# MANAGEMENT OF PEDIATRIC CERVICAL SPINE AND SPINAL CORD INJURIES

## RECOMMENDATIONS

**Diagnostic**:

Standards: There is insufficient evidence to support diagnostic standards.

Guidelines:

- In children who have experienced trauma and are alert, have no neurological deficit, no midline cervical tenderness, no painful distracting injury, and are not intoxicated, cervical spine radiographs are unnecessary to exclude cervical spine injury and are not recommended.
- In children who have experienced trauma and who are either not alert or have neurological deficit, midline cervical tenderness, painful distracting injury, or are intoxicated, it is recommended that cervical spine radiographs be obtained.

Options:

- In children less than nine years of age who have experienced trauma, and who are non-conversant or have an altered mental status, a neurological deficit, neck pain, a painful distracting injury, are intoxicated, or have unexplained hypotension, it is recommended that AP and lateral cervical spine radiographs be obtained.
- In children nine years of age or older who have experienced trauma, and who are non-conversant or have an altered mental status, a neurological deficit, neck pain, a painful distracting injury, are intoxicated, or have unexplained hypotension it is recommended that AP, lateral, and open-mouth cervical spine radiographs be obtained.

• CT scan with attention to the suspected level of neurological injury to exclude occult fractures, or to evaluate regions not seen adequately on plain radiographs is recommended.

• Flexion and extension cervical radiographs or fluoroscopy may be considered to exclude gross ligamentous instability when there remains a suspicion of cervical spine instability following static radiographs.

• MRI of the cervical spine may be considered to exclude cord or nerve root compression, evaluate ligamentous integrity, or provide information regarding neurological prognosis.

## Treatment

Standards: There is insufficient evidence to support treatment standards.

Guidelines: There is insufficient evidence to support treatment guidelines.

Options:

• Thoracic elevation or an occipital recess to prevent flexion of the head and neck when restrained supine on an otherwise flat backboard may allow for better neutral alignment and immobilization of the cervical spine in children less than eight years of age and is recommended.

• Closed reduction and halo immobilization for injuries of the C2 synchondrosis between the body and odontoid is recommended in children less than seven years of age.

• Consideration of primary operative therapy is recommended for isolated ligamentous injuries of the cervical spine with associated deformity.

## RATIONALE

There are distinct, unique aspects of the management of children with potential injuries of the cervical spinal column and cervical spinal cord compared to adult patients that warrant specific recommendations. The methods of pre-hospital immobilization necessary to approximate "neutral" cervical spinal alignment in a young child differ from those methods commonly employed for adults. The spinal injury patterns among young children differ from those that occur in adults. The diagnostic studies and images necessary to exclude a cervical spine injury in a child may be different than in the adult as well. The interpretation of pediatric radiographic studies must be made with knowledge of age-related development of the osseous and ligamentous anatomy. Methods of reduction, stabilization, and subsequent treatment, surgical and non-surgical, must be customized to each child taking into account the child's degree of physical maturation and his/her specific injury. The purpose of this review is to address the unique aspects of children with real or potential cervical spinal injuries and provide recommendations regarding their management.

## SEARCH CRITERIA

A National Library of Medicine computerized literature search from 1966 to 2001 was undertaken using Medical Subject Headings in combination with "spinal cord injuries" and "child" yielded 1022 citations. These citations were reviewed in combination with "cervical vertebra", "spinal injuries" and "child" which yielded 152 citations. Non-English language citations were deleted. The remaining abstracts were reviewed for those that described children who had sustained or were being evaluated for a cervical spinal cord or cervical spinal column injury. Articles describing the clinical aspects and management of children were used to generate these guidelines. Case reports were excluded. Of the 57 articles meeting selection criteria, none were Class I studies. There was one Class II study addressing diagnostic imaging in children. All remaining articles were case series representing Class III evidence. Summaries of these 57 articles are provided in Evidentiary Table format.

## SCIENTIFIC FOUNDATION

### *Pre-hospital Immobilization*

The primary goal of pre-hospital management of pediatric patients with potential cervical spine or spinal cord injury is to prevent further injury. Along with assuring an adequate airway, ventilation, and perfusion, spinal immobilization likely plays an important role in preventing further injury to the vertebral column and spinal cord. Immobilization of the child's cervical spine in the neutral position is desired. To achieve neutral alignment of the cervical spine in children less than eight years of age, allowances must be made for the relatively large head compared to the torso, that forces the neck into a position of flexion when the head and torso are supine on a flat surface (39). Nypaver and Treloar prospectively evaluated 40 children less than eight years of age seen in an emergency room for reasons other then head and neck trauma and assessed them with respect to neutral positioning upon a backboard (39). They found that all 40 children required elevation of the torso to eliminate positional neck flexion and achieve neutral alignment as determined by two independent observers. The mean amount of elevation required was 25 millimeters. Children less than four years of age required greater elevation than those four years of age or older ($P<0.05$). Because of these findings it was recommended that when immobilizing children less than eight years of age that either the torso be elevated or an occipital recess be created to achieve a more neutral position for immobilization of the cervical spine. In a separate report, Treloar and Nypaver similarly found that semi-rigid cervical collars placed on children less than eight years of age did not prevent this positional forced flexion when placed supine on standard, rigid spinal boards (60).

Herzenberg, et al, studied ten children less than seven years of age with cervical spine injuries who were positioned on a backboard. All had anterior angulations or translation at the injured segment that was reduced by allowing neck extension into a more neutral position (26). They suggested that alignment of the patient's external auditory meatus with his/her shoulders would help to achieve neutral cervical spine positioning.

Curran, et al, however, found no correlation with age regarding degree of cervical kyphosis identified in children transported on backboards (8). They did note however, that 30% of children had greater than ten degrees of kyphosis as determined by Cobb angle measurements between C2 and C6. No specific technique or device allowed superior neutral positioning of the cervical spine in patients they studied. None of their patients were immobilized on boards with an occipital recess or thoracic padding.

Huerta, et al, evaluated a variety of immobilization devices on children, infants and child-sized mannequins (27). They concluded that no collar provided "acceptable immobilization" when used alone. They found that the combination of a modified half-spine board, rigid cervical collar, and tape was the most effective means of immobilization of the cervical spine for transport in children.

Shafermeyer, et al, however, cautioned that immobilization techniques that employ taping across the torso to secure the child to the spine board may have deleterious effects on respiratory function (55). They studied 51 healthy children, ages six to 15 years by measuring forced vital capacity (FVC). FVC dropped when going from the upright to supine position.

Taping across the torso to secure the volunteer to the spine board caused further reductions in FVC of 41% to 96% (mean 80%), compared to the supine FVC without tape. The authors cautioned that this restriction of FVC might be enough to create respiratory insufficiency in some trauma patients.

In summary when spinal immobilization is indicated for children for transportation, the type of immobilization should take into account the child's age and physical maturity. It should allow for the relatively larger head with respect to the torso in younger children. While ideal spinal immobilization of pediatric trauma victims appears to be provided by a combination of a spinal board, rigid collar, and tape, these immobilization techniques may influence negatively the child's respiratory function.

***Imaging***

Following immobilization and transport to an acute care facility, initial clinical evaluation and medical/hemodynamic support, the need for and type of radiographic assessment must be decided and undertaken. Several authors have evaluated the indications for radiographic assessment of children with a potential cervical spinal injury (4,32). Laham, et al, investigated the role of cervical spine x-ray evaluation of 268 children with apparent isolated head injuries (32). They retrospectively divided the children into high (n=133) and low-risk (n=135) groups. High-risk characteristics were children incapable of verbal communication either because of age (less than two years of age) or head injury, and those children with neck pain. They employed the "three-view approach" of A-P, lateral, and open-mouth radiographs. They discovered no cervical spine injuries in the low-risk group but discovered ten in the high-risk group (7.5%). The authors concluded that cervical spine radiographs are not necessary in children with isolated head injuries who can communicate and have no neck pain or neurological deficit. Bohn, et al, emphasized that unexplained hypotension or absent vital signs in childhood trauma victims are likely to be from a severe cervical cord injury (4). Therefore, they advocate suspicion for a cervical spinal cord injury in children with either multisystem trauma, or an isolated head injury presenting with hypotension or cardiopulmonary arrest.

Viccellio, et al, evaluated the cervical spines in children less than 18 years of age utilizing the National Emergency X-Radiography Utilization Study (NEXUS) decision instrument in a Class II prospective multicenter study (62). They employed five low-risk criteria. These criteria were the absence of: 1) midline cervical tenderness, 2) evidence of intoxication, 3) altered level of alertness, 4) focal neurological deficit, and 5) a painful distracting injury. Radiographs were obtained at the discretion of the treating physician. When radiographs were obtained a minimum of three-views was obtained. Only those patients who obtained radiographs were included in the study. If all five criteria were met the child was considered low-risk. If any one of the five criteria were present the child was considered high-risk. Three thousand and sixty-five children were evaluated. Of these 603 fulfilled the low-risk criteria. None of these 603 children defined as low-risk had a documented cervical spine injury by radiographic evaluation. Thirty injuries (0.98%) were documented in children not fulfilling the low-risk criteria. They concluded that applying the NEXUS criteria to children would reduce cervical spine radiograph use by 20% and not result in missed injuries. They cautioned that they had relatively small numbers of young children less than two years of age (n=88). Statistically this created large confidence intervals for the sensitivity of their instrument when applied to younger children. From this Class II study, they “cautiously” endorsed the application of NEXUS criteria in children, particularly those from birth to nine years of age. Their conclusions are consistent with the Class III evidence previously described by Laham, et al, on this topic (32).

