American College of Radiology
ACR Appropriateness Criteria®
Suspected Spine Trauma-Child

Variant: 1 Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
US cervical spine	Usually Not Appropriate	O
Radiography cervical spine	Usually Not Appropriate	☢☢
Arteriography cervicocerebral	Usually Not Appropriate	☢☢☢☢
MRA neck without and with IV contrast	Usually Not Appropriate	O
MRA neck without IV contrast	Usually Not Appropriate	O
MRI cervical spine without and with IV contrast	Usually Not Appropriate	O
MRI cervical spine without IV contrast	Usually Not Appropriate	O
CT cervical spine with IV contrast	Usually Not Appropriate	☢☢☢☢
CT cervical spine without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CT cervical spine without IV contrast	Usually Not Appropriate	☢☢☢☢
CTA neck with IV contrast	Usually Not Appropriate	☢☢☢
CT myelography cervical spine	Usually Not Appropriate	☢☢☢

Variant: 2 Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
Radiography cervical spine	Usually Appropriate	☢☢
MRI cervical spine without IV contrast	May Be Appropriate (Disagreement)	O
CT cervical spine without IV contrast	May Be Appropriate (Disagreement)	☢☢☢☢
US cervical spine	Usually Not Appropriate	O
Arteriography cervicocerebral	Usually Not Appropriate	☢☢☢☢
MRA neck without and with IV contrast	Usually Not Appropriate	O
MRA neck without IV contrast	Usually Not Appropriate	O
MRI cervical spine without and with IV contrast	Usually Not Appropriate	O
CT cervical spine with IV contrast	Usually Not Appropriate	☢☢☢☢
CT cervical spine without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CTA neck with IV contrast	Usually Not Appropriate	☢☢☢
CT myelography cervical spine	Usually Not Appropriate	☢☢☢

Variant: 3 Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
Radiography cervical spine	Usually Appropriate	☢☢
MRI cervical spine without IV contrast	May Be Appropriate (Disagreement)	O
US cervical spine	Usually Not Appropriate	O
Arteriography cervicocerebral	Usually Not Appropriate	☢☢☢☢
MRA neck without and with IV contrast	Usually Not Appropriate	O

MRA neck without IV contrast	Usually Not Appropriate	O
MRI cervical spine without and with IV contrast	Usually Not Appropriate	O
CT cervical spine with IV contrast	Usually Not Appropriate	☢☢☢☢
CT cervical spine without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CT cervical spine without IV contrast	Usually Not Appropriate	☢☢☢☢
CTA neck with IV contrast	Usually Not Appropriate	☢☢☢
CT myelography cervical spine	Usually Not Appropriate	☢☢☢

Variant: 4 Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
Radiography thoracic and lumbar spine	Usually Appropriate	☢☢☢
MRI thoracic and lumbar spine without IV contrast	May Be Appropriate (Disagreement)	O
CT thoracic and lumbar spine without IV contrast	May Be Appropriate (Disagreement)	☢☢☢☢
Arteriography thoracic and lumbar spine	Usually Not Appropriate	☢☢☢☢
MRA thoracic and lumbar spine without and with IV contrast	Usually Not Appropriate	O
MRA thoracic and lumbar spine without IV contrast	Usually Not Appropriate	O
MRI thoracic and lumbar spine without and with IV contrast	Usually Not Appropriate	O
CT thoracic and lumbar spine with IV contrast	Usually Not Appropriate	☢☢☢☢
CT myelography thoracic and lumbar spine	Usually Not Appropriate	☢☢☢☢
CT thoracic and lumbar spine without and with IV contrast	Usually Not Appropriate	☢☢☢☢
CTA thoracic and lumbar spine with IV contrast	Usually Not Appropriate	☢☢☢☢☢

Panel Members

Nadja Kadom, MD[a], Susan Palasis, MD[b], Sumit Pruthi, MD, MBBS[c], Walter L. Biffl, MD[d], Timothy N. Booth, MD[e], Nilesh K. Desai, MD[f], Richard A. Falcone Jr., MD, MPH[g], Jeremy Y. Jones, MD[h], Madeline M. Joseph, MD[i], Abhaya V. Kulkarni, MD[j], Jennifer R. Marin, MD, MSc[k], Sarah S. Milla, MD[l], David M. Mirsky, MD[m], John S. Myseros, MD[n], Charles Reitman, MD[o], Richard L. Robertson, MD[p], Maura E. Ryan, MD[q], Gaurav Saigal, MD[r], Jacob Schulz, MD[s], Bruno P. Soares, MD[t], Aylin Tekes, MD[u], Andrew T. Trout, MD[v], Matthew T. Whitehead, MD[w], Boaz Karmazyn, MD[x]

