

Management of Pediatric Cervical Spine and Spinal Cord Injuries

Curtis J. Rozzelle, MD*
Bizhan Aarabi, MD, FRCSC‡
Sanjay S. Dhall, MD§
Daniel E. Gelb, MD¶
R. John Hurlbert, MD, PhD, FRCSC||
Timothy C. Ryken, MD, MS#
Nicholas Theodore, MD**
Beverly C. Walters, MD, MSc, FRCSC‡‡§§
Mark N. Hadley, MD‡‡

*Division of Neurological Surgery, Children's Hospital of Alabama University of Alabama at Birmingham, Birmingham Alabama; ‡Department of Neurosurgery, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; **Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
 UAB Division of Neurological Surgery,
 510 – 20th St S, FOT 1030,
 Birmingham, AL 35294-3410.
 E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS:

Diagnostic:

Level I:

- Computed tomographic (CT) imaging to determine the condyle-C1 interval (CCI) for pediatric patients with potential atlanto-occipital dislocation (AOD) is recommended.

Level II:

- Cervical spine imaging is not recommended in children who are > 3 years of age and who have experienced trauma and who:
 - are alert,
 - have no neurological deficit,
 - have no midline cervical tenderness,
 - have no painful distracting injury,
 - do not have unexplained hypotension,
 - and are not intoxicated.
- Cervical spine imaging is not recommended in children who are < 3 years of age who have experienced trauma and who:
 - have a Glasgow Coma Scale (GCS) > 13,
 - have no neurological deficit,
 - have no midline cervical tenderness,

- have no painful distracting injury,
- are not intoxicated,
- do not have unexplained hypotension,
- and do not have motor vehicle collision (MVC), a fall from a height > 10 feet, or non-accidental trauma (NAT) as a known or suspected mechanism of injury.
- Cervical spine radiographs or high resolution CT is recommended for children who have experienced trauma and who do not meet either set of criteria above.
- Three-position CT with C1-C2 motion analysis to confirm and classify the diagnosis is recommended for children suspected of having atlantoaxial rotatory fixation (AARF).

Level III:

- Anteroposterior (AP) and lateral cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children < 9 years of age.
- AP, lateral, and open-mouth cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children 9 years of age and older.
- High resolution CT scan with attention to the suspected level of neurological injury is recommended to exclude occult fractures or to evaluate regions not adequately visualized on plain radiographs.
- Flexion and extension cervical radiographs or fluoroscopy are recommended to exclude gross ligamentous instability when there remains a suspicion of cervical spinal instability following static radiographs or CT scan.
- Magnetic resonance imaging (MRI) of the cervical spine is recommended to exclude spinal cord or nerve root compression, evaluate

ABBREVIATIONS: AP, anteroposterior; AARF, atlantoaxial rotatory fixation; AOD, atlanto-occipital dislocation; CCI, condyle-C1 interval; CCR, Canadian C-spine Rule; DGZ, diagnostic grey zone; FVC, forced vital capacity; GCS, Glasgow Coma Scale; MVC, motor vehicle collision; NAT, non-accidental trauma; NEXUS, National Emergency X-Radiography Utilization Study; SCIWORA, spinal cord injury without radiographic abnormality; TAS, transarticular screw TAS

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ligamentous integrity, or provide information regarding neurological prognosis.

Treatment

Level III:

- Thoracic elevation or an occipital recess is recommended in children < 8 years of age to prevent flexion of the head and neck when restrained supine on an otherwise flat backboard for better neutral alignment and immobilization of the cervical spine.
- Closed reduction and halo immobilization are recommended for injuries of the C2 synchondrosis in children < 7 years of age.
- Reduction with manipulation or halter traction is recommended for patients with acute AARF (< 4 weeks duration) that does not reduce spontaneously. Reduction with halter or tong/halo traction is recommended for patients with chronic AARF (> 4 weeks duration).
- Internal fixation and fusion are recommended in patients with recurrent and/or irreducible AARF.
- Consideration of primary operative therapy is recommended for isolated ligamentous injuries of the cervical spine and unstable or irreducible fractures or dislocations with associated deformity.
- Operative therapy is recommended for cervical spine injuries that fail non-operative management.

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

Incorporating and expanding upon the first iteration of these guidelines,¹ a National Library of Medicine (PubMed)

computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injuries” and “child” and yielded 1125 citations. These citations were reviewed in combination with “cervical vertebra,” “spinal injuries,” and “child” which yielded 197 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 80 articles meeting selection criteria, 1 provided Class I medical evidence for diagnostic imaging in AOD. In addition, there were 10 Class II medical evidence studies addressing diagnostic imaging in children. There was only 1 Class II medical evidence study concerning treatment. All remaining articles were case series representing Class III medical evidence. Summaries of these 80 articles are provided in Evidentiary Table format (Tables 1-2).

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 < 8 years of age, allowances must be made for the relatively large head compared to the torso, which forces the neck into a position of flexion when the head and torso are supine on a flat surface.² Nypaver and Treloar² prospectively evaluated 40 children < 8 years of age seen in an emergency room for reasons other than head and neck trauma and assessed them with respect to neutral positioning upon a backboard. They found that all 40 children required elevation of the torso to eliminate positional neck flexion and achieve neutral alignment as determined by 2 independent observers. The mean amount of elevation required was 25 mm. Children < 4 years of age required greater elevation than those 4 years of age or older ($P < .05$). Because of these findings, it was recommended that children < 8 years of age requiring immobilization either 1) have the torso elevated or 2) place the head in an occipital recess to achieve a more neutral position for immobilization of the cervical spine. In a separate report, Treloar and Nypaver³ similarly found that semi-rigid cervical collars placed on children < 8 years of age did not prevent this positional forced flexion when placed supine on standard, rigid spinal boards.

Herzenberg et al⁴ studied 10 children < 7 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. They suggested that alignment of the patient’s external

auditory meatus with his/her shoulders would help to achieve neutral cervical spine positioning.

However, Curran et al⁵ found no correlation with age regarding degree of cervical kyphosis identified in children transported on backboards. They did note however, that 30% of children had $> 10^\circ$ 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 al⁶ evaluated a variety of immobilization devices on children, infants, and child-sized mannequins. 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,⁷ 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. They studied 51 healthy children, ages 6 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 negatively influence 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 imaging assessment must be determined and performed. Several authors have evaluated the indications for radiographic assessment of children with a potential cervical spinal injury.^{8,9} Laham et al⁹ investigated the role of cervical spine x-ray evaluation of 268 children with apparent isolated head injuries. 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 (< 2 years of age) or head injury, and those children with neck pain. They employed the “3-view approach” of anteroposterior (AP), lateral, and open-mouth radiographs. They discovered no cervical spine injuries in the low-risk group but discovered 10 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 al⁸ emphasized that unexplained hypotension or absent vital signs in childhood trauma victims are likely to be from a severe cervical cord injury. 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 al¹⁰ evaluated the cervical spines in children < 18 years of age utilizing the National Emergency X-Radiography Utilization Study (NEXUS^{Ref.}) decision instrument in a Class II prospective multicenter study. They employed 5 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) other painful distracting injury. Radiographs were obtained at the discretion of the treating physician. When radiographs were obtained a minimum of 3-views was obtained. Only those patients who obtained radiographs were included in the study. If all 5 criteria were met, the child was considered low-risk. If any one of the 5 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 < 2 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 zero to 9 years of age. Their conclusions are consistent with the Class III evidence previously described by Laham et al⁹ on this topic.