The need for and utility of open-mouth odontoid views in pediatric trauma victims has been questioned (6,59). Swischuk, et al, surveyed 984 pediatric radiologists to determine how many injuries were missed on lateral cervical spine radiographs, yet detected on an open-mouth view (59). There were 432 responses. One hundred and sixty-one respondents did not routinely use open-mouth views. Of the 271 that obtained open-mouth views in young children, 191 (70%) would not persist beyond a single attempt. Seventy-one radiologists (26%) would make up to five attempts to obtain an adequate image. Twenty-eight of the 432 respondents (7%) reported missing a total of 46 fractures on the lateral view that were detected on the open-mouth view. The types of injuries were not classified (i.e. odontoid versus C1 injury). The authors calculated a missed fracture rate of 0.007 per year per radiologist in their study. They concluded that the open-mouth view x-ray might not be needed routinely in children less than five years of age. Buhs, et al, also investigated the utility of open mouth views in children (6). They performed a multi-institutional retrospective review of a large metropolitan population of patients less than 16 years of age who were assessed for cervical spine trauma over a ten-year period. Fifty-one children with cervical spinal injuries were identified. The lateral cervical spine radiograph made the diagnosis in 13 of 15 children less than nine years of age. In none of the 15 younger patients did the open-mouth view provide the diagnosis. In only one of 36 patients in the nine to 16 years of age group was the open mouth view the diagnostic study (a type III odontoid injury). The authors concluded that the open mouth view radiograph is not necessary for clearing the cervical spine in children less than nine years of age.

Lui, et al, in their review of 22 children with C1-C2 injuries commented that flexion and extension radiographs were required to "identify the instability" of traumatic injuries to the dens in four of 12 children with odontoid fractures, and in six of nine children with purely ligamentous injuries resulting in atlantoaxial dislocation (33). The authors did not state whether an abnormality on the static radiograph led to the dynamic studies, or whether the initial static studies were normal. Because they did not describe flexion and extension x-rays as part of their routine for the assessment of children with potential cervical spine injuries it is likely that some imaging or clinical finding prompted the decision to obtain dynamic films in these children.

The experience of Ruge, et al, highlighted the propensity for upper cervical injuries in children under the age of nine years (49). They reported no injuries below C3. Evans and Bethem described 24 children with cervical spine injuries (14). In half of the patients, the injury was at C3 or higher (14). Givens, et al, however, described the occurrence of important injuries occurring at all levels of the cervical spine in young children (20). They described 34 children with cervical spine injuries. There was no correlation of level of injury with age. Two of the children they managed had injuries at C7-T1. Hence, it would be dangerous to assume that lower cervical spine injuries do not occur in young children and irresponsible to discount the need for adequate imaging of the lower cervical spine and cervical-thoracic junction in these young patients.

Scarrow, et al, attempted to define a protocol to evaluate the cervical spine in obtunded children following trauma (50). They utilized somatosensory-evoked responses during flexion and extension fluoroscopy. Of the 15 children evaluated with this protocol, none showed pathological motion during flexion and extension fluoroscopy. Three children were thought to have a change in the evoked responses during flexion and extension. Only one of the three children with an abnormal evoked response underwent magnetic resonance imaging (MRI) that was normal. Their investigation failed to demonstrate any utility for evoked responses, flexion and extension fluoroscopy, or MRI of the cervical spine in the evaluation of the cervical spine in children with altered mental status following trauma. Larger numbers of children investigated in this manner might define a role for one or more of these diagnostic maneuvers but as yet there is no evidence to support their use.

Ralston, et al, retrospectively analyzed the cervical spine radiographs of 129 children who had flexion and extension x-rays performed after an initial static radiograph (45). They found that if the static radiograph was normal or depicted only loss of lordosis the flexion and extension views would reveal no abnormality. The authors concluded that the value of the dynamic radiographs was confirmation of cervical spinal stability when there was a questionable finding on the static, lateral radiograph (45).

The interpretation of cervical spine x-rays must account for the age and anatomical maturation of the patient. Common normal findings on cervical spine radiographs obtained on young children are pseudosubluxation of C2 on C3, overriding of the anterior atlas in relation to the odontoid on extension, exaggerated atlanto-dens intervals, and the radiolucent synchondrosis between the odontoid and C2 body. These normal findings can be mistaken for acute traumatic injuries in children following trauma. Cattell and Filtzer obtained lateral cervical radiographs in neutral, flexion, and extension in 160 randomly selected children who had no history of trauma or head and neck problems (7). The subjects' ages ranged from one to 16 years with ten children for each year of age. They found a 24% incidence of moderate to marked C2 on C3 subluxation in children between one and seven years of age. Thirty-two of 70 children (46%) less than eight years of age had three millimeters or more of anterior-posterior motion of C2 on C3 on flexion and extension radiographs. Fourteen percent of all children had radiographic pseudosubluxation of C3 on C4. Twenty percent of children from one to seven years of age had an atlanto-dens interval of three millimeters or greater. Overriding of the anterior arch of the atlas on the odontoid was present in 20% of children less than eight years-old. The synchondrosis between the odontoid and axis body was noted as a lucency in all children imaged up to the age of four years. The synchondrosis remained visible in half the children up to eleven years of age. The authors also described an absence of the normal cervical lordosis in 14% of subjects, most commonly in the eight to 16 year-old age groups. Shaw, et al, in a retrospective review of cervical spine x-rays in 138 children less than 16 years of age who were evaluated following trauma, found a 22% incidence of radiographic pseudosubluxation of C2 on C3 (56). The only factor that correlated with the presence of pseudosubluxation in their study was patient age. The pseudosubluxation group had a median age of 6.5 years versus nine years in the group without this finding. It was identified however, in children as old as 14 years of age. Intubation status, injury severity score, and gender had no correlation with pseudosubluxation of C2 on C3. To differentiate between physiological and traumatic subluxations they recommend a method that involves drawing a line through the posterior arches of C1 and C3. In the circumstance of pseudosubluxation of C2 on C3, the C1-C3 line should pass through, touch, or lie up to one millimeter anterior to the anterior cortex of the posterior arch of C2. If the anterior cortex of the posterior arch of C2 is two millimeters or more behind the line, then a true dislocation (rather than pseudosubluxation) should be assumed.

Keiper, et al, reviewed their experience of employing MRI in the evaluation of children with clinical evidence of cervical spine trauma who had no evidence of fracture by plain radiographs or CT, but who had persistent or delayed symptoms, or instability (29). There were

16 abnormal MRI examinations in 52 children. Posterior soft tissue and ligamentous changes were described as the most common abnormalities. Only one child had a bulging disc. Four of these 52 children underwent surgical treatment. In each of the four surgical cases, the MRI findings led the surgeon to stabilize more levels than otherwise would have been undertaken without the MRI information. Davis, et al, described the use of MRI in evaluating pediatric spinal cord injury and found it did not reveal any lesion that would warrant surgical decompression (9). They did note however that MRI findings did correlate with neurological outcome. Evidence of hematomyelia was associated with permanent neurological deficit. While little information is available on this subject, it appears that preoperative MRI of children with unstable cervical spinal injuries, who require surgical stabilization, may affect the specifics of the surgical management.

There are no studies that have systematically reviewed the role of CT in the evaluation of the cervical spines of pediatric patients following trauma. In children less than ten years of age with cervical spinal injuries, the majority of patients will have ligamentous injuries without fracture (10,13,24,25,41). In older children with cervical spinal injuries, the incidence of a fracture is much greater than ligamentous injury without fracture, 80% vs. 20% respectively (14, 62). Therefore, normal osseous anatomy as depicted on an axial CT image should not be used alone to exclude injury to the pediatric cervical spine. Schleehauf, et al, in 1989, concluded that CT should not be relied upon to exclude ligamentous injuries in a series of pediatric and adult trauma patients (51). They reported two false negative CT studies in patients with C1-C2 ligamentous injuries in their study of the merits of CT to evaluate the cervical spine in high-risk trauma patients. The authors favored CT for the evaluation of regions that could not be viewed adequately with plain radiographs (e.g. C7-T1), and for the investigation of the osseous integrity of specific vertebra suspicious for fracture on plain radiographs (51).

In a series consisting of almost entirely adults, the role of helical CT in the evaluation of the cervical spine in "high-risk" patients following severe, blunt, multisystem trauma has been prospectively studied (3). The plain spine radiographs and CT images were reviewed by a radiologist blinded to the patients and their history. The investigators found 20 cervical spine injuries (12 stable, eight unstable) in 58 patients (34%). Eight of these injuries (five stable, three unstable) were not detected on plain radiographs. The authors concluded that helical cervical spinal CT should be utilized to assess the cervical spine in high risk trauma patients. In young children in whom the entire cervical spine is often easily and accurately visualized on plain x-ray studies, the need for cervical spinal helical CT is likely not as great. In older high-risk children who have spinal biomechanics and injury patterns more consistent with those of adult trauma patients, helical CT of the cervical spine may be fruitful.