Summary of Literature Review

Introduction/Background

Traumatic spine injury in children includes both accidental and abusive trauma mechanisms. Imaging in cases of suspected nonaccidental spine trauma is beyond the scope of this document and is covered in the ACR Appropriateness Criteria® topic on "Suspected Physical Abuse — Child" [1]. For spinal injury in patients >16 years of age, please refer to the Appropriateness Criteria® topic on "Suspected Spine Trauma" [2]. Spinal injuries are uncommon in children and most of the literature is based on adult populations. Only 1% to 10% of all spinal injuries affect children [3]. With the exception of abusive head trauma, spinal injuries are rarely associated with head trauma in children [4,5].

In general, the diagnostic evaluation of children with traumatic spine injury is determined by

clinical findings, such as pain, limitation of movements, and neurological deficits, as well as injury mechanisms (eg, high- versus low-energy trauma mechanisms) [6]. However, the clinical assessment of spine injuries in children may be limited in unconscious or intubated patients, in children with intellectual disabilities, and in children who lack the ability to communicate because of their developmental stage (typically <2 years of age) [7,8].

Cervical spine injuries in young children (<8 years of age) are unique. In this age group, most injuries are in the upper cervical spine because of incomplete ossification, unfused synchondroses, ligamentous laxity, and large head-to-body ratio [9]. Children have a higher risk of spinal cord injury without radiological abnormality (SCIWORA), which is defined as "clinical symptoms of traumatic myelopathy with no radiographic or CT features of spinal fracture or instability" [10]. Specifically, certain sports and recreational activities in children are associated with higher odds of SCIWORA [11]. After the age of 8 years, spinal column development matures and most injuries involve the lower cervical spine [12]. Therefore, the diagnosis, workup, and management of cervical spinal trauma in children varies with age [6].

Two major clinical decision rules, the National Emergency X-Radiography Utilization Study (NEXUS) criteria [13] and the Canadian C-Spine Rule [14], were demonstrated to have high negative predictive values (97% and 100%, respectively) to rule out cervical spine injury in adults without the need for imaging. The first NEXUS validation study [15] included children, but the sample size was small and there were few young children with cervical spine injury and none <2 years of age. A later pediatric validation study showed that no clinically important injuries were missed when the NEXUS clinical decision rule was used [16]; however, this validation study was also limited by a low incidence of cervical spine injury and small numbers of very young children [17].

The Pediatric Emergency Care Applied Research Network (PECARN) study identified risk factors associated with cervical spine injury in children in a large case control study [18]. The advantage of these risk factors is that they were based on a pediatric population and demonstrated 98% sensitivity. However, these risk factors have not yet been prospectively validated in a pediatric population. We decided to use the PECARN age <16 years to frame the variants in this document. There has only been one study evaluating predictors of cervical spine injury in blunt trauma in patients <3 years of age [19]. The study used a large cohort and a retrospective study design and there were no subsequent validation studies [19] (see Appendix 1).

Several congenital disorders have been associated with a higher risk for cervical injury in athletes. For example, increased ligamentous laxity in patients with Down syndrome is associated with higher rates of spinal cord injury; patients with achondroplasia and spinal stenosis are at risk for significant spinal cord injury at the cervicomedullary junction with hyperflexion and hyperextension; similar injury risks related to atlantoaxial instability probably apply in patients with mucopolysaccharidosis type VI and Marfan syndrome [20]. In addition, children receiving systemic glucosteroid therapy for inflammatory diseases, such as juvenile dermatomyositis, juvenile idiopathic arthritis, systemic lupus erythematosus, systemic arthritis, and systemic vasculitis, are at higher risk for vertebral body fractures [21,22].