A NEXUS-based pediatric (0-18 years) cervical spine clearance protocol was evaluated by Anderson et al¹¹ in a Class II prospective multicenter trial, using historical controls. Plain radiographs were obtained on all children presenting in a cervical collar. Children > 3 years old with normal radiographs who met all 5 NEXUS low-risk criteria were “cleared.” All others required additional imaging, neurosurgical consultation, or both. Cervical spine injury detection rates were equivalent with historical controls and no late injuries were detected. Use of the protocol “increased the number of cervical spines cleared by non-neurosurgical personnel by nearly 60%.” The protocol design and study did not, however, allow for any cervical spine clearance without radiography.

In a parallel Class II prospective study at the same institutions, Anderson et al¹² evaluated a cervical spine clearance protocol designed for trauma patients aged < 3 years. All children underwent plain radiography (AP and lateral views) and CT scans only if radiographic findings were inadequate or suspicious for an injury. If initial imaging was negative, further evaluation

depended on the patient's airway status (intubated or not) and included clinical factors, dynamic radiography, and/or MRI. MRI scans were reserved for patients with signs of spinal cord injury, intubation/obtundation for > 48 hours, or persistent neck pain with range of motion. Application of this protocol resulted in cervical spine clearance of 575 noncommunicative children < 3 years old over a 5-year period without any missed injuries detected. CT scans were necessary in only 14% of cases and MRI in 10%. The authors recognize that the low incidence of injuries (28 of 575) limits the statistical strength of their findings.

Garton et al¹³ evaluated NEXUS criteria retrospectively in 190 consecutive pediatric cervical spine injury cases with particular attention to younger children. In their Class II analysis, application of NEXUS criteria to determine the need for c-spine imaging would not have missed any injuries in the 157 patients older than 8 years. Applying NEXUS criteria to the 33 patients aged < 8 years, however, would have missed 2 injuries (94% sensitivity). Also in children < 8 years old they reported a higher sensitivity for combination plain radiography/occiput-C3 CT scan compared with plain radiography/flexion/extension views (sensitivity, 94% vs 81%).

Both NEXUS low-risk criteria and the Canadian C-spine Rule (CCR) were assessed retrospectively by Ehrlich et al¹⁴ in children < 10 years of age. Both protocols would have missed clinically important cervical spine injuries in the imaged cohort. Sensitivity and specificity were 43% and 96% for NEXUS, and 86% and 94% for CCR, respectively. They concluded that neither protocol is sensitive or specific enough to be used as designed for young children.

Pieretti-Vanmarcke et al¹⁵ performed a Class II multi-institutional review of 12 537 blunt trauma cases < 3 years of age to identify clinical predictors of cervical spine injury (n = 83). Four independent predictors of cervical spine injury were reported to be significant: (GCS < 14; GCSeve = 1; motor vehicle crash; age 2 to 3 years [by definition, a patient with GCSeve = 1 must have a total GCS < 14 so these 2 predictors can be combined]). Using the weighted scoring system reported for these predictors, a child < 3 years old presenting after blunt trauma with a GCS > 13 and any non-MVC mechanism has only a 0.07% chance of having a cervical spine injury. (NPV = 99.93%). This is comparable to the probability of missing an injury when using appropriate imaging. The only 5 outliers they encountered had neck splinting, associated facial/skull fractures, and/or documented loss of consciousness compounding their assessment.

Another study focused on c-spine injury in very young children was reported by Katz et al.¹⁶ They reviewed 905 consecutive infants (<12 months of age) presenting after minor (low impact) head trauma and found only 2 c-spine injuries, both due to non-accidental trauma (NAT). Low impact head trauma was defined as any mechanism other than MVC or a fall from > 10 feet. They concluded that routine c-spine imaging in this population has very low diagnostic yield unless NAT is suspected.

Hutchings et al¹⁷ reviewed c-spine clearance methods retrospectively in 115 consecutive obtunded major trauma patients <16 years of age. No protocol was used during the 7-year study period.¹⁷ Six c-spine injuries were identified by a variety of screening methods. CT imaging alone was found to have 100% sensitivity and 100% specificity in this population, although the validity of this finding is undermined somewhat by the low incidence of injury.

The need for and utility of open-mouth odontoid views in pediatric trauma victims has been questioned (6,59).^{18,19} Swischuk et al¹⁹ 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 5 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 (ie, odontoid vs 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 < 5 years of age. Buhs et al¹⁸ also investigated the utility of open mouth views in children. They performed a multi-institutional retrospective review of a large metropolitan population of patients < 16 years of age who were assessed for cervical spine trauma over a 10-year period. Fifty-one children with cervical spinal injuries were identified. The lateral cervical spine radiograph made the diagnosis in 13 of 15 children < 9 years of age. In none of the 15 younger patients did the open-mouth view provide the diagnosis. In only 1 of 36 patients in the 9 to 16 years of age group was the open mouth view the key 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 < 9 years of age.

Lui et al,²⁰ 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 4 of 12 children with odontoid fractures, and in 6 of 9 children with purely ligamentous injuries resulting in atlantoaxial dislocation. 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 al²¹ highlighted the propensity for upper cervical injuries in children under the age of 9 years. They reported no injuries below C3. Evans and Bethem²² described 24 children with cervical spine injuries. In half of the patients, the injury was at C3 or higher.²² Givens et al,²³ however, described

the occurrence of important injuries occurring at all levels of the cervical spine in young children. 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 al²⁴ attempted to define a protocol to evaluate the cervical spine in obtunded children following trauma. 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 1 of the 3 children with an abnormal evoked response underwent 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 1 or more of these diagnostic maneuvers, but as yet there is no evidence to support their use.

Ralston et al²⁵ retrospectively analyzed the cervical spine radiographs of 129 children who had flexion and extension x-rays performed after an initial static radiograph. They found that if the static radiograph was normal or depicted only loss of lordosis, only 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.²⁵

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 Filtzer²⁶ 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. The subjects' ages ranged from 1 to 16 years with 10 children for each year of age. They found a 24% incidence of moderate to marked C2 on C3 subluxation in children between 1 and 7 years of age. Thirty-two of 70 children (46%) < 8 years of age had 3.0 mm 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 1 to 7 years of age had an atlanto-dens interval of 3 millimeters or greater. Overriding of the anterior arch of the atlas on the odontoid was present in 20% of children < 8 years old. The synchondrosis between the odontoid and axis body was

noted as a lucency in all children imaged up to the age of 4 years. The synchondrosis remained visible in half the children up to 11 years of age. The authors also described an absence of the normal cervical lordosis in 14% of subjects, most commonly in the 8- to 16-year-old age groups. Shaw et al²⁷ in a retrospective review of cervical spine x-rays in 138 children < 16 years of age who were evaluated following trauma, found a 22% incidence of radiographic pseudosubluxation of C2 on C3. 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 vs 9.0 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 1 mm anterior to the anterior cortex of the posterior arch of C2. If the anterior cortex of the posterior arch of C2 is 2.0 mm or more behind the line, then a true dislocation (rather than pseudosubluxation) should be assumed.