In summary, to "clear" a child's cervical spine Class II and Class III evidence supports obtaining lateral and A-P cervical spine radiographs in children who have experienced trauma and cannot communicate because of age or head injury, have a neurological deficit, have neck pain, have a painful distracting injury, or are intoxicated. In children who are alert, have no neurological deficit, no midline cervical tenderness, no painful distracting injury, and are not intoxicated cervical spine radiographs are not necessary to exclude cervical spine injury (32,62). Unexplained hypotension should raise the suspicion of a spinal cord injury. Open-mouth views of the odontoid do not appear to be useful in children less than nine years of age. Open-mouth views should be attempted in children nine years of age and older. Flexion and extension studies (fluoroscopy or radiographs) are likely to be unrevealing in children with static radiographs proven to be normal. Dynamic studies could be considered however, when the static radiographs or the child's clinical findings suggest but do not definitively demonstrate cervical spinal instability. CT studies of the cervical spine should be employed judiciously to define bony anatomy at specific levels but are not recommended as a means to "clear" the entire cervical spine in children. MRI may provide important information about ligamentous injury that may influence surgical management, and may provide prognostic information regarding neurological outcome.

***Injury Management***

Injury patterns that have a strong predilection for or are unique to children merit discussion because of the specialized management paradigms employed to treat them. Spinal cord injury without radiographic abnormality (SCIWORA) and atlanto-occipital dislocation injuries have been addressed in other sections (see SCIWORA guideline, see Atlanto-occipital dislocation guideline). Spinal cord injuries secondary to birth-related trauma and epiphysiolysis of the axis are injuries unique to children. Common but not unique to children are C1-C2 rotary subluxation injuries. These entities will be discussed below in light of the available literature. It should be noted that there is no information provided in the literature describing the medical management of pediatric patients with spinal cord injuries. The issue of steroid administration following acute pediatric spinal cord injury, for example, has not been addressed. While prospective, randomized clinical trials such as NASCIS II and NASCIS III have evaluated pharmacological therapy following acute spinal cord injury, children younger than 13 years of age were excluded from study (5).

*Neonatal spinal cord injury.* Birth injuries of the spinal cord occur approximately one per 60,000 births (63). The most common level of injury is upper cervical followed by cervico-thoracic (34). Mackinnon, et al, described 22 neonates with birth-related spinal cord injuries (34). The diagnosis was defined by the following criteria: clinical findings of acute cord injury for at least one day and evidence of spinal cord or spinal column injury by imaging or electrophysiological studies. Fourteen neonates had upper cervical injuries, six had cervicothoracic injuries, and two had thoracolumbar injuries. All upper cervical cord injuries were associated with cephalic presentation and the use of forceps for rotational maneuvers. Cervicothoracic injuries were associated with the breech presentation. All infants had signs of "spinal shock", defined as flaccidity, no spontaneous motion and no deep tendon reflexes. Of the nine infants with upper cervical injuries surviving longer than three months, seven were alive at last follow-up. Six of these seven are dependent upon mechanical ventilation. The two neonates with upper cervical injuries who had breathing movements on day one of life were the only two thought to have satisfactory outcomes. All survivors with upper cervical cord injuries whose first respiratory effort was beyond the first 24 hours of life have remained ventilator dependent. Only two children of six who sustained cervicothoracic spinal cord injuries lived and remained paraplegic. One requires mechanical ventilation. Hypoxic and ischemic encephalopathy was noted in nine of 14 newborns with upper cervical cord injuries, and in one of six with a cervicothoracic cord injury. The authors did not describe any treatment provided for the underlying spinal column or cord injury, or whether survivors experienced progression of any spinal deformities.

Menticoglou, et al, drawing partly from the same patient data as Mackinnon, et al, reported 15 neonates with birth-related upper cervical spinal cord injuries (37). All were associated with cephalic deliveries requiring rotational maneuvers with forceps. All but one child was apneic at birth with quadriplegia. There is no description of post-injury spinal column or spinal cord management, medical or surgical, in their report.

Rossitch and Oakes described five neonates with birth-related spinal cord injuries (48). They reported that incorrect diagnoses were made in four. They consisted of Werdnig-Hoffmann syndrome, occult myelodysplasia, and birth asphyxia. Only one neonate had an abnormal plain radiograph (atlanto-occipital dislocation). They provided no description of the management of the spinal cord or column injuries in these five neonates.

Fotter, et al, reported the use of bedside ultrasound to diagnose neonatal spinal cord injury. They found excellent correlation with MRI studies with respect to the extent of cord injury in their two cases (17).

Pang and Hanley provide the only description of an external immobilization device for neonates (42). They described a thermoplastic molded device that is contoured to the occiput, neck, and thorax. Velcro straps cross the forehead and torso, securing the infant and immobilizing the spinal column.

In summary cervical instability following birth-related spinal cord injury is not addressed in the literature. The extremely high mortality rate associated with birth-related spinal cord injury may have generated therapeutic nihilism for this entity, hence the lack of aggressive management. The literature suggests that the presentation of apnea with flaccid quadriplegia following cephalic presentation with forceps manipulation is the hallmark of upper cervical spinal cord injury. Absence of respiratory effort within the first 24 hours of life is associated with dependence upon long-term mechanical ventilation. It appears reasonable to treat these neonates with spinal immobilization for a presumed cervical spinal injury. The method and length of immobilization is at present arbitrary.

*Odontoid Epiphysiolysis*. The neurocentral synchondrosis of C2 that may not fuse completely until age seven years represents a vulnerable site of injury in young children (22). The lateral cervical spine radiograph is the diagnostic imaging modality of choice to depict this injury. It will often reveal the odontoid process to be angulated anteriorly, and rarely posteriorly (57). While injuries to the neurocentral or subdental synchondrosis may be seen in children up to seven years of age, it most commonly occurs in pre-school aged children (35). Mandabach, et al, described 13 children with odontoid injuries ranging in age from nine months to seven years (35). They reported that eight of ten children who were initially managed with halo immobilization alone achieved stable fusion. The average time to fusion was 13 weeks with a range of ten to 18 weeks. Because the injury occurs through the epiphysis, it has a high likelihood of healing if closed reduction and immobilization are employed. Mandabach, et al, in their review cited several other reports describing the successful treatment of young children with odontoid injuries who were managed with a variety of external immobilization devices. Sherk, et al, reported 11 children with odontoid injuries and reviewed an additional 24 from the literature. Only one of these 35 children required surgical fusion (57). While the literature describes the use of Minerva jackets, soft collars, hard collars, and the halo vest as means of external immobilization to achieve successful fusion in young children with odontoid injuries, the halo is the most widely employed immobilization device in the contemporary literature for these injuries (35,40,57).

To obtain injury reduction in these children Mandabach, et al, advocate the application of the halo device under ketamine anesthesia followed by realignment of the dens utilizing C-arm fluoroscopy (35). Other reports describe using traction to obtain alignment, before immobilizing the child in an external orthosis (22). Compared to halo application and immediate reduction and immobilization, traction requires a period of bed rest and is associated with the potential risk of over-distraction (35).

The literature is scant regarding the operative treatment of C2 epiphysiolysis. Most reports describe employing operative internal fixation and fusion only if external immobilization has failed to maintain reduction or achieve stability. Reinges, et al, noted that only three "young" children have been reported in the literature who have had odontoid injuries primarily treated with surgical stabilization (47). This underscores the near universal application of external immobilization as the primary means of treating odontoid injuries in young children. Odent, et al, reported that of the 15 young children with odontoid injuries they managed, three that were treated with surgical stabilization and fusion experienced complications. The other 12 children with similar injuries nonoperatively managed did well (40). Wang, et al, described using anterior odontoid screw fixation as the primary treatment option in a three-year-old child with C2 epiphysiolysis (64). A hard cervical collar was used postoperatively. Halo immobilization was not used either preoperatively or postoperatively. They successfully employed anterior odontoid screw fixation as the primary treatment in two older children (ages ten and 14 years) followed by hard collar immobilization. It is likely that these two children had true type II odontoid fractures and not C2 epiphysiolysis. Likewise, Godard et al performed anterior odontoid screw fixation in a two-year-old child with a severe head injury. They used skeletal traction to align the fracture pre-operatively (21). The rationale for proceeding to operative stabilization without an attempt at treatment with external immobilization was to avoid the halo orthosis, and to allow for more aggressive physiotherapy in this severely injured child. They believe that anterior odontoid screw fixation is advantageous because no motion segments are fused, normal motion is preserved, and the need for halo immobilization is obviated.

For management of injuries of the C2 neurocentral synchondrosis the literature supports the use of closed reduction and external immobilization for approximately ten weeks. This strategy is associated with an 80% fusion success rate. While primary surgical stabilization of this injury has been reported, the experience in the literature is limited. Surgical stabilization appears to play a role when external immobilization is unable to maintain alignment of the odontoid atop the C2 body. While both anterior and posterior surgical approaches have been successfully employed in this setting, there are more reports describing posterior C1-2 techniques than reports describing anterior operative techniques.

