial pediatric spinal injuries, defined as injuries involving the levels between C-3 and C-7, to determine

mechanisms and patterns of injury and factors affecting management and outcome.

Clinical Material and Methods

All pediatric trauma admissions to our Level I trauma service since 1999 were reviewed retrospectively. All patients 16 years of age and younger who presented with cervical spine trauma were included in the study. Between 1999 and June 2005, 51 pediatric patients (38 boys and 13 girls; mean age 12.4 years, range 10 months–16 years) with subaxial cervical spine injuries with and without SCIs were treated. Forty-one patients with a subaxial spine injury (80%) were between 9 and 16 years of age, and 10 (20%) were between 0 and 9 years of age.

The predominant mechanism of subaxial cervical spine injury (Table 1) was an MVA (50%), followed by sports-related activities (25%), fall-related injuries (17%), motor vehicle versus pedestrian accidents (6%), and motorcycle accidents (2%). Of the cases involving MVAs, 52% of patients were unrestrained at the time of the accident (13 cases). Patients with missile, brachial plexus, or peripheral nerve injuries were excluded from the study.

Abbreviations used in this paper: CT = computerized tomography; MR = magnetic resonance; MVA = motor vehicle accident; SCI = spinal cord injury; VB = vertebral body.

Diagnostic radiographic studies, including plain cervical x-ray films (anteroposterior, lateral, and swimmer's views) and CT scans were obtained in all patients. Flexion–extension radiographs were obtained to assess spinal stability in awake and neurologically intact patients. If the presence of a fracture was uncertain or if a patient had an SCI, MR imaging was performed (32 cases, 63%).

We evaluated the level and pattern of injury, the diagnosis made, the incidence of neurological compromise, associated injuries, radiographic findings, and outcomes. The patients' neurological function was graded according to the Frankel classification.¹⁵ Follow-up assessment included clinical evaluation and 3- and 6-month radiographic studies (mean follow-up duration 9.05 months, range 2.5–53 months).

Results

Patterns of Injury

Four patterns of injury were recognized on radiographic studies: fractures (63%), fracture with dislocation (19%), dislocation (12%), and purely ligamentous injury (6%). Single-level injuries were distributed along the cervical spine as follows: three (6%) at C3–4; 10 (20%) at C4–5; 12 (23%) at C5–6; and 17 (33%) at C6–7 (Table 2). In nine children (18%) the injury involved more than one level.

Of the 51 patients, 33 (64%) were neurologically intact on admission, eight (16%) had incomplete neurological injuries, and seven (14%) had a complete SCI. Neurological status (according to Frankel grade) could not be evaluated in three patients with severe head injury. Associated injuries included head/facial trauma (24%), multiple trauma (10%), and orthopedic injuries (6%).

Treatment of Injuries

Axial traction was applied in 25 patients as soon as possible after admission. Realignment of a kyphotic deformity and reduction of dislocated facet joints were attempted, and careful neurological monitoring and radiological evaluation of the reduction were performed. All patients with neurological deficits and compressive injuries underwent immediate surgery.

Of the 51 children, 18 (36%) required surgical intervention (Table 3). An anterior cervical approach was performed in 15 patients (83%). Of these, three (20%) had VB fractures, seven (47%) had a fracture and dislocation, four (26%) had vertebral dislocations, and one (7%) had a ligamentous injury. In 11 surgical cases (61%), anterior cervical discectomy and fusion was the only procedure performed. Four patients (22%) were treated with corpectomy, allograft bone, and plate fixation (Fig. 1). The posterior approach was performed in two patients (11%) (Fig. 2). One patient (6%) with a C-7 fracture–dislocation underwent a combined anterior–posterior approach. The age range of surgically treated patients was 8 to 16 years (Table 4). Injuries in the younger patient population in our series did not require surgical intervention. All patients wore either a Miami J or a Philadelphia collar for 8 to 12 weeks post-surgery.