For thoracolumbar spine fractures in children, the clinical assessment only has 81% sensitivity and 68% specificity. This argues in favor of screening children with thoracolumbar trauma with radiographs, regardless of clinical symptoms. Since thoracic and lumbar spine injuries are most

commonly seen in children >9 years of age [3], it may be appropriate to apply adult clinical decision rules to the pediatric population. A recently proposed clinical decision rule in adults (age range 15-103 years) that takes into account the patient's mental status, positive physical examination findings, trauma mechanism, and age showed sensitivity of 98.9% and specificity of 29% for clinically significant injuries [23].

Children may have cartilaginous injuries that are not visualized on radiographs but are better detected with MRI [24]. In adults, MRI is the modality of choice to evaluate thoracolumbar trauma patients with neurologic deficits, abnormal CT scans, and high clinical suspicion despite negative radiographic evaluation [25]. Recently, a scoring system based on injury morphology, neurological status, and integrity of the thoracolumbar posterior ligament complex has been introduced to guide treatment decisions in adults >17 years of age [26]. It was shown that MRI facilitates the ability to classify thoracolumbar fractures in adults and children [27,28].

Sacral fractures account for only 0.16% of all pediatric trauma patients [3]. In a retrospective study of 89 patients, only 5% sacral fractures were found, all of which were Denis zone 1 fractures [3], which are located lateral to the neural elements and commonly involve the sacral alae [29]. Adequate radiographs still miss 35% of sacral fractures; therefore, CT and MRI are superior to radiographs in the diagnosis of sacral fractures [29].

Imaging plays a crucial role in the detection and classification of traumatic spinal injuries in children. Failure to identify patients with an unstable spine injury and potential spinal cord compromise can lead to increased patient morbidity [7]. Conversely, the ability to identify patients without spinal injury can avoid unnecessary imaging and aids in the decision to discontinue spinal precaution protocols, which can result in skin breakdown and ulceration when used over prolonged periods of time [7].

Discussion of Procedures by Variant

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
A. Radiography Cervical Spine

The routine radiograph of the cervical spine in children with head trauma has a very low yield; in fact, the two cases of cervical injury in a cohort of 905 infants (0.02%) were due to an abusive trauma mechanism [4] (based on PECARN or NEXUS in Appendix 1).

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
B. CT Cervical Spine

In adult populations, CT is the superior screening modality for patients who are at very high risk for cervical spine injury. In children, there is no evidence in favor of replacing screening radiographs with CT in children at low risk for cervical spine injury [30].

Normal variants in young children <8 years of age, such as pseudosubluxation of C2-C3, absence of lordosis, C3 vertebral wedged appearance, widening of the atlantodental interval, prevertebral

soft-tissue thickening, intervertebral widening, and pseudo-Jefferson fracture, can adversely affect the accuracy of CT imaging interpretations [19]. Metrics, such as the condyle-C1 interval on CT or MRI in pediatric patients, have relatively high sensitivity (93%) but lack significantly in specificity depending on the choice of measurement cut-offs (18%–100%) [31,32].

Young children and those with developmental delays may require sedation in order to obtain adequate CT and MR images. The risks of sedation should be balanced against the benefit of a CT, particularly when radiographs are normal [19].

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
C. MRI Cervical Spine

MRI is not routinely used in the evaluation of suspected pediatric spine trauma in the absence of risk factors (based on PECARN or NEXUS in Appendix 1).

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
D. Arteriography Cervicocerebral

Cervicocerebral arteriography is not routinely used in the evaluation of suspected pediatric spine trauma in the absence of risk factors (based on PECARN or NEXUS in Appendix 1).

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
E. US Cervical Spine

Ultrasound (US) is not routinely used in the evaluation of suspected pediatric spine trauma in the absence of risk factors (based on PECARN or NEXUS in Appendix 1).

Variant 1: Child, 3 to 16 years of age, acute cervical spine trauma, meets low risk criteria (based on PECARN or NEXUS). Initial imaging.
F. CT Myelography Cervical Spine

Myelography is not routinely used in the evaluation of suspected pediatric spine trauma in the absence of risk factors (based on PECARN or NEXUS in Appendix 1).