*Atlanto-axial rotary subluxation.* Fixed rotary subluxation of the atlanto-axial complex is not unique to children but is more common during childhood. They can present following minor trauma, in association with an upper respiratory infection, or without an identifiable inciting event. The head is rotated to one side with the head tilted to the other side causing the so-called "cock-robin" appearance. The child is unable to turn his/her head past the midline. Attempts to move the neck are often painful. The neurological status is almost always normal (12,31,44,58).

It can be difficult to differentiate atlanto-axial rotary subluxation from other causes of head rotation on clinical grounds alone. Several reports describe the radiographic characterization and diagnosis of this entity. Fieldings and Hawkins described 17 children and adults with atlanto-axial rotary subluxation, and classified their dislocations into four types based on radiographic features (15). Type I was the most common type identified in eight of the 17 patients. It was described as unilateral anterior rotation of the atlas pivoting around the dens with a competent transverse ligament. Type II was identified in five patients. It was described as unilateral anterior subluxation of the atlas with the pivot being the contralateral C1-C2 facet. The atlanto-dens interval is increased to no more than five millimeters. Type III is described as anterior subluxation of both C1 facets with an incompetent transverse ligament. Type IV is posterior displacement of C1 relative to C2 with an absent or hypoplastic odontoid process.

Kawabe, et al, reviewed the radiographs of a series of 17 children with C1-C2 rotary subluxation and classified them according to Fieldings and Hawkins (28). There were ten Type I, five Type II, two Type III, and no Type IV subluxations in their experience. CT has been employed to help define the C1-C2 complex in cases of suspected rotary subluxation. Kowalski, et al, demonstrated the superiority of dynamic CT studies compared to information obtained with static CT studies (31). They compared the CT scans of eight patients with C1-C2 pathology to CT studies of six normal subjects. The CT scans obtained with normal subjects maximally rotating their heads could not be differentiated from the CT scans of those with known C1-C2 rotary subluxation. When the CT scans were performed with the head rotated as far as possible to the contralateral side, CT studies of normal subjects could be easily differentiated from those performed on patients with rotary subluxation.

Type I and Type II subluxation account for the vast majority of rotary atlanto-axial subluxations in reports describing these injuries. Grogaard, et al, (23) and Subach, et al, (58) have published retrospective reviews on the success of conservative therapies in children presenting early following C1-C2 rotary subluxation. Grogaard, et al, described eight children who presented within five days of subluxation, and one child who presented eight weeks after injury (23). All were successfully treated with closed reduction and immobilization. The child presenting late required one week of skeletal traction to achieve reduction and was ultimately treated with halo immobilization for ten weeks. The children who presented early had their injuries reduced with manual manipulation. They were treated in a hard collar for four to six weeks. Two patients had recurrent subluxation. Both were reduced and treated successfully without surgical intervention. Subach et al reported 20 children with C1-C2 rotary subluxation, in whom four injuries reduced spontaneously (58). Injury reduction was accomplished in fifteen of 16 patients treated with traction for a mean duration of four days. Six children required fusion because of recurrent subluxation (n=5) or irreducible subluxation (n=1). No child experienced recurrent subluxation if reduced within 21 days of symptom onset.

El-Khoury, et al, reported three children who presented within 24 hours of traumatic rotary subluxation (12). All three were successfully treated with traction or manual reduction within 24 hours of presentation. One child experienced recurrent subluxation the next day that was successfully reduced manually. External orthoses were used from ten weeks to four months. Phillips, et al, reviewed 23 children with C1-C2 rotary subluxation (44). Sixteen children were seen within one month of subluxation onset and experienced either spontaneous reduction or were reduced with traction. Of seven children presenting with a duration of symptoms greater than one month, one subluxation was irreducible, and four recurred after initial reduction. Schwarz described four children who presented greater than three months after the onset of C1-C2 rotary subluxation (53). Two children had irreducible subluxations. One child had recurrent subluxation despite the use of a Minerva cast. Only one child had successful treatment with closed reduction and a Minerva cast immobilization for eight weeks. These experiences highlight the ease and success of non-surgical management for these injuries when the subluxation is treated early rather than late. If the subluxation is easily reducible and treated early, four weeks in a rigid collar appears to be sufficient for healing. Because C1-C2 rotary subluxation can reduce spontaneously in the first week, traction or manipulation can be reserved for those subluxations that do not reduce spontaneously in the first few days. The use of more restrictive external immobilization devices (e.g. halo vest, Minerva cast) for longer periods of treatment up to four months has been described in those children presenting late, or those who have recurrent subluxations (44).

Operative treatment for C1-C2 rotary subluxations has been reserved for recurrent subluxations or those that cannot be reduced by closed means. Subach, et al, operated on six of the 20 children they reported with rotary subluxation using these indications. They employed a posterior approach and accomplished atlantoaxial fusion (58). They had no complications and all fusions were successful.

In summary the diagnosis of atlantoaxial rotary subluxation is suggested when findings of a “cock-robin” appearance are present, the patient is unable to turn the head past midline to the contralateral side, and experiences spasm of the ipsilateral (the side to which the chin is turned) sternocleidomastoid muscle (44). Plain cervical spine radiographs may reveal the lateral mass of C1 rotated anterior to the odontoid on a lateral view. The A-P radiograph may demonstrate rotation of the spinous processes toward the ipsilateral side in a compensatory motion to restore alignment. If the diagnosis of C1-C2 rotary subluxation is not certain after clinical examination and plain radiographic study, a dynamic CT study should be considered. It appears that the longer a C1-C2 rotary subluxation is present before attempted treatment, the less likely reduction can be accomplished. If reduction is accomplished in these older injuries it is less likely to be maintained. Therefore, rotary subluxations that do not reduce spontaneously should undergo attempted reduction with manipulation or traction. The subsequent period of immobilization should be proportional to the length of time that the subluxation was present before treatment.

Surgical arthrodesis can be considered for those with irreducible subluxations, recurrent subluxations, or subluxations present for greater than three weeks duration.

*Other injuries*. Lui et al, described nine children with ligamentous injuries resulting in atlantoaxial dislocation (33). Unlike children with traumatic injuries to the dens who can be managed with closed reduction and immobilization, these children with atlantoaxial dislocation required surgical stabilization and fusion. The authors attempted to treat two children with halo immobilization for three months duration; both failed to achieve stability. All nine children with atlanto-axial instability required operative stabilization and fusion.

Finally, Rathbone, et al, described a series of 12 children who sustained a "spinal cord concussion" while participating in athletic events. They found that four of these children had plain spine radiographs consistent with cervical spinal stenosis (46). The authors raised the concern that children with congenital cervical stenosis may be more susceptible to spinal cord injury in contact sports.

*Therapeutic Cervical Spine Immobilization*. Once an injury to the pediatric cervical spine has been diagnosed some form of external immobilization is usually necessary to allow for either application of traction to restore alignment, or to immobilize the spine to allow for healing of the injury. This section will discuss the literature available concerning methods of skeletal traction in children, and various external orthoses used to immobilize the pediatric cervical spine.

Traction for the purpose of restoring alignment or reducing neural compression in children is rarely addressed in the literature. Unique concerns of cervical traction in children exist because of the relatively thinner skull with a higher likelihood of inner skull table penetration, lighter body weight which provides less counter force to traction, more elastic ligaments and less well-developed musculature increasing the potential for over-distraction. The placement of bilateral pairs of parietal burr holes and passing 22 gauge wire through them to provide a point of fixation for traction has been described for infants with cervical spinal injuries. Gaufin and Goodman reported a series of three infants with cervical injuries, two of whom had injuries reduced in this fashion (19). Up to nine pounds was used in a ten week-old infant and a 16 month-old boy. They experienced no complications with 14 and 41 days of traction, respectively. Other techniques of cervical traction application in children are not described in the literature.

Mubarak, et al, described halo application in infants for the purpose of immobilization but not halo-ring traction (38). They described three infants ages seven months, 16 months, and 24 months. Ten pins were used in each child. The pins in the youngest child were “inserted to finger tightness only”, while the older children had two inch/pounds of torque applied. The children were maintained in the halo devices for two to three and a half months. Only the youngest child had a minor complication of frontal pin site infection necessitating removal of two anterior pins.

Marks, et al, described eight children ages three months to 12 years who were immobilized in halo vests for six weeks to 12 months with a mean duration of two months (36). Only three of these children had cervical spinal instability. Five had thoracic spinal disorders. The only complication they reported was the need to remove and replace the vest when a foreign body became lodged under the vest. Dormans, et al, reported on 37 children ages three to 12 years they managed in halo immobilization devices (11). They had a 68% complication rate. Pin-site infections were most common. They arbitrarily divided their patient population into those less than ten years of age and those ten years or older. Purulent pin site infections occurred more commonly in the older group. Loosening of pins occurred more commonly in the younger group. Both loosening and infection occurred more often at the anterior pin sites. They also reported one incident of dural penetration and one transient supraorbital nerve injury. Baum, et al, compared halo use complications in children and adults (1). The complication rates in their series were eight per cent for adults and 39 per cent among children. The complications reported for the children were one skull penetration and four pin site infections. While the halo device appears to provide adequate immobilization of the cervical spine in children, there is a higher rate of minor complications compared to halo use with adults.