Keiper et al²⁸ 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. There were 16 abnormal MRI examinations in 52 children. Posterior soft tissue and ligamentous changes were described as the most common abnormalities. Only 1 child had a bulging disc. Four of these 52 children underwent surgical treatment. In each of the 4 surgical cases, the MRI findings led the surgeon to stabilize more levels than otherwise would have been undertaken without the MRI information. Davis et al²⁹ described the use of MRI in evaluating pediatric spinal cord injury in 15 patients, and found it did not reveal any lesion that would warrant surgical decompression. They did note, however, that MRI findings did correlate with neurological outcome. Evidence of hematomyelia was associated with permanent neurological loss. While little information is available on this subject, it appears that pre-operative MRI of children with unstable cervical spinal injuries, who require surgical stabilization, may affect the specifics of the surgical management.

Except for the review of obtunded major trauma patients by Hutchings et al¹⁷ discussed above, there are few studies that have systematically reviewed the role of CT in the evaluation of the cervical spines of pediatric patients following trauma. In children < 10 years of age with cervical spinal injuries, the majority of patients will have ligamentous injuries without fracture.³⁰⁻³⁴ In older children with cervical spinal injuries, the incidence of a fracture is much greater than ligamentous injury without fracture, 80% vs 20% respectively.^{10,22} Therefore, normal osseous anatomy as depicted on an axial CT image should not be used alone to exclude injury to the pediatric cervical spine. In 1989, Schleeauf et al³⁵ concluded that CT should not be relied

upon to exclude ligamentous injuries in a series of pediatric and adult trauma patients. They reported 2 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 (eg, C7-T1), and for the investigation of the osseous integrity of specific vertebra suspicious for fracture on plain radiographs.³⁵ In a focused study in pediatric patients with potential AOD, Pang et al proposed the CCI as a sensitive diagnostic measurement of AOD as determined on CT imaging. They analyzed and compared CCI from sagittal and coronal reformatted CT images of the craniovertebral junction of 89 children without AOD and 16 children with AOD. They found the CCI to have sensitivity and specificity of 100% compared to “standard” tests on plain films that had a sensitivity between 25% and 50% and a specificity between 10% and 60%. They concluded that the CCI criterion has the highest diagnostic sensitivity and specificity for AOD among all radiographic methods. Their work provided Class I medical evidence for the diagnosis of AOD among pediatric patients.^{36,37}

In a series consisting almost entirely of 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.³⁸ 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, 8 unstable) in 58 patients (34%). Eight of these injuries (5 stable, 3 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 screening cervical spine imaging 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. Additionally, children who have experienced trauma that are non-communicative due to age (< 3 years old) and have motor vehicle collision, fall from a height > 10 feet, or suspected NAT as mechanisms, or GCS < 14 should have screening cervical spine imaging performed. In children who are alert, have no neurological deficit, no midline cervical tenderness, no painful distracting injury, and are not intoxicated, cervical spine imaging is not necessary to exclude cervical spine injury.^{9,10} Unexplained hypotension should raise the suspicion of a spinal cord injury. Screening cervical spine imaging for children may consist of adequate AP and lateral radiographs (\pm open mouth odontoid) or high resolution CT scanning. Open-mouth views of the odontoid

do not appear to be useful in children < 9 years of age. Open-mouth views should be attempted in children 9 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 should 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 are not necessary to “clear” the entire cervical spine in most children, and should be employed judiciously to define bony anatomy at specific levels, except in the case of potential AOD. For this latter entity, Class I medical evidence supports the use of CT as the preferred modality. MRI may provide important information about ligamentous injury that may influence surgical management, and may provide prognostic information regarding existing neurological deficits.

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, including “spinal cord concussion”) and atlanto-occipital dislocation injuries have been addressed in other sections (see SCIWORA guideline chapter, see Atlanto-occipital dislocation guideline chapter). 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.³⁹

Neonatal Spinal Cord Injury

Birth injuries of the spinal cord occur approximately 1 per 60 000 births.¹⁰ The most common level of injury is upper cervical followed by cervicothoracic.⁴⁰ Mackinnon et al⁴⁰ described 22 neonates with birth-related spinal cord injuries. The diagnosis was defined by the following criteria: clinical findings of acute cord injury for at least 1 day and evidence of spinal cord or spinal column injury by imaging or electrophysiological studies. Fourteen neonates had upper cervical injuries, 6 had cervicothoracic injuries, and 2 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 9 infants with upper cervical injuries surviving longer than 3 months, 7 were alive at last follow-up. Six of these 7 are dependent upon mechanical ventilation. The 2 neonates with upper cervical injuries who had breathing movements on day 1 of life were the only 2 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 2 children of 6 who sustained cervicothoracic spinal cord injuries lived and both remained paraplegic. One required long-term mechanical ventilation. Hypoxic and ischemic encephalopathy was noted in 9 of 14 newborns with upper cervical cord injuries, and in 1 of 6 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,⁴¹ drawing partly from the same patient data as Mackinnon et al,⁴⁰ reported 15 neonates with birth-related upper cervical spinal cord injuries. All were associated with cephalic deliveries requiring rotational maneuvers with forceps. All but 1 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 Oakes⁴² described 5 neonates with birth-related spinal cord injuries. They reported that incorrect diagnoses were made in 4. They consisted of Werdnig-Hoffmann syndrome, occult myelodysplasia, and birth asphyxia. Only 1 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 5 neonates.

Fotter et al⁴³ 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 2 cases.

Pang and Hanley⁴⁴ provide the only description of an external immobilization device for neonates. They described a thermo-plastic 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 remains arbitrary.

Odontoid Epiphysiolysis

The neurocentral synchondrosis of C2 that may not fuse completely until age 7 years represents a vulnerable site of injury in young children.⁴⁵ 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.⁴⁶ While injuries to the neurocentral or subdental synchondrosis may be seen in children up to 7 years of age, it most commonly occurs in pre-school aged children.⁴⁷ Mandabach et al⁴⁷ described 13 children with odontoid injuries ranging in age from 9 months to 7 years. They reported that 8 of 10 children who were initially managed with halo immobilization alone achieved stable fusion. The average time to fusion was 13 weeks with a range of 10 to 18 weeks. Because the injury occurs through the epiphysis, it has a high likelihood of healing if closed reduction and immobilization are employed. In their review, Mandabach et al⁴⁷ 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 al⁴⁶ reported 11 children with odontoid injuries and reviewed an additional 24 from the literature. Only 1 of these 35 children required surgical fusion. More recently, Fassett et al⁴⁸ reported a meta-analysis of 55 odontoid synchondrosis fractures, including the Mandabach and Sherk series' plus 4 new cases. Closed reduction and immobilization was performed initially in 45 cases, resulting in stable fusion in 42 (93%). Most were immobilized with halo (n = 20) or Minerva jacket (n = 20). Surgical fusion was performed in 8 cases; 4 as initial treatment, 3 following immobilization failure, and 1 after a delayed diagnosis. All reported posterior C1-2 fusion (n = 6) and motion preservation procedures (1 odontoid screw and 1 temporary posterior wiring) achieved stable fusion without complications.⁴⁸

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, followed closely by the Minerva.⁴⁶⁻⁴⁹

To obtain injury reduction in these children, Mandabach et al⁴⁷ advocates the application of the halo device under ketamine anesthesia followed by realignment of the dens utilizing C-arm fluoroscopy. Other reports describe using traction to obtain alignment, before immobilizing the child in an external orthosis.⁴⁵ 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.⁴⁷

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 al⁵⁰ noted that only 3 "young" children have been reported in the literature having odontoid injuries primarily treated with surgical stabilization. This underscores the near universal application of external immobilization as the primary means of treating odontoid injuries in young children. Odent et al⁴⁹ reported that of the 15 young children with odontoid injuries they managed, 3 that were treated with surgical stabilization and fusion experienced complications. The other 12 children with similar injuries

managed non-operatively all did well. Wang et al⁵¹ described using anterior odontoid screw fixation as the primary treatment option in a 3-year-old child with C2 epiphysiolysis. 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 2 older children (ages 10 and 14 years) followed by hard collar immobilization. It is likely that these 2 children had true type II odontoid fractures and not C2 epiphysiolysis. Likewise, Godard et al⁵² performed anterior odontoid screw fixation in a 2-year-old child with a severe head injury. They used skeletal traction to align the fracture pre-operatively. 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. Fassett et al⁴⁸ advocate for external immobilization as primary treatment, even though 4 cases in their meta-analysis received primary surgical treatment.