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
A. Radiography Cervical Spine

The strength of radiographs is the visualization of bony structures. Disadvantages include the difficulty of optimal positioning in children, whether they experience pain or not, which may decrease image quality and lengthen examination times [33,34]. Radiographs do not provide detailed evaluation of the soft tissues or evaluation of intraspinal contents. In a cohort of 206 children with cervical spine injury, the sensitivity of 2 or more radiographic views for detecting cervical spine injury was 90% (95% confidence interval [CI], 85%–94%) [35]. A lateral radiograph alone had 73% sensitivity (95% CI, 50%–89%) and 92% specificity (95% CI, 87%–95%) for detecting cervical spine abnormalities compared with multidetector CT (MDCT) and that additional views did not alter sensitivity but did decrease specificity [36]. Another study stated that the sensitivity for the lateral views ranged from 79% to 85% and increased to 94% with the addition of

anteroposterior (AP) and odontoid views [37]. It should be considered that the odontoid view can be difficult to obtain as it requires exerting spine movement that poses an injury risk and can be time consuming and delay care [9].

For suspected ligamentous injury in conscious children, it was shown that cervical flexion and extension views in children and adults with acute blunt cervical trauma are unlikely to yield additional results [36,38-41] and are rarely needed in children [42]. Neck pain and muscle spasm may limit spinal motion of flexion and extension views in the acute setting and prevent the diagnosis of ligamentous injury from being made [34].

There are not sufficient data for imaging recommendations in unevaluable children. In general, two or more radiographic views detect cervical spine abnormalities with a sensitivity of 90% (95% CI, 85%–94%) [35], and lateral radiograph alone had 73% sensitivity and 92% specificity (95% CI, 87%–95%) [36]. In a study of unconscious intubated adult patients, lateral radiographs were shown to have a sensitivity of only 51.7% for unstable injuries [30,43]. A study comparing cervical spine clearance in unconscious pediatric patients using plain cervical radiographs, flexion-extension under fluoroscopy, CT, and MRI found that flexion-extension fluoroscopy in children with negative cervical radiographs or CT imaging is superior to MRI because MRI lacks specificity with regards to ligamentous injury [44,45].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
B. CT Cervical Spine

CT cervical spine may be of value as a follow-up examination in patients who had radiographs with abnormal or ambiguous findings.

The strengths of CT without intravenous (IV) contrast include its superior visualization of bony detail and ability to differentiate congenital variants from traumatic injuries. Dealing with an uncooperative child may lengthen the CT examination time and may require sedation, which adds an increased risk for complications [19]. Currently, CT is considered the reference standard for evaluation of traumatic spine injury in adults [25,46,47]. However, given the high sensitivity of radiographs [35] and MRI [48] in the detection of pediatric spine fractures and soft-tissue injuries, CT plays a lesser role in pediatric spine imaging than in adults. The sensitivity of CT for the detection of cervical spine injuries ranges from 81% to 100%, which is lower than in adults (97%–100%) [19].

Normal variants in children <8 years of age, such as pseudosubluxation of C2-C3, absence of lordosis, C3 vertebral wedged appearance, widening of the atlantodental interval, prevertebral soft-tissue thickening, intervertebral widening, and pseudo-Jefferson fracture, can adversely affect the accuracy of CT imaging interpretations [19]. In addition, children <8 years of age may need to be sedated to obtain adequate cross-sectional imaging studies, which carries a low complication risk [19].

Cervical ligamentous injury may remain undetected on CT imaging [19], and CT is not considered an effective modality for evaluation of this type of injury [49]. CT alone performs similarly in the classification of subaxial cervical spine injury as CT and MRI combined [50]. Fat-saturated T2-weighted MRI has been shown to be superior to CT and radiographs in children with craniocervical junction and soft-tissue injury [51]. In cases where MRI is not available or the patient cannot safely

undergo MRI, CT performs similarly to MRI in the evaluation of unstable cervical trauma [52].

The spine in children >8 years of age is considered to be similar to the adult spine in that the cervical spine fulcrum is located at the C3-C4 level [12]. In this age group, the lower cervical spine is more commonly injured with trauma and may be difficult to confidently evaluate on radiographs [17].

In a study of unconscious intubated adult patients, lateral radiographs were shown to have a sensitivity of only 51.7% for unstable injuries, while CT showed sensitivity of 98.1%, specificity of 98.8%, and a negative predictive value of 99.7% [30,43].