Gaskill and Marlin described six children ages two years to four years who had cervical spinal instability managed with a thermoplastic Minerva orthosis as an alternative to a halo immobilization device (18). Two of the children they described had halo devices removed because of complications before being placed in Minerva orthoses. The authors described no problems with eating or with activities of daily living in these children. Only one child had a minor complication from Minerva use, a site of skin breakdown. The authors concluded that immobilization with a thermoplastic Minerva orthosis offered a reliable and satisfactory alternative to halo immobilization in young children.

Benzel, et al, analyzed cervical motion during spinal immobilization in adults serially treated with halo and Minerva devices (2). They found that the Minerva offered superior immobilization at all intersegmental levels of the cervical spine with the exception of C1-C2. While this study was carried out in adults with cervical spine instability, it underscores the utility of the Minerva device as a cervical immobilization device. Because a great proportion of pediatric cervical spine injuries occur between the occiput and C2, the Minerva device may not be ideal for many pediatric cervical spine injuries.

In summary the physical properties of young skin, skull thickness, and small body size likely contribute to the higher complication rate among children who require traction or long-term cervical spinal immobilization compared to adults. The literature includes descriptions of options available for reduction and immobilization of cervical spine injuries in children, but does not provide evidence for a single best method.

*Surgical Treatment*. There are no reports in the literature that address the topic of early versus late surgical decompression following acute pediatric cervical spinal cord injury. Pediatric spinal injuries account for only 5% of all vertebral column injuries. Recent reports that describe the management of pediatric spinal injuries have been offered by Turgut et al, Finch and Barnes, and Elaraky, et al (13,16,61). These authors managed pediatric spinal injuries operatively in 17%, 25%, and 30% of patients, respectively. The report by Elaraky, et al, in 2000 suggests that operative treatment of pediatric cervical spine injuries is being utilized more frequently than in the past. Specific details of the operative management including timing of intervention, the approach (anterior versus posterior), and the method of internal fixation as an adjunct to fusion are scarce in the literature. Finch and Barnes employed primary operative stabilization in most children they managed with ligamentous injuries of the cervical spine (16). They stated that while external immobilization may have resulted in ligamentous healing, they elected to internally fixate and fuse such injuries. They based their approach on two cases of ligamentous injuries of the cervical spine that they managed with external immobilization, which failed to heal, that later required operative fusion. Shaked, et al, described six children ages three years to 14 years who had cervical spine injuries that they treated surgically via an anterior approach (54). They reported successful fusion with good alignment and normal cervical spine growth in follow-up for all six children. The procedure varied (i.e. total or partial corpectomy versus discectomy only) depending on the pathology. All underwent autograft fusion without instrumentation. The authors described severe hyperflexion injury with fracture and avulsion of the vertebral body, fracture-dislocation with disruption of the posterior elements and disc, and major anatomic deformity of the cervical spine with cord compression as indications for an anterior approach.

Pennecot et al described 16 children with ligamentous injuries of the cervical spine (43). They managed minor ligamentous injuries (atlanto-dens interval of five to seven mm, or interspinous widening without dislocation or neurological deficit) with reduction and immobilization. Of eleven children with injuries below C2, eight required operative treatment with fusion via a posterior approach. They used interspinous wiring techniques in younger children (preschool aged) and posterior plates and screws in older children as adjuncts to fusion. All had successful fusion at last follow-up. All children were immobilized in a plaster or halo cast postoperatively. Similarly, Koop, et al, described 13 children with acute cervical spine injuries who required posterior arthrodesis and halo immobilization (30). They reported successful fusion in 12 patients. The single failure was associated with allograft fusion substrate. All other children had autologous grafts. Internal fixation with wire was employed in only two children. Halo immobilization was utilized for an average of 150 days. They reduced the length of post-operative halo immobilization to 100 days in their most recent cases. They commented that careful technique allowed successful posterior fusion in children with minimal complications. Schwarz, et al, described ten children with traumatic cervical kyphosis (52). Two children who underwent anterior reconstruction with fusion had successful deformity reduction. All others managed with either external immobilization with or without traction (n=7) or posterior fusion (n=1) had either progression of the post-traumatic deformity or a stable unreduced kyphotic angulation.

In summary, pediatric spinal injuries are relatively infrequent. The vast majority are managed non-operatively. Selection criteria for operative intervention in children with cervical spine injuries are difficult to glean from the literature. Anatomic reduction of deformity, stabilization of unstable injuries and decompression of the spinal cord, and isolated ligamentous injuries associated with deformity are indications for surgical treatment cited by various authors (16,30,33,43,52,54,64). These multiple reports provide Class III evidence.

## SUMMARY

The available medical evidence does not allow the generation of diagnostic or treatment standards for the management of pediatric patients with cervical spine or cervical spinal cord injuries. Only diagnostic guidelines and options, and treatment options are supported by this evidence. The literature suggests that obtaining neutral cervical spine alignment in a child may be difficult when standard backboards are used. The determination that a child does not have a cervical spine injury can be made on clinical grounds alone is supported by Class II and Class III evidence. When the child is alert and communicative and is without neurological deficit, neck tenderness, painful distracting injury, or intoxication, cervical radiographs are not necessary to exclude cervical spinal injury. When cervical spine radiographs are utilized to verify or rule out a cervical spinal injury in children less than nine years of age, only lateral and A-P cervical spine views need be obtained. The traditional three-view x-ray assessment may increase the sensitivity of plain spine radiographs in children nine years of age and older. The vast majority of pediatric cervical spine injuries can be effectively treated non-operatively. The most effective immobilization appears to be accomplished with either halo devices and Minerva jackets. Halo immobilization is associated with acceptable but considerable minor morbidity in children, typically pin site infection and pin loosening. The only specific pediatric cervical spine injury for which medical evidence supports a particular treatment paradigm is an odontoid injury in children less than seven years of age. These children are effectively treated with closed reduction and immobilization. Primarily ligamentous injuries of the cervical spine in children may heal with external immobilization alone, but are associated with a relatively high rate of progressive deformity when treated non-operatively. Pharmacological therapy and intensive care unit management schemes for children with spinal cord injury have not been described in the literature.

**KEY ISSUES FOR FUTURE INVESTIGATION**

Prospective epidemiological data may be the best source of information that could lead to methods of prevention by identifying the more common mechanisms of spinal injury in children. Future studies involving pediatric cervical spine injury patients should be multi-institutional because of the infrequency of these injuries treated at any single institution. Further defining the indications and methods for cervical spine clearance in young children (less than nine years of age) with prospective gathering of data would be a valuable addition to the literature. The role of flexion and extension radiographs is poorly defined in the literature and a prospective evaluation of their sensitivity and specificity for spinal column injury in specific clinical scenarios would be a valuable addition to the literature. The incidence and clinical significance of complications of cervical spine injuries in children such as syringomyelia and vertebral artery injury are unknown and could be studied by prospectively gathering data in a multi-institutional setting.

More common injuries, such as odontoid injuries could be studied prospectively in a randomized fashion (e.g. closed reduction and immobilization vs. anterior screw fixation), although it would be difficult from technical and feasibility standpoints. Prospectively collected data could also provide the basis for case-control or other comparative studies to generate Class II evidence.

## Evidentiary Tables – Diagnostic

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Viccellio, et al, Pediatrics, 2001 | Prospective multicenter evaluation of cervical spine radiographs obtained in 3065 children incurring trauma. Low-risk criteria of absence of: neck tenderness, painful distracting injury, altered alertness, neurological deficit, or intoxication | II | No child fulfilling all five low-risk criteria had a cervical spine injury. Radiographs may not be necessary to clear the cervical spine in children fulfilling all five criteria. |
| Ralston et al, Academ Emer Med, 2001. | Blinded review of 129 children with blunt cervical trauma who had flexion and extension radiographs. | III | Flexion and extension views with normal cervical spine radiographs or with only loss of cervical lordosis did not unmask any new abnormalities. |
| Buhs C et al, J Ped Surg, 2000. | Multi-institutional review of pediatric cervical spine injuries and the radiographs needed to achieve a diagnosis. | III | Lateral cervical radiograph was diagnostic in 13 of 15 children less than 9-years. In no child less than nine years-old was the open mouth view the diagnostic study. Only one of 36 children older than 9-years was the open-mouth view the diagnostic study. |
| Swischuk LE et al, Pediatr Radiol, 2000. | Survey of pediatric radiologists regarding use of open mouth view of the odontoid. | III | Less than 50% response. Approximately 40% of respondents did not employ open mouth views in children. |
| Scarrow AM et al, Pediatr Neurosurg, 1999. | Performed flexion extension cervical fluoroscopy with SSEP monitoring in 15 comatose pediatric patients. | III | None had radiographic abnormalities. three children had changes in the SSEP's. One of these three children was studied with MR and it was normal. |
| Shaw et al, Clin Radiol, 1999 | Retrospective review of the cervical radiographs 138 trauma patients under 16 years-old | III | 22% incidence of pseudosubluxation of C2 on C3. Median age of pseudosubluxation group was 6.5 years versus nine years for those without pseudosubluxation. |
| Berne JD et al, J Trauma, 1999. | 58 patients with severe blunt trauma underwent helical CT of entire cervical spine. | III | 20 had cervical spine injuries. Plain radiographs missed eight injuries. CT missed two injuries. |
| Keiper et al, Neurorad, 1998. | Retrospective review of evaluating 52 children by MR with suspected cervical spine trauma or instability without fracture | III | There were 16 abnormal studies. The most common abnormality was posterior ligamentous injury. Four children underwent surgical stabilization. The MR findings caused the surgeon to extend his length of stabilization in all four cases. |
| Davis PC et al, AJNR, 1993 | Retrospective review of 15 children with spinal cord injury underwent MR 12 hours to two months after injury. seven with SCIWORA | III | MR correlated with prognosis. Hemorrhagic cord contusions and cord "infarction" were associated with permanent deficits. No compressive lesions in SCIWORA cases. Normal MR was associated with no myelopathy |
| Schleehauf K et al, Ann Emerg Med, 1989. | 104 "high-risk" patients underwent CT as screening tool for cervical spine injury. | III | Sensitivity overall was 0.78. Sensitivity was 1.0 for unstable injuries not able to be seen by plain radiographs. Two upper cervical subluxations without fracture were missed. |