For management of injuries of the C2 neurocentral synchondrosis, the literature supports the use of closed reduction and external immobilization for approximately 10 weeks. This strategy is associated with an 80% fusion success rate.⁴⁶⁻⁴⁹ 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.⁴⁶⁻⁵²

Atlantoaxial Rotatory Subluxation or Fixation

Fixed rotatory subluxation of the atlantoaxial complex (AARF) is not unique to children but is more common during childhood. AARF may 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.⁵³⁻⁵⁷

It can be difficult to differentiate AARF from other causes of head rotation on clinical grounds alone. Several reports describe the radiographic characterization and diagnosis of this entity. Fieldings and Hawkins⁵⁸ described 17 children and adults with "atlantoaxial rotatory subluxation," and classified their dislocations into 4 types based on radiographic features. Type I was the most common type, identified in 8 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 5 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 > 5.0 mm. 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 al⁵⁹ reviewed the radiographs of a series of 17 children with C1-C2 rotatory subluxation and classified them according to Fieldings and Hawkins. There were 10 Type I, 5 Type II, 2 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 rotatory subluxation. Kowalski et al⁵⁴ demonstrated the superiority of dynamic CT studies compared to information obtained with static CT studies. They compared the CT scans of 8 patients with C1-C2 pathology to CT studies of 6 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 rotatory 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 rotatory subluxation.

Type I and Type II subluxation account for the vast majority of rotatory atlantoaxial subluxations in reports describing these injuries. Grøgaard et al⁶⁰ and Subach et al⁵⁶ have published retrospective reviews on the success of conservative therapies in children presenting early following C1-C2 rotatory subluxation. Grøgaard et al⁶⁰ described 8 children who presented within 5 days of subluxation, and 1 child who presented 8 weeks after injury. All were successfully treated with closed reduction and immobilization. The child presenting late required 1 week of skeletal traction to achieve reduction, and was ultimately treated with halo immobilization for 10 weeks. The children who presented early had their injuries reduced with manual manipulation. They were treated in a hard collar for 4 to 6 weeks. Two patients had recurrent subluxation. Both were reduced and treated successfully without surgical intervention. Subach et al⁵⁶ reported 20 children with C1-C2 rotatory subluxation, in whom 4 injuries reduced spontaneously. Injury reduction was accomplished in 15 of 16 patients treated with traction for a mean duration of 4 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 al⁶¹ reported 3 children who presented within 24 hours of traumatic rotatory subluxation. All 3 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 10 weeks to 4 months. Phillips et al⁴ reviewed 23 children with C1-C2 rotatory subluxation. Sixteen children were seen within 1 month of subluxation onset, and experienced either spontaneous reduction or were reduced with traction. Of 7 children presenting with a duration of symptoms

> 1 month, 1 subluxation was irreducible, and 4 recurred after initial reduction. Schwarz described 4 children who presented > 3 months after the onset of C1-C2 rotatory subluxation.⁶² Two children had irreducible subluxations. One child had recurrent subluxation despite the use of a Minerva cast. Only 1 child had successful treatment with closed reduction and a Minerva cast immobilization for 8 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, 4 weeks in a rigid collar appears to be sufficient for healing. Because C1-C2 rotatory 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 (eg halo vest, Minerva cast) for longer periods of treatment up to 4 months has been described in those children presenting late, or those who have recurrent subluxations.⁵⁵

Operative treatment for C1-C2 rotatory subluxations has been reserved for recurrent subluxations or those that cannot be reduced by closed means. Subach et al⁵⁶ operated on 6 of the 20 children they reported with rotatory subluxation using these indications. They employed a posterior approach and accomplished atlantoaxial fusion. They had no complications and all fusions were successful.

In the most comprehensive study of this condition to date, Pang and Li applied a C1-C2 motion analysis protocol to 3-position dynamic CT scans performed prospectively on 40 children with clinically suspected AARF and compared those findings to 21 normal controls described previously.^{57,63} The protocol is too complex to elucidate here, but it reliably distinguished all cases of AARF from normal controls. A classification system derived from the motion analysis protocol identified 5 distinct groups (3 types of AARF “diagnostic grey zone” or DGZ, and normal), and reportedly aided in selecting appropriate treatment regimens according to AARF type. Concurrently, Pang and Li⁶⁴ reported an analysis of 29 cases of AARF diagnosed and classified prospectively per their protocol (8 type I cases; 11 type II; 10 type III), and managed according to an algorithm that incorporates their classification scheme. Diagnosis and management of 6 DGZ cases are also reported. Basically, all cases of AARF were managed initially with traction reduction and immobilization (halo or Guilford brace). Those that could not be reduced (n = 3) and those that recurred following HALO immobilization (n = 3) received posterior C1-C2 fusion. DGZ patients were treated symptomatically and restudied after 2 weeks, leading either to normalization or treatment with halter traction if still symptomatic or dynamic CT motion analysis findings worsened. They concluded that type I AARF correlated with delayed treatment and was least likely to respond to conservative management. Prolonged duration of AARF and type I motion analysis also correlated with recurrence of AARF after traction and immobilization. Their exhaustive analysis of AARF provides Class II diagnostic and Class III treatment medical evidence.

In summary, the diagnosis of atlantoaxial rotatory fixation is suggested when findings of a “cock-robin” appearance are present, and the patient is unable to turn the head past midline to the contralateral side, and experiences spasm of the contralateral (opposite the side to which the chin is turned) sternocleidomastoid muscle.⁵⁵ Plain cervical spine radiographs may reveal the lateral mass of C1 rotated anterior to the odontoid on a lateral view. The AP radiograph may demonstrate rotation of the spinous processes toward the ipsilateral side in a compensatory motion to restore alignment. If the diagnosis of AARF is suspected after clinical examination and plain radiographic study, a dynamic CT study should be obtained and analyzed using the Pang protocol. It appears that the longer AARF is present before attempted treatment, the less likely reduction can be accomplished. Even if reduction is accomplished in these chronic injuries, it is less likely to be maintained. Therefore, acute AARF (< 4 weeks duration) that does not reduce spontaneously should undergo attempted reduction with manipulation or halter traction. Chronic AARF (4 weeks duration or more) should undergo attempted reduction with halter or tong/halo traction. Reductions achieved with manipulation or halter traction should be immobilized with a cervicothoracic brace, while those requiring tong/halo traction should be kept in a halo. 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 > 3 months duration.