Thirty-three patients were treated nonsurgically. Seven

TABLE 1
Mechanism of injury in pediatric subaxial spine injuries

Mechanism of Injury	No. of Patients (%)
MVA	
unrestrained	13 (25)
restrained	12 (24)
sports	13 (25)
fall	9 (17)
automobile vs pedestrian accident	3 (6)
motorcycle accident	1 (2)

of them wore a halo vest or other rigid cervicothoracic stabilizing device, and 26 wore a rigid cervical orthosis for a mean of 8 to 12 weeks. In a 10-month-old infant with unilateral facet dislocation, two attempts at fluoroscopically guided closed reduction were unsuccessful and the patient was placed in a specially designed external orthosis. All patients underwent follow-up evaluation with CT scanning or dynamic flexion–extension x-ray films. None of the conservatively treated patients needed surgical intervention in the follow-up period for nonfusion or instability, or for complications.

Postoperative Outcomes

Solid arthrodesis was demonstrated in all 15 patients who underwent fusion procedures and were available for follow-up evaluation (mean duration 13.43 months, range 2.5–40 months). Of the conservatively treated patients, 24 were available for follow up, six were lost to follow up, and three died. There were no surgery-related deaths or complications. The neurological condition of all 33 patients who

TABLE 2
*Summary of clinical data in 51 pediatric patients with subaxial cervical injuries at admission**

Factor	No. of Patients (%)
level of injury	
C3–4	3 (6)
C4–5	10 (20)
C5–6	12 (23)
C6–7	17 (33)
multilevel	9 (18)
fx	
burst	1 (2)
compression	10 (20)
teardrop	6 (12)
pst element	15 (29)
disloc	
unilat	5 (10)
bilat	1 (2)
fx & disloc	10 (19)
lig injury	3 (6)
neuro status at admission	
complete	7 (14)
incomplete	8 (16)
intact	33 (65)
ND†	3 (6)

* Disloc = dislocation; fx = fracture; lig = ligament; ND = not determined; neuro = neurological; pst = posterior.

† Comatose on admission; neurological evaluation could not be performed.

TABLE 3

Clinical summary of management and outcome in 51 patients with subaxial cervical injury

Factor	No. of Patients (%)
surgical tx	
ant discect & fusion*	11 (22)
corpectomy/fusion	4 (8)
pst fusion	2 (4)
combined	1 (2)
nonsurgical tx	
rigid orthosis	26 (51)
halo vest	7 (13)
outcome	
complete	4 (8)
incomplete	6 (12)
intact	37 (72)
death	4 (8)

* Ant = anterior; discect = discectomy; tx = treatment.

were intact on admission and available for follow-up review remained stable. Of the eight patients with an incomplete neurological deficit on admission who were available for follow up, five improved one neurological grade and were intact at their last examination, whereas three remained unchanged. Of the seven patients with complete neurological deficits, one died after admission, and the other six were available for follow up. Of these, one improved from Frankel Grade A to C, another improved from Grade A to D, and four remained unchanged.

Ten patients with complete or incomplete injuries were transferred to a rehabilitation center. The mean duration of hospital stay was 7 days (range 1–78 days). Long hospital stays reflected concomitant injuries or severe neurological deficits. One patient with a complete SCI died within 12 hours of head injury. Three other patients also died of a concomitant severe head injury.

Discussion

Patterns and Mechanisms of Subaxial Cervical Spine Injury

Several factors contribute to differences in the frequency, type, location, and incidence of spinal column and cord injuries in children compared with those in adults. These differences are largely attributed to developmental, anatomical, and biomechanical factors associated with the pediatric spine.³⁵ The disproportionately large head and underdeveloped neck musculature in the pediatric population contribute to greater bending of the cervical spine when it is subjected to flexion and extension forces. Furthermore, the elasticity of the joint capsules, ligaments, and cartilaginous endplates serves to absorb and distribute traumatic forces. Horizontally angulated articulating facets, especially at C1–2, and wedge-shaped VBs allow anterior sliding.^{3,10,17,18,36} The resulting patterns of injury include cervical fractures and dislocation (especially in the upper cervical spine), SCI without radiographic abnormality, and severe ligamentous injury.^{11,18,31}