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Kowalski et al, AJR, 1987. | Eight patients with occipitalatlantoaxial problems and six normal subjects were studied with CT. | III | CT looked similar for those with C1-2 rotary subluxation to normal subjects with their heads maximally turned. CT with the head turned to the contralateral side differentiated rotary subluxation from normals and spasmodic torticollis. |
| Cattell & Filtzer, J Bone Joint Surg, 1965. | Lateral upright cervical radiographs in neutral, flexion, and extension in 160 randomly selected children ages one to 16 years. | III | C2-3 subluxation was moderate to marked in 24% predominantly in children less than eight years of age. The atlanto-dens interval was three millimeters or more during flexion in 20% of children less than eight years of age. |

## EVIDENTIARY TABLES – Treatment

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Eleraky MA et al, J Neurosurg (Spine) 2000 | Retrospective review of 102 children with cervical spinal injuries. | III | 30 children (30%) were treated surgically. |
| Odent T et al, J Ped Ortho, 1999 | Review of 15 young children with odontoid injuries | III | 6 with neurological deficits had cervicothoracic cord injuries. External immobilization was a successful primary therapy. Three children who were operated upon as their primary therapy experienced complications. |
| Schwarz, Arch Orthop Trauma Surg, 1998 | A review of four children presenting at least three months after the onset of C1-2 rotary subluxation. | III | Two children had irreducible subluxations. One child had recurrent subluxation in a Minerva cast. One child was successfully treated with closed reduction and eight weeks in a Minerva cast. |
| Subach et al, Spine, 1998 | A review of 20 children with C1-2 rotary subluxation. | III | Four reduced spontaneously. 15 of 16 treated with traction reduced in a mean of four days. Six children required fusion because of recurrent subluxation or irreducible subluxation. No child experienced recurrent subluxation if reduced within 21 days of symptom onset. |
| Finch GD, Barnes MJ, J Ped Ortho, 1998 | Retrospective review of 32 children with major cervical spine injuries. | III | Eight children (25%) were treated surgically. All achieved union or radiological stability. No neurological deterioration from surgery or closed reduction. Operated on ligamentous injuries. |
| Reinges MHT et al, Child Nerv Sys, 1998 | Report of primary C1-2 fusion in a young child with an odontoid injury and lower cervical cord injury | III | No neurological improvement. Successful fusion. |
| Treloar and Nypaver, Ped Emer Care, 1997. | They measured cervical spine flexion in children with semi-rigid collars on spinal boards. | III | Semi-rigid collars did not prevent the cervical spine from being forced into flexion in children less than eight-years old when on a spinal board. |
| Lui TN et al, J Trauma, 1996 | Retrospective review of C1-2 injuries in 22 children. 12 children had odontoid injuries (OI). nine children had ligamentous injuries (atlanto-axial dislocations) only. | III | Flexion/extension radiographs needed to diagnose four OI and six atlanto-axial dislocations (AAD). 9/12 OI reduced easily. 5/7 OI treated successfully with halo. two OI operated immediately. two OI failed external immobilization. five AAD initially treated with surgical fusion. two AAD initially treated with halo required surgical stabilization. |
| Givens TG et al, J Trauma, 1996 | Review of 34 children with cervical spine injuries over a three-year-period | III | 18 injuries occurred below C3. The level of injury did not correlate with age.Young age is not associated with exclusively upper cervical spine injuries. |
| Turgut M et al, Eur Spine J, 1996 | Retrospective review of 82 children with spinal cord or column injuries | III | 14 children (17%) were treated surgically. |

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Dormans JP et al, J Bone Joint Surg, 1995 | A review of 37 children with halo rings and vests ages three to 16 years. Arbitrarily divided into those less than ten years-old, and older. | III | Overall 68% complication rate. Pin-site infection was the most common complication. Purulent infections occurred more frequently in the older group. Both loosening and infection occurred more frequently in the anterior pin sites. |
| Menticoglou SM et al, Obstet Gyn, 1995. | Retrospective case series of 15 neonates with birth-related high cervical cord injuries. | III | All 15 were cephalic presentations in which forceps and attempted rotation were employed. All but one were apneic at birth. |
| Curran et al, J Trauma, 1995 | Prospective study of 118 children who arrived immobilized to a single emergency room. The cervical spine alignment was measured and compared to age and type of immobilization. | III | No correlation with degree of kyphosis or lordosis was found with age. 30% had a kyphosis of greater than ten degrees. No single immobilization technique was superior. |
| Schwarz et al, Injury, 1994. | Review of ten children with vertebral fractures and kyphotic angulation. | III | The kyphotic angulation remained unchanged or worsened when external immobilization alone (n=7) or dorsal fusion (n=1) was employed. Only those undergoing a ventral fusion (n=2) had a stable reduction of the kyphotic deformity. |
| Nypaver M, Treloar D, Ann Emer Med, 1994 | 40 children were placed on spine boards and observers judged whether the cervical spine was in the "neutral" position. | III | Children less than eight years of age required torso elevation to achieve neutral alignment<br>Children four years of age or younger required the greatest amount of elevation. |
| Laham JL et al, Pediatr Neurosurg, 1994. | Divided head-injured children into high (less than two years of age, non-communicative, or with neck pain) and low risk groups for cervical spine injury. | III | No cervical spine injuries detected in the low-risk group. Ten injuries (7.5%) were detected in the high-risk group. |
| Fotter R et al, Ped Radiol, 1994. | Report of birth-related spinal cord injuries imaged with ultrasound and MRI | III | A neonate with complete injury had normal plain radiographs with spinal ultrasound showing inhomogeneous echogenecity and disrupted cord surface. A neonate with an incomplete injury had intact cord surface with increased cord echogenicity. MRI corroborated these findings. |
| Marks DS et al, Arch Orthop Trauma Surg, 1993 | Review of eight children, ages three months to 12 years, immobilized in a halo jacket for six weeks to 12 months (mean two months). | III | The only complication was a jacket change was required for a foreign body (coin). Only three of these children had cervical instability. |
| Shacked I et al, Clin Orthop, 1993 | Retrospective review of six children (3 to 14 years-old) with cervical spine injuries treated via an anterior approach. | III | Autograft without instrumentation following corpectomy was used. They were stabilized postoperatively with hard collar or Minerva cast. All with solid fusions, good alignment, and normal cervical growth. Follow-up three to eight years. |

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Grogaard et al, Arch Orthop Trauma Surg, 1993. | Atlanto-axial rotary subluxation described in nine children. Eight diagnosed within five days, one diagnosed after eight weeks. | III | Eight children were treated successfully with "mild" traction and then a collar for four to six weeks. The one child presenting late required one week of traction for reduction. There were two redislocations. All eventually healed in algnment without surgery. |
| Mandabach M et al, Pediatr Neurosurg, 1993 | Thirteen children with axis injuries were reviewed. Ten were treated primarily with closed reduction and halo immobilization | III | Eight of the ten treated primarily with closed reduction and halo immobilization fused. Two required surgical stabilization and fusion. |
| MacKinnon JA et al, J Pediatr, 1993. | Retrospective case series of 22 neonates with birth-related spinal cord injuries. They excluded neonates with SCIWORA. | III | All 14 with high cervical injuries had cephalic presentations with attempted forceps rotation. All six with cervicothoracic injuries had breech presentations. Both neonates with thoracolumbar injuries were premature. |
| Rossitch E & Oakes WJ, Pediatr Neurosurg 1992 | Retrospective review of five neonates with perinatal spinal cord injury. No flexion/extension views reported. | III | 4 of the five had no abnormality on static spinal radiographs. Respiratory insufficiency and hypotonia were common signs. Myelograms were unrevealing. All three with high cervical injuries died by age three years. |
| Osenbach RK & Menezes AH, Neurosurgery 1992 | Retrospective review of 179 children with spinal injuries | III | 59 (33%) underwent surgical treatment for irreducible unstable injuries. 83% of those treated surgically were nine years of age or older. No child with complete or severe partial myelopathy regained useful function. |
| Rathbone D et al, J Ped Orthop, 1992 | Retrospective review of 12 children with presumed spinal cord concussion during athletics were investigated for the presence of cervical stenosis. | III | 3 had a Torg ratio < 0.8 and four had a canal AP diameter <13.4 mm. MRI was not used to evaluate for stenosis. |
| Hamilton MG & Myles ST, J Neurosurg, 1992 | Retrospective review of all pediatric spinal injuries over 14 year period. 73 children had cervical injuries. | III | Surgery was performed in 26% of children. 13% of children with fracture and no subluxation, 50% with subluxation alone, and 57% with fracture and subluxation were treated surgically. Of 39 children with complete myelopathy, four improved one or two Frankel grades. |
| Schafermeyer RW et al, Ann Emer Med, 1991. | Forced vital capacity (FVC) was studied in healthy children when upright, supine, and supine taped to a spinal board. | III | Taping the child to the spinal board caused FVC to drop to 41% to 96% (mean 80%) of supine FVC. |
| Bohn D et al, J Trauma, 1990. | 16 of 19 children presenting with absent vital signs or severe hypotension unexplained by blood loss underwent postmortem examination | III | 13 of 16 had cord laceration or transection. Two of these children had a normal cervical radiograph. |