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 Goodman⁶⁵ reported a series of 3 infants with cervical injuries, 2 of whom had injuries reduced in this fashion. Up to 9 pounds was used in a 10-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 al⁶⁶ described halo application in infants for the purpose of immobilization but not halo-ring traction. They

described 3 infants ages 7 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 2 inch/pounds of torque applied. The children were maintained in the halo devices for 2 to 3 and a half months. Only the youngest child had a minor complication of frontal pin site infection, necessitating removal of 2 anterior pins.

Marks et al⁶⁷ described 8 children ages 3 months to 12 years who were immobilized in halo vests for 6 weeks to 12 months with a mean duration of 2 months. Only 3 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 al³¹ reported on 37 children ages 3 to 12 years that they managed in halo immobilization devices. They had a 68% complication rate. Pin-site infections were most common. They arbitrarily divided their patient population into those < 10 years of age and those 10 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 1 incident of dural penetration and 1 transient supraorbital nerve injury. Baum et al⁶⁸ compared halo use complications in children and adults. The complication rates in their series were 8% for adults and 39 percent among children. The complications reported for the children were one skull penetration and 4 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 Marlin⁶⁹ described 6 children ages 2 years to 4 years who had cervical spinal instability managed with a thermoplastic Minerva orthosis as an alternative to a halo immobilization device. 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 1 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 al⁷⁰ analyzed cervical motion during spinal immobilization in adults serially treated with halo and Minerva devices. 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 vs late surgical decompression following acute pediatric cervical spinal cord injury. Pediatric spinal injuries account for only 5% of all vertebral column injuries. Since the initial publication of “Guidelines for the Management of Acute Cervical Spine and Spinal Injuries,” the preponderance of the recent treatment literature describes surgical management techniques in case series format. Gluf et al⁷¹ reported a retrospective review of 67 consecutive C1-C2 transarticular screw (TAS) fixation cases (127 screws) in patients < 16 years old for various indications. Trauma was the indication for 24 cases and radiographic fusion was achieved in every case. The overall complication rate was 10.4%, including 2 vertebral artery injuries—neither of which caused a permanent neurological deficit. Klimo et al⁷² reported a series of 78 patients treated surgically for os odontoideum; 56% (n = 44) presented following trauma and 63% (n = 49) were < 21 years of age. Posterior C1-C2 fusions were performed in 75 patients, O-C2 fusions in 2, and an odontoid screw was placed in 1. All patients except the odontoid screw recipient had at least 1 TAS placed with no major complications and a radiographic fusion rate of 100%.

Heuer et al⁷³ described their experience with the Goel-Harms internal fixation technique in 6 children undergoing posterior C1-C2 fusion for os odontoideum. All 6 achieved radiographic fusion and no complications were reported. Chamoun et al reported on 7 pediatric cervical spine fusion procedures supplemented with axial and subaxial translamina screw fixation. Trauma was the surgical indication in 3 cases; all 7 achieved radiographic fusion. One patient experienced prolonged dysphagia due to a malpositioned C1 lateral mass screw. Couture et al⁷⁴ reviewed 22 cases of pediatric occipitocervical fusion with internal fixation using the “Wasatch loop.” All 6 cases performed to stabilize traumatic instability led to radiographic fusion without major complications or the need for revision surgery. Most recently, Hankinson et al⁷⁵ reported a prospective multicenter comparison of internal fixation techniques (Class II) for pediatric occipitocervical fusion surgery. Traumatic instability was the indication for 22 of the 77 procedures analyzed. The internal fixation techniques compared were 1) O-C2 instrumentation without direct fixation of C1; 2) C1 and C2 instrumentation without TAS fixation; and 3) any TAS fixation. Their analysis revealed 100% radiographic fusion rates in all groups and no significant difference in complication rates among the 3 fixation techniques. They reported 3 vertebral artery injuries, 2 in the TAS group and 1 in the C1-C2 instrumentation group.

The remaining noteworthy reports describing management of pediatric cervical spine and spinal cord injuries are all Class III case series. Parisini et al⁷⁶ reported 12 cervical spine fractures in a series

TABLE 1. Evidentiary Table: Diagnosis of Pediatric SCI

Authors & Year	Description of Study	Class of Data	Conclusions
Anderson et al, ¹² <i>JNS: Peds</i> , 2010	Multicenter prospective assessment of a c-spine clearance protocol for patients aged 0 to 3 years (n = 575)	II	Clinical and plain radiographic findings were sufficient to clear the majority of c-spines in non-communicative children. CT scans were required in 14% and MRI in only 10%, using this protocol.
Katz et al, ¹⁶ <i>JNS: Peds</i> , 2010	Retrospective review of CSI in 905 patients < 1 year of age presenting with minor (low-impact) head trauma	II	Only 2 infants (0.2%) were found to have a CSI and the mechanism was NAT in both. Routine c-spine imaging has very low diagnostic yield unless NAT is suspected.
Ehrlich et al, ¹⁴ <i>J Ped Surg</i> , 2009	Retrospective case-control comparison of CCR and NEXUS low-risk criteria in determining the need for c-spine radiography in patients < 11 years of age	II	Both criteria would have missed c-spine injuries and both are not sensitive or specific enough to be applied to pediatric patients as designed.
Pieretti-Vanmarcke et al, ¹⁵ <i>Trauma</i> , 2009	Multi-institutional retrospective review of 12 537 blunt trauma cases < 3 years of age to identify clinical predictors of cervical spine injury (n = 83)	II	Four independent predictors of CSI were identified: GCS < 14, GCSeve = 1, motor vehicle crash, and age 2 years or older. A score of < 2 had a negative predictive value of 99.93% in ruling out CSI.
Hutchings et al, ¹⁷ <i>Trauma</i> , 2009	Retrospective review of c-spine clearance modalities in 115 pediatric major trauma admissions (all obtunded)	III	CT scan demonstrated 100% sensitivity and specificity with positive and negative predictive values of 1.0 for all spinal regions.
Garton et al, ⁸⁵ <i>Neurosurgery</i> , 2008	Retrospective evaluation of NEXUS criteria on 190 consecutive pediatric cervical spine injuries	II	NEXUS criteria applied to children < 8 years of age would have missed 2/33 injuries but missed none in patients > 8 years old. Occiput-C3 CT scan may provide better diagnostic yield in young children than flexion/extension radiographs.
Pang et al, ³⁶ <i>Neurosurgery</i> , 2007	CT evaluation of CCI in 89 normal children and 16 children with AOD	I	"Standard" tests 25 to 50% sensitivity, 10 to 60% specificity; CCI 100% sensitivity, 100% specificity for AOD.
Anderson et al, ¹¹ <i>JNS: Peds</i> , 2006	Prospective evaluation of a NEXUS-based pediatric c-spine clearance protocol (n = 937) compared to historical "control" (n = 936)	II	The protocol used safely facilitated c-spine clearance by non-neurosurgical personnel while it reduced the need for neurosurgical consultation by 60%.
Pang et al, ⁶³ <i>Neurosurgery</i> , 2005	Prospective multicenter evaluation of 3-position CT scan C1-C2 motion analysis protocol to diagnose and classify AARF in 40 children compared to 21 normal controls	II	AARF reliably diagnosed by protocol and classified to help select best management regimen.
Slack et al, ⁸⁶ <i>Emerg Med J</i> , 2004	Systematic review of Class II and III pediatric trauma c-spine imaging studies.	II	Conclusions similar to those in previous <i>Guidelines for Management of Acute Cervical Spine Injuries</i> .
Hernandez et al, ⁸⁷ <i>Emerg Rad</i> , 2003	Retrospective review of 147 ER c-spine CT scans in patients < 5 years of age	III	All 4 injuries identified from 147 scans were evident on initial plain radiography.