A child's cervical spine does not attain the characteristics of the adult spine until the individual is 8 or 9 years old. Thereafter, the vertebrae usually start to ossify and mature, the VB loses its wedge shape, the facets become more vertically aligned, the cervical musculature becomes more developed, and the ligaments and capsules gain more tensile strength.^{14,17,21,33}

Young children seem to sustain upper cervical injuries, whereas adolescents tend to sustain lower cervical injuries. As demonstrated in our findings, most of the patients with subaxial injuries (60%) were between 9 and 16 years of age. This pattern reflects the fulcrum of cervical motion at C5–6 in adolescents, whereas it is located at C2–3 in younger children.^{18,28} In our patients, the most commonly involved levels in subaxial injury were C6–7 and C5–6 (33 and 23%, respectively), which is consistent with the recent literature. Kokoska, et al.,²² reported that 56% of their patients sustained injuries between C-5 and C-7, and

FIG. 1. A: Reconstructed sagittal (left) and coronal (right) CT scans obtained in a 10-year-old patient with a C-6 fracture and kyphosis. B: Lateral radiograph obtained 1 year after surgical stabilization, confirming excellent alignment and fusion.

FIG. 2. A: Reconstructed sagittal CT scans obtained in an 8-year-old boy, demonstrating C6–7 subluxation and widening of the facets at that level. This patient also had a craniocervical injury. B: Sagittal T₂-weighted MR image demonstrating the severe SCI at C6–7. C: Postoperative plain x-ray film showing the posterior occipital-to-thoracic (T-3) instrumentation needed to stabilize the patient's multilevel cervical injuries.

Patel, et al.,³² found that 28% of their patients had injuries between these levels.

Nine (18%) of our patients had injuries involving more than one segment of the spine. In fact, the incidence of multilevel spinal involvement reported in the literature ranges from 7 to 22% in children.^{5,37} This high incidence is attributed to the increased flexibility of the immature spine,^{3,36} although all of our patients with multilevel injuries were 8 years of age and older. Nevertheless, flexibility of the spine may not be the only explanation. Even older children with stiffer spines or adults may have a similar incidence of multilevel involvement. In adults, the incidence of multilevel cervical spine injury is reported to be approximately 19%.¹⁹ The dissipation of the energy of a trauma-producing force through a smaller body, or the

amount of that force may explain the high incidence of multilevel involvement.⁶ Interestingly, all patients in the surgically treated group were 8 years and older (Table 4), whereas the injuries in younger patients could be managed conservatively.

At our institution, spinal injuries included minor ones such as spinous process fractures, as well as severe fracture–dislocations of the spine. Most of our patients had fractures involving the posterior elements (spinous process, lamina, facet, and pedicle fracture). Compression fractures and fracture–dislocations occurred at equal rates (19%). Patients with a dislocation or fracture–dislocation had a higher incidence of neurological injury than patients with a fracture alone. This finding is to be expected because dislocation and fracture–dislocation cause a greater

TABLE 4

Summary of 18 pediatric patients who underwent surgical treatment for subaxial spinal injuries*