There is no pediatric scientific literature to support the use of contrast-enhanced CT in the setting of spinal trauma, although IV contrast may be given when whole-body CT is performed to evaluate for other traumatic injuries [53-55].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
C. MRI Cervical Spine

MRI of cervical spine may be of value as a follow-up examination in patients who have an abnormal neurological examination.

MRI without IV contrast is considered the reference standard for evaluation of soft tissues [48,56], although one study showed that MRI detected osseous injury in children with a sensitivity of 100% and a specificity of 97% [48]. MRI was shown to be superior to CT and radiographs in children with craniocervical junction injuries to ligaments and the spinal cord, including soft-tissue injuries that are best seen on fat-saturated T2 sequences [51]. It was shown in adults that while MRI has high sensitivity for soft-tissue injury, its lack of specificity makes it less suitable for operative decision making [45].

MRI is the modality of choice in children who fulfill criteria for myelopathy or SCIWORA [51,57-59]. It has been shown in children and adults that MRI following a completed cervical CT did not add any clinically significant information [7,60-64]. Some reports stated that adult cervical injuries were detected with MRI and not with CT and that these changed management [65,66]. A study of 45 patients showed that children with normal radiography and CT may have signs of traumatic cervical injury on MRI [51]. However, a recent meta-analysis showed that the pooled incidence of unstable injuries detected by MRI but missed on CT was 0.0029% [67].

MRI can identify vascular intramural hematomas and early ischemic spinal cord injuries and thus identify patients who may benefit from additional vascular imaging and management of ischemic complications [68]. Disadvantages include lengthy examination times in an environment where patient monitoring can be difficult. The requirement for a motion-free examination and the need for optimal positioning in children may lengthen examination times or require sedation.

In adults, cervical MRI has been recommended as the reference standard for clearing the adult cervical spine in unevaluable patients and in patients with clinical suspicion for spine injury [69-71]. MRI has been suggested for those children in whom unconsciousness is predicted to last beyond 48 hours or in whom clinical clearance within 72 hours is unlikely [72]. Meta-analyses in adults showed that it was safe to clear the adult cervical spine in unevaluable patients based on CT scans

[73-75]. Interestingly, the United Kingdom's National Institute for Health Care Excellence guidelines suggest that in children <16 years of age, cervical MRI should be the first imaging modality both for suspected spinal cord and spinal column injury [76].

There are no pediatric studies comparing IV contrast versus noncontrast MRI for the detection of spinal cord injury, but adult studies have shown that contrast-enhanced MRI may be more effective in the evaluation of severe soft-tissue injury but is not more effective for the detection of spinal cord injury [77].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
D. CTA Neck

There are currently no sufficient reports regarding outcomes of vascular imaging in children with spinal trauma. Cervical vascular injury in pediatric blunt trauma can be seen in 11.5% of pediatric patients [68]. CT angiography (CTA) has been validated against digital subtraction angiography (DSA) for imaging of cerebrovascular injury in adults, but DSA remains the reference standard [68]. When compared to DSA, CTA has the benefit of being less time intensive, having a lower risk of iatrogenic injury, and having fewer complications than those associated with DSA (such as stroke or death, arterial dissection, and vasospasm) [68,78]. CTA can also be easily performed in conjunction with other CT examinations, and the noninvasive nature of CTA makes it better suited as a screening tool in cervical trauma patients [68,78-80]. Both CTA and MR angiography (MRA) may be considered in children with cervical trauma [68]. Certain risk factors can indicate the need for vascular screening, such as fractures involving the transverse foramen, traumatic facet dislocations (with or without fracture), ligamentous injury, neurological deficits, and fractures of C1-C3 [68,80-82]. Injury patterns at C2 that are specifically associated with vertebral artery injury in adults are dens fractures and traumatic spondylolisthesis [83]. Cerebrovascular injury after blunt trauma was diagnosed with CTA in 5.8% of 137 children with blunt trauma [84]. Scoring systems to identify adult patients that should undergo vascular imaging exist, but they have not been validated in children [85].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
E. MRA Neck