(Continues)

TABLE 1. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Viccellio et al, ¹⁰ <i>Pediatrics</i> , 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 5 low-risk criteria had a cervical spine injury. Radiographs may not be necessary to clear the cervical spine in children fulfilling all 5 criteria.
Ralston et al, ²⁵ <i>Academ Emer Med</i> , 2001	Blinded review of 129 children with blunt cervical trauma who had flexion and extension radiographs	II	Flexion and extension views with normal cervical spine radiographs or with only loss of cervical lordosis did not unmask any new abnormalities.
Buhs et al, ¹⁸ <i>J Ped Surg</i> , 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 < 9 years old. In no child < 9 years old was the open mouth view the diagnostic study. Only 1 of 36 children older than 9 years had open-mouth view as the diagnostic study.
Swischuk et al, ¹⁹ <i>Pediatr Radiol</i> , 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 et al, ²⁴ <i>Pediatr Neurosurg</i> , 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 3 children was studied with MR and it was normal.
Shaw et al, ²⁷ <i>Clin Radiol</i> , 1999	Retrospective review of the cervical radiographs 138 trauma patients under 16 years old	III	Twenty-two percent incidence of pseudosubluxation of C2 on C3. Median age of pseudosubluxation group was 6.5 years vs 9 years for those without pseudosubluxation.
Berne et al, ³⁸ <i>J Trauma</i> , 1999	58 patients with severe blunt trauma underwent helical CT of entire cervical spine	III	Twenty had cervical spine injuries. Plain radiographs missed 8 injuries. CT missed 2 injuries.
Keiper et al, ²⁸ <i>Neurorad</i> , 1998	Retrospective review 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 4 cases.
Davis PC et al, ²⁹ <i>AJNR</i> , 1993	Retrospective review of 15 children with spinal cord injury underwent MR 12 hours to 2 months after injury, 7 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 et al, ³⁵ <i>Ann Emerg Med</i> , 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.
Kawabe et al, ⁵⁹ <i>J Pediatr Orthop</i> , 1989	Review of the radiology of 17 children with C1-2 rotatory subluxation	III	Classified according to Fielding and Hawkins as 10 type I, 5 type II, 2 type III, and no type IV.

(Continues)

TABLE 1. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Kowalski et al, ⁵⁴ <i>AJR</i> , 1987	Eight patients with occipitoatlantoaxial problems and 6 normal subjects were studied with CT	III	CT looked similar for those with C1-2 rotatory subluxation to normal subjects with their heads maximally turned. CT with the head turned to the contralateral side differentiated rotatory subluxation from normals and spasmodic torticollis.
Cattell and Filtzer, ²⁶ <i>J Bone Joint Surg</i> , 1965	Lateral upright cervical radiographs in neutral, flexion, and extension in 160 randomly selected children ages 1 to 16 years	II	C2-3 subluxation was moderate to marked in 24% predominantly in children < 8 years of age. The atlanto-dens interval was 3 mm or more during flexion in 20% of children < 8 years of age.

of 44 pediatric traumatic spinal injuries. Of 6 unstable cervical fractures (3 with SCI), 4 were treated primarily with posterior fusion procedures and 2 with external immobilization (halo and Minerva). Those treated surgically had no residual deformity at last follow-up (9-23 years), while the 2 managed conservatively had residual kyphosis of 18° and 24°. Dogan et al⁷⁷ reported a single center retrospective series of 51 pediatric subaxial cervical spine injuries collected over a 6-year period.⁷⁷ Forty-one injuries were in children aged 9 to 16 years and only 10 in children under 9 years old. Thirty-three children were treated non-surgically (7 halo; 26 rigid cervical orthosis), and 18 children age 8 to 16 years underwent a wide variety of stabilization/fusion procedures. There were no surgery-related deaths or complications and no one in either group developed delayed instability, although 3 patients expired and 6 were lost to long-term follow-up. They concluded that subaxial injuries tend to occur in older children, can usually be managed conservatively, and that surgical treatment appears to be safe and effective. Lastly, Duhem et al⁷⁸ described their single center retrospective experience with 28 unstable pediatric upper c-spine injuries over 28 years. Seven were treated surgically, all of whom achieved stable radiographic fusion with no surgery-related deaths or complications. None of the 28 patients experienced a neurologic decline during or after treatment. In conclusion, the authors favor surgical intervention for patients with “signs of medullary compression, significant spine deformation, dynamic instability, and an age higher than 8 years.”

Earlier reports describing the management of pediatric spinal injuries have been offered by Turgut et al,⁸⁰ Finch and Barnes,⁷⁹ and Elaraky, et al.⁵³ These authors managed pediatric spinal injuries operatively in 17%, 25%, and 30% of patients, respectively. The report by Elaraky et al⁵³ 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 vs posterior), and the method of internal fixation as an adjunct to fusion are scarce in the literature. Finch

and Barnes⁷⁹ employed primary operative stabilization in most children they managed with ligamentous injuries of the cervical spine. 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 2 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 al⁸¹ described 6 children ages 3 years to 14 years who had cervical spine injuries that they treated surgically via an anterior approach. They reported successful fusion with good alignment and normal cervical spine growth in follow-up for all 6 children. The procedure varied (ie total or partial corpectomy vs 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 al⁸² described 16 children with ligamentous injuries of the cervical spine. They managed minor ligamentous injuries (atlanto-dens interval of 5.0 mm to 7.0 mm, or interspinous widening without dislocation or neurological deficit) with reduction and immobilization. Of 11 children with injuries below C2, 8 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 al⁸³ described 13 children with acute cervical spine injuries who required posterior arthrodesis and halo immobilization. They reported successful fusion in 12 patients. The single failure was associated with use of allograft fusion substrate. All the other children were treated with autologous grafts. Internal fixation with wire was employed in only 2 children. Halo immobilization was utilized for an average