Case No.	Age (yrs), Sex	Level of Injury	Preop Neuro Status (Frankel grade)	Procedure	Postop Neuro Status (Frankel grade)	FU
1	8, M	C6–7 fx, C1–2 disloc	complete (A)	Oc–T3 pst stabilization	incomplete (C)	10 mos
2	8, M	C6–7 fx & disloc, C1–4 pst element fx	complete (A)	Oc–T1 pst stabilization	died	12 days postadmission
3	8, F	C6–7 fx & disloc	incomplete (B)	ant fusion, C6–7 stabilization	incomplete (B)	lost to FU
4	10, F	C5–6 fx & disloc	intact (E)	C-5 corpectomy, fusion, C4–6 stabilization	intact (E)	13 mos
5	12, M	C6–7 fx & disloc	intact (E)	ant fusion, C6–T1 stabilization	intact (E)	lost to FU
6	13, F	C5–6 unilat disloc	incomplete (D)	ant fusion, C5–6 stabilization	intact (E)	12 mos
7	13, M	C-4 compression fx	intact (E)	C-4 corpectomy, fusion, C3–5 stabilization	intact (E)	9 mos
8	13, M	C6–7 bilat disloc	incomplete (D)	ant fusion, C6–7 stabilization	incomplete (D)	8 mos
9	14, M	C5–6 unilat disloc	incomplete (D)	ant fusion, C5–6 stabilization	intact (E)	13 mos
10	15, M	C4–5 fx & disloc	complete (A)	C-5 corpectomy, fusion, C4–6 stabilization	complete (A)	2.5 mos
11	15, M	C3–4, C4–5 fx & disloc	incomplete (B)	ant fusion, C3–5 stabilization	incomplete (B)	40 mos
12	15, F	C6–7 fx & disloc	complete (A)	C-7 corpectomy, fusion, C6–T1 stabilization & pst wiring C6–T1	complete (A)	12 mos
13	15, M	C-6 compression fx	complete (A)	C6 corpectomy, fusion, C5–7 stabilization	complete (A)	9 mos
14	15, M	C6–7 fx & disloc	intact (E)	ant fusion, C6–7 stabilization	intact (E)	13 mos
15	15, M	C4–5 lig injury	incomplete (D)	ant fusion, C4–5 stabilization	intact (E)	24 mos
16	15, M	C4–5 unilat disloc	complete (A)	ant fusion, C4–5 stabilization	incomplete (D)	7 mos
17	16, M	C-6 burst fx	complete (A)	ant fusion, C6–7 stabilization	complete (A)	9 mos
18	16, M	C4–5 fx & disloc	incomplete (C)	ant fusion, C4–5 stabilization	incomplete (C)	8 mos

* FU = follow up; Oc = occiput.

degree of displacement, and more force is usually required to produce such displacement.

The most common mechanisms of subaxial injury were MVAs (50%) and sports-related accidents (25%). This is similar to our overall experience with pediatric cervical spine injury: 48% were caused by MVAs and 35% were sports-related accidents in our earlier studies.^{13,17} In the series reported by Patel, et al.,³² MVAs caused 61% of the injuries and 18% involved falls. Thus, the mechanisms of subaxial cervical spine injury do not differ overall from the mechanisms responsible for injury to the entire cervical spine. Alarming, however, more than half of our patients involved in MVAs (52%) were unrestrained.

As many as 66% of the cervical spine injuries encountered in pediatric patients may be associated with head injury.^{2,26} In our current series, this rate was lower (24%) than the findings in our previous report (40%).¹³ It is also lower than the findings in other studies, which have ranged from 30 to 53%.^{16,29} These findings are plausible and are consistent with our previous report, considering that mainly patients with upper cervical injuries had associated head trauma.¹³

Management of Pediatric Subaxial Cervical Injuries

Treatment of such injuries during a period of growth may be problematic. Most of these injuries can be treated nonsurgically with external stabilization.^{14,24,30} Nevertheless, the management of cervical spine injuries in the pediatric population must be individualized. Therapy depends on the patient's age, severity and level of injury, amount of neurological compromise, and the presence of associated injuries.³⁴

Any patient with a suspected spine injury must be immobilized until the entire vertebral column and spinal cord have been assessed and cleared. As observed in our study, as many as 18% of patients may be injured at more than one level. Thus, full spinal column assessment is indicat-

ed for these patients, as it is for patients with severe head or systemic trauma, or those who are unconscious.