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Gaskill S & Marlin A, Pediatr Neurosurg, 1990 | Six children ages two to four years were placed in Minerva jackets for cervical spine instability. | III | One child had skin breakdown of the chin. Eating and other daily activities were not impaired. Two were placed in Minerva jackets after complications of halo ring and vest immobilization. |
| Phillips et al, J Bone Joint Surg, 1989 | A review of 23 children with C1-2 rotary subluxation. | III | 16 children seen within one month of onset had either spontaneous reduction or reduced with traction. Of the seven children presenting with greater than one month of symptoms, one subluxation was irreducible, and four had recurrent subluxations. |
| Kawabe et al, J Pediatr Orthop, 1989. | Review of the radiology of 17 children with C1-2 rotary subluxation | III | Classified according to Fielding & Hawkins as ten type I, five type II, two type III, and no type IV. |
| Benzel et al, J Neurosurg, 1989. | A comparison of cervical motion of injured patients (only one child) immobilized in halo and Minerva jackets. | III | The Minerva jacket allowed less motion than the halo jacket at every level except C1-2. |
| Baum, et al, Spine, 1989. | A review comparing the halo complications 13 children and 80 adults. | III | 39% complication rate in children versus 8% in adults. The children had four pin-site infections and one inner table skull pin penetration. |
| Mubarak SJ et al, J Ped Ortho, 1989 | Review of three children less than two years-old who were placed in halo rings for two to three ½months. | III | Ten pins tightened "finger-tight" in a seven month-old, and two in/lb in a 16 and 24 month-old. Two of three developed minor pin site infections necessitating pin removal. |
| Herzenberg JE et al, J Bone Joint Surg, 1989 | Reported ten children less than seven years of age with cervical spine injuries positioned on a flat backboard. | III | The injuries were anteriorly angulated or translated when on a flat backboard because the head was in forced into flexion. Elevating the torso allowed for more neutral alignment and reduction of the injured segment. |
| Evans & Bethem, J Ped Ortho, 1989 | Review of 24 consecutive cervical spine injuries in children 18 years-old or less. | III | Half of the children had injuries at C3 or above. One child was treated with laminectomy and two with fusion. Fractures healed in 21 of 22 with nonoperative therapy. |
| Birney TJ and Hanley EN, Spine, 1988 | Retrospective review of 61 children with cervical spine injuries. 23 of these injuries were C1-2 rotary subluxation. | III | Rotary subluxation unassociated with neurological deficit. The deformity resolved with halter traction (n=10) or cervical bracing . One child had a recurrence.<br>A child with transverse ligament disruption was treated successfully with a soft collar only. |
| Hadley MN et al, J Neurosurg, 1988 | Retrospective review of 122 children with spinal injuries. There were 97 cervical injuries. | III | Only 12 cervical injuries were treated surgically. |
| Huerta C et al, Ann Emer Med, 1987. | They evaluated the immobilization of commercially available infant and pediatric cervical collars. | III | No collar used alone provided acceptable immobilization. The use of a modified half-spine board, rigid collar, and tape provided the best immobilization. |

| Authors & Year | Description of Study | Class of Data | Conclusions |
|---|---|---|---|
| Pennecot GF et al, J Ped Ortho, 1984. | Review of 16 children with ligamentous injuries of the cervical spine. Five with C1-2 injuries. | III | Of the 11 children with injuries below C2, eight underwent surgical stabilization. They recommended a three-month trial of external immobilization in children with ligamentous injuries but no neurological deficit or dislocation. |
| El-Khoury et al, J Bone Joint Surg, 1984 | A review of three children with C1-2 rotary subluxation. | III | All three were treated successfully with traction or manual reduction within 24 hours of presentation. One child had recurrent subluxation the next day and was treated successfully with manual reduction. External orthoses were used for ten weeks, three, and four months, respectively. |
| Koop SE et al, J Bone Joint Surg, 1984 | Retrospective review of 13 children with cervical instability treated with posterior arthrodesis and halo immobilization. Only three had traumatic lesions. | III | One failed fusion when bank-bone was used. Others successfully fused with autogenous iliac crest or rib. Internal wiring used in two children. Average halo immobilization was 150 days. |
| Sherk HH et al, J Bone Joint Surg (Am),1978. | Report of 11 children with odontoid injuries, and review of 24 from the literature. | III | Majority of injured odontoids are angled anteriorly. All but one child was treated successfully with external immobilization. |
| Fielding & Hawkins, J Bone Joint Surg, 1977. | The radiographic findings of seventeen patients with atlanto-axial rotary fixation are described and classified into four types. | III | Four classes of C1-2 rotary subluxation were described, types I-IV. Type I: odontoid acts as pivot with competent transverse ligament;type II: one lateral articular process acts as pivot with up to five mm of anterior displacement; type III: both C1 inferior facets are subluxed anteriorly with greater than five mm of anterior displacement which suggests an incompetemt transverse ligament; type IV: posterior displacement with absent or incompetent odontoid. |
| Gaufin & Goodman, J Neurosurg, 1975. | A review of three children less than 20 months-old with cervical spine injuries. Two of these children were treated with traction delivered via 22 gauge wire placed through bilateral parietal burr holes. | III | Successful traction applied to the ten week-old and 16 month old child. Up to nine pounds was used in the 10-week-old infant. No complications were encountered with the traction in place for 14 and 41 days, respectively. |

## REFERENCES


1. Baum JA, Hanley EN, Pullekines J: Comparison of halo complications in adults and children. Spine 14:251-252, 1989.
2. Benzel EC, Hadden TA, Saulsbery CM: A comparison of the Minerva and halo jackets for stabilization of the cervical spine. J Neurosurg 70:411-414, 1989.
3. Berne JD, Velmahos GC, El-Tawil Q, Demetriades D, Asensio JA, Murray JA, Cornwell EE, Belzberg H, Berne TV: Value of complete cervical helical computed tomographic scanning in identifying cervical spine injury in the unevaluable blunt trauma patient with multiple injuries: a prospective study .J Trauma 47:896-902, 1999.
4. Bohn D, Armstrong D, Becker L, Humphreys R: Cervical spine injuries in children. J Trauma 30:463-466, 1990.
5. Bracken MB, Shepard MJ, Collins WF, Holford TR, et al: A randomized trial of methylprednisolone or naloxone in the treatment of acute spinal cord injury: Results of the second National Acute Spinal Cord Injury Study (NASCIS II). N Engl J Med 322:1405-1411,1990.
6. Buhs C, Cullen M, Klein M, Farmer D: The pediatric trauma C-spine: is the 'odontoid' view necessary? J Ped Surg 35:994-997, 2000.
7. Cattell HS**.** Filtzer DL. Pseudosubluxation and other normal variations in the cervical spine in children. A study of one hundred and sixty children. J Bone Joint Surg 47-A:1295-309, 1965.
8. Curran C, Dietrich AM, Bowman MJ, Ginn-Pease ME, King DR, Kosnick E: Pediatric cervical-spine immobilization: Achieving neutral position?. J Trauma 39:729-732, 1995.

9. Davis PC, Reisner A, Hudgins PA, Davis WE, O'Brien MS: Spinal injuries in children: Role of MR. AJNR 14:607-617-1993.

10. Dickman CA, Rekate HL, Sonntag VKH, Zabramski JM: Pediatric spinal trauma: Vertebral column and spinal cord injuries in children. Pediatr Neurosci 15:237-256, 1989.

11. Dormans JP, Criscitiello AA, Drummond DS, Davidson RS: Complications in children managed with immobilization in a halo vest. J Bone Joint Surg 77-A:1370-1373, 1995.

12. El-Khoury GY, Clark CR, Gravett AW: Acute traumatic rotatory atlanto-axial dislocation in children. J Bone Joint Surg 66-A:774-777, 1984.

13. Eleraky MA, Theodore N, Adams M, Rekate HL, Sonntag VKH: Pediatric cervical spine injuries: report of 102 cases and review of the literature. J Neurosurg (Spine) 92:12-17, 2000.