TABLE 2. Evidentiary Table: Treatment of Pediatric SCI

Authors & Year	Description of Study	Class of Data	Conclusions
Hankinson et al, ⁷⁵ <i>JNS: Peds</i> , 2010	Multicenter retrospective comparison of O-C2 fusion rates with or without direct C1 instrumentation (total n = 77; trauma = 22)	II	One hundred percent radiographic fusion rates were reported in both groups with no significant difference in complication rates. Excellent O-C fusion rates can be achieved without direct instrumentation of C1.
Couture et al, ⁷⁴ <i>JNS: Peds</i> , 2010	Retrospective case series of 22 children who underwent O-C fusion using "Wasatch loop" instrumentation	III	Trauma was the indication in 6 cases, radiographic fusion was achieved in 100%, 3 non-trauma cases required revision surgery, and no major complications occurred.
Chamoun et al, ⁸⁸ <i>Neurosurgery</i> , 2009	Report of 7 pediatric cervical spine fusions (3 for trauma) using axial and subaxial translaminar screw fixation	III	Radiographic fusion was achieved in 100% and 1 patient experienced prolonged dysphagia due to C1 lateral mass screw malposition.
Heuer et al, ⁷³ <i>Eur Spine J</i> , 2009	Retrospective series of 6 C1-C2 posterior fusions in children using Goel-Harms internal fixation constructs	III	Although none were acutely posttraumatic, all had os odontoideum, all achieved radiographic fusion, and no major complications were reported.
Klimo et al, ⁸⁹ <i>JNS: Peds</i> , 2008	Retrospective review of 78 patients treated surgically for os odontoideum, traumatic presentation occurred in 56% and 63% were \leq 20 years old	III	All underwent posterior C1-C2 fusion with transarticular screw fixation (except 1 odontoid screw and 2 O-C2 fusions), radiographic fusion was achieved in 100%, and no major complications occurred.
Duhem et al, ⁷⁸ <i>Childs Nerv Syst</i> , 2008	Single center retrospective review of 28 cases of unstable pediatric upper c-spine injuries over a 28-year period	III	Seven patients were managed surgically and all achieved radiographic fusion on late follow-up. None of the 28 experienced a neurologic decline during or after treatment. Two of 5 incomplete SCI cases normalized.
Dogan et al, ⁷⁷ <i>Neurosurg Focus</i> , 2006	Single center retrospective review of 51 pediatric subaxial cervical spine injuries over a 6-year period	III	Conservative management was successful for 64%, while 36% required surgery. No deaths or complications were attributed to surgical intervention.
Fassett et al, ⁴⁸ <i>Neurosurg Focus</i> , 2006	Meta-analysis of odontoid synchondrosis fractures: 7 series' totaling 55 cases	III	Ninety-three percent of fractures initially managed with external immobilization (HALO or Minerva) attained fusion without surgery.
Pang et al, ⁶⁴ <i>Neurosurgery</i> , 2005	Prospective case series of 29 children with AARF diagnosed, classified, and managed per the authors' protocol	III	Prolonged delay in treatment may adversely affect C1-C2 rotatory dynamics. Type I AARF correlated with delayed treatment and need for HALO immobilization \pm posterior C1-C2 fusion.
Gluf et al, ⁷¹ <i>JNS: Spine</i> , 2005	Retrospective case series of 67 C1-C2 transarticular screw fixations in patients < 16 years of age	III	Trauma was the indication in 24 cases, radiographic fusion was achieved in 100%, and 2 asymptomatic vertebral artery injuries were observed.
Parisini et al, ⁷⁶ <i>Spine</i> , 2002	Retrospective case series of 44 pediatric spine fractures (12 cervical) with mean follow-up of 18 years	III	Four unstable c-spine fractures (2 with SCI) managed conservatively developed late deformity. Stable fractures managed conservatively healed without deformity.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Meyer et al, ⁹⁰ <i>Acta Neurochir</i> , 2001	Retrospective case series of 13 cervical spine fusion procedures in 11 children—8 for post-traumatic instability	III	Radiographic fusion occurred in 100%, 3 transient neurologic deteriorations occurred, and 2 developed "bystander fusion."
Eleraky et al, ⁵³ <i>J Neurosurg (Spine)</i> , 2000	Retrospective review of 102 children with cervical spinal injuries	III	Thirty children (30%) were treated surgically.
Odent et al, ⁴⁹ <i>J Ped Ortho</i> , 1999	Review of 15 young children with odontoid injuries	III	Six 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, ⁶² <i>Arch Orthop Trauma Surg</i> , 1998	A review of 4 children presenting at least 3 months after the onset of C1-2 rotatory 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 8 weeks in a Minerva cast.
Subach et al, ⁵⁶ <i>Spine</i> , 1998	A review of 20 children with C1-2 rotatory subluxation	III	Four reduced spontaneously. Fifteen of 16 treated with traction reduced in a mean of 4 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 and Barnes, ⁷⁹ <i>J Ped Ortho</i> , 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 et al, ⁵⁰ <i>Child Nerv Sys</i> , 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, ³ <i>Ped Emer Care</i> , 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 < 8 years old when on a spinal board.
Lui TN et al, ²⁰ <i>J Trauma</i> , 1996	Retrospective review of C1-2 injuries in 22 children; 12 children had odontoid injuries (OI), 9 children had ligamentous injuries (atlantoaxial dislocations) only	III	Flexion/extension radiographs needed to diagnose 4 OI and 6 atlanto-axial dislocations (AAD). Nine of 12 OI reduced easily. Five of 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 et al, ²³ <i>J Trauma</i> , 1996	Review of 34 children with cervical spine injuries over a 3-year period	III	Eighteen 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 et al, ⁸⁰ <i>Eur Spine J</i> , 1996	Retrospective review of 82 children with spinal cord or column injuries	III	Fourteen children (17%) were treated surgically.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Dormans et al, ³¹ <i>J Bone Joint Surg</i> , 1995	A review of 37 children with halo rings and vests ages 3 to 16 years. Arbitrarily divided into those < 10 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 et al, ⁴¹ <i>Obstet Gyn</i> , 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, ⁵ <i>J Trauma</i> , 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	II	No correlation with degree of kyphosis or lordosis was found with age. Thirty percent had a kyphosis of > 10°. No single immobilization technique was superior.
Schwarz et al, ⁸⁴ <i>Injury</i> , 1994	Review of 10 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 and Treloar, ² <i>Ann Emerg Med</i> , 1994	40 children were placed on spine boards and observers judged whether the cervical spine was in the "neutral" position Children 4 years of age or younger required the greatest amount of elevation.	III	Children < 8 years of age required torso elevation to achieve neutral alignment
Laham JL et al, ⁹ <i>Pediatr Neurosurg</i> , 1994	Divided head-injured children into high (< 2 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 et al, ⁴³ <i>Ped Radiol</i> , 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 echogenicity and disrupted cord surface. A neonate with an incomplete injury had intact cord surface with increased cord echogenicity. MRI corroborated these findings.
Marks et al, ⁶⁷ <i>Arch Orthop Trauma Surg</i> , 1993	Review of 8 children, ages 3 months to 12 years, immobilized in a halo jacket for 6 weeks to 12 months (mean 2 months)	III	The only complication was a jacket change was required for a foreign body (coin). Only 3 of these children had cervical instability.
Shacked et al, ⁸¹ <i>Clin Orthop</i> , 1993	Retrospective review of 6 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 3 to 8 years.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Grøgaard et al, ⁶⁰ <i>Arch Orthop Trauma Surg</i> , 1993	Atlanto-axial rotatory subluxation described in 9 children, 8 diagnosed within 5 days, 1 diagnosed after 8 weeks	III	Eight children were treated successfully with "mild" traction and then a collar for 4 to 6 weeks. The 1 child presenting late required 1 week of traction for reduction. There were 2 redislocations. All eventually healed in alignment without surgery.
Mandabach et al, ⁴⁷ <i>Pediatr Neurosurg</i> , 1993	13 children with axis injuries were reviewed, 10 were treated primarily with closed reduction and halo immobilization	III	Eight of the 10 treated primarily with closed reduction and halo immobilization fused. Two required surgical stabilization and fusion.
MacKinnon et al, ⁴⁰ <i>J Pediatr</i> , 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 6 with cervicothoracic injuries had breech presentations. Both neonates with thoracolumbar injuries were premature.
Rossitch and Oakes, ⁴² <i>Pediatr Neurosurg</i> 1992	Retrospective review of 5 neonates with perinatal spinal cord injury, no flexion/extension views reported	III	Four of the 5 had no abnormality on static spinal radiographs. Respiratory insufficiency and hypotonia were common signs. Myelograms were unrevealing. All 3 with high cervical injuries died by age 3 years.
Osenbach and Menezes, ³⁴ <i>Neurosurgery</i> 1992	Retrospective review of 179 children with spinal injuries	III	Fifty-nine (33%) underwent surgical treatment for irreducible unstable injuries. 83% of those treated surgically were 9 years of age or older. No child with complete or severe partial myelopathy regained useful function.
Rathbone et al, ⁹¹ <i>J Ped Orthop</i> , 1992	Retrospective review of 12 children with presumed spinal cord concussion during athletics were investigated for the presence of cervical stenosis	III	Three had a Torg ratio < 0.8 and 4 had a canal AP diameter < 13.4 mm. MRI was not used to evaluate for stenosis.
Hamilton and Myles, ³³ <i>J Neurosurg</i> , 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. Thirteen percent 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, 4 improved 1 or 2 Frankel grades.
Schafermeyer et al, ⁹² <i>Ann Emerg Med</i> , 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 et al, ⁸ <i>J Trauma</i> , 1990	16 of 19 children presenting with absent vital signs or severe hypotension unexplained by blood loss underwent postmortem examination	III	Thirteen of 16 had cord laceration or transection. Two of these children had a normal cervical radiograph.
Gaskill and Marlin, ⁶⁹ <i>Pediatr Neurosurg</i> , 1990	6 children ages 2 to 4 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.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Phillips et al, ⁵⁵ <i>J Bone Joint Surg</i> , 1989	A review of 23 children with C1-2 rotatory subluxation	III	Sixteen children seen within 1 month of onset had either spontaneous reduction or reduced with traction. Of the 7 children presenting with > 1 month of symptoms, 1 subluxation was irreducible, and 4 had recurrent subluxations.
Benzel et al, ⁷⁰ <i>J Neurosurg</i> , 1989	A comparison of cervical motion of injured patients (only 1 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, ⁶⁸ <i>Spine</i> , 1989	A review comparing the halo complications 13 children and 80 adults	III	Thirty-nine percent complication rate in children vs 8% in adults. The children had 4 pin-site infections and 1 inner table skull pin penetration.
Mubarak et al, ⁶⁶ <i>J Ped Ortho</i> , 1989	Review of 3 children < 2 years old who were placed in halo rings for 2 to 3 ½ months	III	Ten pins tightened "finger-tight" in a 7-month-old, and 2 in/lb in a 16- and 24-month-old. Two of 3 developed minor pin site infections necessitating pin removal.
Herzenberg et al, ⁴ <i>J Bone Joint Surg</i> , 1989	Reported 10 children < 7 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 and Bethem, ²² <i>J Ped Ortho</i> , 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 2 with fusion. Fractures healed in 21 of 22 with nonoperative therapy.
Birney and Hanley, ⁹³ <i>Spine</i> , 1989	Retrospective review of 61 children with cervical spine injuries, 23 of these injuries were C1-2 rotatory subluxation	III	Rotatory subluxation unassociated with neurological deficit. The deformity resolved with halter traction (n = 10) or cervical bracing. One child had a recurrence.
			A child with transverse ligament disruption was treated successfully with a soft collar only.
Hadley et al, ³² <i>J Neurosurg</i> , 1988	Retrospective review of 122 children with spinal injuries There were 97 cervical injuries	III	Only 12 cervical injuries were treated surgically.
Huerta et al, ⁶ <i>Ann Emer Med</i> , 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.
Pennecot et al, ⁸² <i>J Ped Ortho</i> , 1984	Review of 16 children with ligamentous injuries of the cervical spine, 5 with C1-2 injuries	III	Of the 11 children with injuries below C2, 8 underwent surgical stabilization. They recommended a 3-month trial of external immobilization in children with ligamentous injuries but no neurological deficit or dislocation.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
El-Khoury et al, ⁶¹ <i>J Bone Joint Surg</i> , 1984	A review of 3 children with C1-2 rotatory subluxation	III	All 3 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 10 weeks, 3, and 4 months, respectively.
Koop et al, ⁸³ <i>J Bone Joint Surg</i> , 1984	Retrospective review of 13 children with cervical instability treated with posterior arthrodesis and halo immobilization, only 3 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 2 children. Average halo immobilization was 150 days.
Sherk et al, ⁴⁶ <i>J Bone Joint Surg (Am)</i> , 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 1 child was treated successfully with external immobilization.
Fielding and Hawkins, ⁵⁸ <i>J Bone Joint Surg</i> , 1977	The radiographic findings of 17 patients with atlanto-axial rotatory fixation are described and classified into 4 types	III	Four classes of C1-2 rotatory subluxation were described, types I-IV. Type I: odontoid acts as pivot with competent transverse ligament; type II: 1 lateral articular process acts as pivot with up to 5 mm of anterior displacement; type III: both C1 inferior facets are subluxed anteriorly with > 5 mm of anterior displacement which suggests an incompetent transverse ligament; type IV: posterior displacement with absent or incompetent odontoid.
Gaufin and Goodman, ⁶⁵ <i>J Neurosurg</i> , 1975	A review of 3 children < 20 months old with cervical spine injuries, 2 of these children were treated with traction delivered via 22 gauge wire placed through bilateral parietal burr holes	III	Successful traction applied to the 10-week-old and 16-month-old child. Up to 9 pounds was used in the 10-week-old infant. No complications were encountered with the traction in place for 14 and 41 days, respectively.