Radiological evaluation begins with routine plain x-ray films. The standard trauma series for cervical spine clearance includes anteroposterior, lateral, and open-mouth radiographs of the cervical spine, which must include the cervicothoracic junction. Fractures identified on plain x-ray films and nonvisualized regions are delineated further by thin-section CT scans. Patients with neurological deficits should undergo MR imaging to exclude the presence of an acute lesion, such as an extradural hematoma or herniated disc.^{8,30} Follow-up radiological assessment may be performed using dynamic flexion–extension radiographs or CT scans. In our series we preferred dynamic radiographs for evaluation of solid fusion.

After initial immobilization and, if possible, reduction, emergency surgical intervention is seldom required; most injuries can be managed nonsurgically. In our study, 33 patients (64%) were treated conservatively. In six patients (including a 10-month-old infant) the injuries were managed successfully with a halo vest or a specially designed external orthosis, with no complications. One patient who was placed in a halo vest died of traumatic head injury within 12 hours. Mubarak, et al.,²⁷ described halo application to immobilize three infants who were 7, 16, and 24 months of age. The patients were maintained in the halo devices for 2 to 3.5 months. Marks, et al.,²³ described the treatment of eight children between 3 months and 12 years of age who were immobilized in halo vests for 6 weeks to 12 months. Osenbach and Menezes³⁰ found that halo vest therapy provided superior immobilization, and they recommended its use for treatment of the cervical spine in children. Previously, we successfully treated 42 patients with cervical spine injury by placing them in a halo vest;¹⁷ however, the use of a halo vest requires special consideration and diligent follow-up evaluation to avoid complications.

Indications for surgical intervention include failure to achieve reduction, persistent instability, ligamentous injury with facet instability, a greater than 15° spinal kyphotic deformity, significant VB compression fracture, vertebral dislocation, and spinal cord compression associated with progressive neurological symptoms.²⁰ Extradural hematomas and herniated discs are also indications for acute surgical intervention, particularly in patients with incomplete injuries.³⁰

Successful arthrodesis and solid fusion associated with good alignment and normal growth of the cervical spine during the follow-up period has been associated with both anterior and posterior approaches.^{4,17,25,36} In this series, 15 patients (30%) with a subaxial cervical injury underwent an anterior approach, two were treated with a posterior approach, and one underwent a combined anterior-posterior approach. In all cases solid fusion was achieved. There was evidence of good alignment and cervical growth at follow up. No postoperative instability and no significant postfusion spinal deformity were observed in any of the patients after rigid screw fixation.

Outcome of Pediatric Subaxial Cervical Injuries

The prognosis of pediatric cervical spine injury depends on the presence of neurological injury at presentation. In our series, all neurologically intact patients remained so at follow-up evaluations. Of the patients with incomplete injuries, 62.5% recovered completely. The high capacity for recovery in these young patients is thought to be related to the rapid healing properties of bone and ligaments in children as well as to the greater potential for recovery of the nervous system.^{9,17} Of the six patients with complete neurological deficits who were available for follow up, one improved three Frankel grades and another improved two grades, whereas four patients remained unchanged. Nevertheless, patients with complete injuries may recover relatively late after injury.^{9,17}

The lower mortality rate (8%) observed in this series compared with the overall reported mortality rate (16–35%) for pediatric cervical injury may reflect our focus on subaxial cervical injuries. Upper cervical injuries are associated with a higher rate of head injuries and seem to be associated with poor outcomes.

Conclusions

Subaxial cervical spine injuries are most common in children between 9 and 16 years of age and are principally located between the C-5 and C-7 vertebrae. Multilevel injuries are most common in children 8 years of age and older, and are rare in younger children and infants. The treatment in each patient must be individualized. Most patients with subaxial cervical spine injuries can be treated conservatively. When indicated, both anterior and posterior approaches are safe and effective for the treatment of pediatric subaxial cervical spine injuries. Complications are minimal and the rate of bone fusion is high. Surgery also allows immediate postoperative mobilization of patients. The prognosis for neurological recovery from pediatric subaxial cervical spine injuries is related to the initial severity of the neurological injuries, but may be better than in the adult population.

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