14. Evans DL, Bethem D: Cervical spine injuries in children. J Ped Orthop 9:563-568, 1989.

15. Fielding JW, Hawkins RJ: Atlanto-axial rotary fixation. J Bone Joint Surg 59A:37-44, 1977.

16. Finch GD. Barnes MJ. Major cervical spine injuries in children and adolescents. J Ped Ortho 18:811-4, 1998.

17. Fotter R. Sorantin E. Schneider U. Ranner G. Fast C. Schober P. Ultrasound diagnosis of birth-related spinal cord trauma: neonatal diagnosis and follow-up and correlation with MRI. Pediatr Radiol 24:241-4, 1994.

18. Gaskill SJ, Marlin AE: Custom fitted thermoplastic Minerva jackets in the treatment of cervical spine instability in preschool age children. Pediatr Neurosurg 16:35-39, 1990-1991.

19. Gaufin LM, Goodman SJ: Cervical spine injuries in infants. J Neurosurg 42:179-185, 1975.

20. Givens TG. Polley KA. Smith GF. Hardin WD Jr. Pediatric cervical spine injury: a three-year experience. J Trauma 41:310-4, 1996.

21. Godard J, Hadji M, Raul JS: Odontoid fractures in the child with neurological injury. Child Nerv Sys 13:105-107, 1997.

22. Griffiths SC: Fracture of the odontoid process in children. J Pediatr Surg 7:680-683, 1972.

23. Grogaard B. Dullerud R. Magnaes B. Acute torticollis in children due to atlanto-axial rotary fixation. Arch Ortho Trauma Surg 112:185-8, 1993.

24. Hadley MN, Zabramski JM, Browner CM, Rekate H, Sonntag VKH: Pediatric spinal trauma. J Neurosurg 68:18-24,1988.

25. Hamilton MG, Myles ST: Pediatric spinal injury: review of 174 hospital admissions. J Neurosurg 77:700-704, 1992.

26. Herzenberg JE, Hensinger RN, Dedrick DK, et al: Emergency transport and positioning of young children who have an injury of the cervical spine: The standard backboard may be dangerous. J Bone Joint Surg 71-A:1, 1989.

27. Huerta CR, Griffith R, Joyce SM: Cervical spine stabilization in pediatric patients: evaluation of current techniques. Ann Emer Med: 16: 1121-6, 1987.

28. Kawabe N, Hirotani H, Tanaka O: Pathomechanism of atlantoaxial rotary fixation in children. J Ped Ortho 9:569-574, 1989.

29. Keiper MD, Zimmerman RA, Bilaniuk LT: MRI in the assessment of the supportive soft tissues of the cervical spine in acute trauma in children. Neuroradiology. 40:359-63, 1998.

30. Koop SE, Winter RB, Lonstein JE: The surgical treatment of instability of the upper part of the cervical spine in children and adolescents. J Bone Joint Surg 66A:403-411, 1984.

31. Kowalski HM, Cohen WA, Cooper P, Wisoff JH: Pitfalls in the CT diagnosis of atlantoaxial rotary subluxation. AJR 149:595-600, 1987.

32. Laham JL, Cotcamp DH, Gibbons PA, Kahana MD, Crone KR: Isolated head injuries versus multiple trauma in pediatric patients:Do the same indications for cervical spine evaluation apply? Pediatr Neurosurg 21:221-226, 1994.

33. Lui TN, Lee ST, Wong CW, Yeh YS, Tzaan WC, Chen TY, Hung SY: C1-C2 fracture-dislocations in children and adolescents. J Trauma 40:408-11, 1996.

34. MacKinnon JA. Perlman M. Kirpalani H. Rehan V. Sauve R. Kovacs L. Spinal cord injury at birth: diagnostic and prognostic data in twenty-two patients. J Pediatr 122:431-7, 1993.

35. Mandabach M, Ruge JR, Hahn YS, McLone DG: Pediatric axis fractures: Early halo immobilization, management and outcome. Pediatr Neurosurg 19:225-232, 1993.

36. Marks DS, Roberts P, Wilton PJ, Burns LA, Thompson AG: A halo jacket for stabilization of the paediatric cervical spine. Arch Orthop Trauma Surg 112:134-135, 1993.

37. Menticoglou SM. Perlman M. Manning FA. High cervical spinal cord injury in neonates delivered with forceps: report of 15 cases. Obstet Gyn 86:589-94, 1995.

38. Mubarak SJ. Camp JF. Vuletich W. Wenger DR. Garfin SR. Halo application in the infant. J Ped Ortho. 9:612-4, 1989.

39. Nypaver M, Treloar D: Neutral cervical spine positioning in children. Ann Emer Med 23:208-211, 1994.

40. Odent T, Langlais J, Glorion C, Kassis B, Bataille J, Pouliquen JC: Fractures of the odontoid process: a report of 15 cases in children younger than six years. J Ped Ortho 19:51-54, 1999.

41. Osenbach RK, Menezes AH: Pediatric spinal cord and vertebral column injury. Neurosurgery 30:385-390, 1992.

42. Pang D, Hanley EN: Special problems of spinal stabilization in children. In Cooper PR (ed): in *Management of Posttraumatic spinal instability*. Park Ridge, IL: American Association of Neurological Surgeons, 1990, pp 181-206.

43. Pennecot GF, Leonard P, Peyrot Des Gachons S, Hardy JR, Pouliquen JC: Traumatic ligamentous instability of the cervical spine in children. J Ped Ortho 4:339-345, 1984.

44. Phillips WA, Hensinger RN: The management of rotatory atlanto-axial subluxation in children. J Bone Joint Surg 71-A:664-668, 1989.

45. Ralston ME. Chung K. Barnes PD. Emans JB. Schutzman SA. Role of flexion-extension radiographs in blunt pediatric cervical spine injury. Acad Emerg Med 8:237-45, 2001.

46. Rathbone D, Johnson G, Letts M: Spinal cord concussion in pediatric athletes. J Ped Ortho 12:616-620, 1992.

47. Reinges MHT, Mayfrank L, Rohde V, Spetzger U, Gilsbach JM: Surgically treated traumatic synchondrotic disruption of the odontoid process in a 15-month-old girl. Childs Nervous System. 14(1-2):85-7, 1998

48. Rossitch E, Oakes WJ: Perinatal spinal cord injury. Pediatr Neurosurg 18: 149-152, 1992.

49. Ruge JR, Sinson GP, McLone DG, Cerullo LJ: Pediatric spinal injury: the very young. J Neurosurg 68:25-30, 1988.

50. Scarrow AM, Levy EI, Resnick DK, Adelson PD, Sclabassi RJ: Cervical spine evaluation in obtunded or comatose pediatric trauma patients: A pilot study. Pediatr Neurosurg 30:169-175, 1999.

51. Schleehauf K, Ross SE, Civil ID, Schwab CW: Computed tomography in the initial evaluation of the cervical spine. Ann Emerg Med 18:815-7, 1989.

52. Schwarz N, Genelin F, Schwarz AF: Post-traumatic cervical kyphosis in children cannot be prevented by non-operative methods. Injury 25:173-175, 1994.

53. Schwarz N: The fate of missed atlanto-axial rotatory subluxation in children. Arch Orthop Trauma Surg 117:288-289, 1998.

54. Shacked I, Ram Z, Hadani M: The anterior cervical approach for traumatic injuries to the cervical spine in children. Clin Ortho Rel Res 292:144-150, 1993.

55. Shafermeyer RW, Ribbeck BM, Gaskins J, Thomason S, Harlan M, Attkisson A: Respiratory effects of spinal immobilization in children. Ann Emer Med 20: 1017-1019, 1991.

56. Shaw M, Burnett H, Wilson A, Chan O: Pseudosubluxation of C2 on C3 in poly-traumatized children-prevalence and significance. Clin Radiol 54:377-380, 1999

57. Sherk HH, Nicholson JT, Chung SMK: Fractures of the odontoid process in young children. J Bone Joint Surg (Am) 60:921-924, 1978.

58. Subach BR, McLaughlin MR, Albright AL, Pollack IF: Current management of pediatric atlantoaxial rotatory subluxation. Spine 23:2174-2179, 1998.

59. Swischuk LE, John SD, Hendrick EP: Is the open-mouth odontoid view necessary in children under five years? Pediatr Radiol 30:186-189, 2000.

60. Treloar DJ, Nypaver M: Angulation of the pediatric cervical spine with and without cervical collar. Pediatric Emergency Care. 13(1):5-8, 1997

61. Turgut M, Akpmar G, Akalan N, Ozcan OE: Spinal injuries in the pediatric age group. Eur Spine J 5:148-152, 1996.

62. Viccellio P, Simon H, Pressman BD, Shah MN, Mower WR, Hoffman JR: A prospective multicenter study of cervical spine injury in children. Pediatrics 108:1-6, 2001.

63. Vogel LC: Unique management needs of pediatric spinal cord injury patients: Etiology and Pathophysiology. J Spinal Cord Med 20:10-13,1997.

64. Wang J. Vokshoor A. Kim S. Elton S. Kosnik E. Bartkowski H. Pediatric atlantoaxial instability: management with screw fixation. Pediatr Neurosurg. 30:707-8, 1999.