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 al⁸⁴ described 10 children with traumatic cervical kyphosis. 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.^{20,51,79,81-84} These numerous reports provide Class III medical evidence.

SUMMARY

The available medical literature supports only 1 Level I recommendation for the management of pediatric patients with cervical spine or spinal cord injuries, specifically related to the diagnosis of patients with potential AOD. Level II and III diagnostic and level III treatment recommendations are supported by the remaining medical 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

medical 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 < 9 years of age, only lateral and AP cervical spine views need be obtained. The traditional 3-view x-ray assessment may increase the sensitivity of plain spine radiographs in children 9 years of age and older. High resolution CT scan of the cervical spine provides more than adequate visualization of the cervical spine, but is not necessary in most children. CT and MRI are most appropriately used in selected cases to provide additional diagnostic information regarding a known or suspected injury (eg, CT for AOD) or to further assess the spine/spinal cord in an obtunded child. 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 or 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 < 7 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 persistent or progressive deformity when treated non-operatively. Pharmacological therapy and intensive care unit management schemes for children with spinal cord injuries 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 small numbers of these injuries treated at any single institution. A prospective analysis defining the indications and methods for cervical spine clearance in young children (< 9 years of age) would be a valuable addition to the literature. The role of flexion and extension radiographs is poorly defined in the literature. 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 better defined by prospective study among investigators at multiple institutions.

More common injuries, such as odontoid injuries, should be studied prospectively in a randomized fashion (eg closed reduction and immobilization vs surgical stabilization/fusion). Prospectively collected data would provide the basis for case-control or other

comparative studies to generate Class II medical evidence on these important topics.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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