In adults, the role of MRA relative to DSA is less well established [68]. Studies comparing CTA, MRA, and DSA have found that CTA has comparable accuracy compared to DSA, while MRA tended to overestimate stenosis and occlusion [68]. Lower-grade vascular injuries may be missed with CTA but not with DSA, even though they are usually asymptomatic [80]. A benefit of MRA over CTA and DSA is its ability to identify intramural hematomas and early ischemic injuries [68]. To date, despite the benefits of MRI as a noninvasive examination, the Eastern Association for the Surgery of Trauma states that MRA should not be considered as the sole imaging modality for blunt cerebrovascular injury based on lower sensitivity of MRA relative to DSA in detecting traumatic vascular injuries in adults [86].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
F. Arteriography Cervicocerebral

DSA remains the reference standard for cerebrovascular injury in adults [68]. There is no recent scientific literature evaluating the use of DSA in children with spinal trauma. DSA is more time

consuming and associated with severe risks, including thrombosis, that could lead to stroke or death, arterial dissection, and vasospasm [68,78].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
G. US Cervical Spine

The value of US has only recently been explored in pediatric cervical spine trauma and is not yet established [87]. Integrity of the posterior ligamentous complex plays an integral role for stability of the spine, and presence of posterior ligamentous complex injury may indicate more severe damage and change treatment interventions [88]. MRI is the modality of choice for evaluation of the posterior ligamentous complex, but it was shown that its sensitivity and specificity are lower than previously thought [89].

Variant 2: Child, 3 to 16 years of age, acute cervical spine trauma, at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). Initial imaging.
H. CT Myelography Cervical Spine

CT myelography is rarely performed and has been largely replaced with MRI. Exceptional indications may exist for patients with contraindications to MRI and in whom impending cord compression is suspected [90].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
A. Radiography Cervical Spine

In children <3 years of age and in children with delays or other deficits, lack of verbal and cognitive skills represents the main limiting factor for establishing appropriate imaging indications based on the clinical examination. Anatomically, in children <3 years of age the dentocentral synchondrosis is still open and the C3-C7 neural arches have not yet fused [91]. A review of the National Trauma Data Bank showed that 48% of cervical spine injuries in children <3 years of age occurred in the lower cervical spine [54]. Nonetheless, children <3 years of age on average and children in forward-facing car seats can experience odontoid fractures, particularly with rapid deceleration with flexion [91]. Radiographs in conjunction with NEXUS criteria were used to clear 80% of cervical spine injuries in a cohort of 575 patients <3 years of age [42]. Certain clinical criteria have been proposed specifically in children <3 years of age to determine the necessity of imaging [19].

A study comparing cervical spine clearance in unconscious pediatric patients using plain cervical radiographs, flexion-extension under fluoroscopy, CT, and MRI imaging found that flexion-extension fluoroscopy in children with negative cervical radiographs and/or CT imaging is superior to MRI because MRI lacks specificity with regards to differentiating ligamentous edema from rupture [44,45].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
B. CT Cervical Spine

CT cervical spine may be of value as a follow-up examination in patients who had radiographs with abnormal or ambiguous findings.

Normal variants in children <3 years of age, such as pseudosubluxation of C2-C3, absence of lordosis, C3 vertebral wedged appearance, widening of the atlantodental interval, prevertebral soft-tissue thickening, intervertebral widening, and pseudo-Jefferson fracture, can adversely affect the accuracy of CT imaging interpretations [19]. In addition, children <3 years of age may need to be sedated to obtain adequate cross-sectional imaging studies, which carries a low complication risk [19].

There is no pediatric scientific literature to support the use of contrast-enhanced CT in the setting of spinal trauma, although IV contrast may be given when whole-body CT is performed to evaluate for other traumatic injuries [53-55].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
C. MRI Cervical Spine

MRI of cervical spine may be of value as a follow-up examination in patients who have an abnormal neurological examination.

The best imaging modality for evaluation of newborn spinal cord injury secondary to cervical spine trauma is MRI [92]. Neonatal spinal cord injury is a rare condition with an estimated incidence of 1 in 80,000 live births.

MRI was shown to be superior to CT and radiographs in children with craniocervical junction injuries, including soft-tissue injuries that are best seen on fat-saturated T2 sequences [51].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
D. CTA Neck

There are currently no sufficient reports regarding outcomes of vascular imaging in children with spinal trauma. Cervical vascular injury in pediatric blunt trauma can be seen in 11.5% of pediatric patients [68]. CTA has been validated against DSA for imaging of cerebrovascular injury in adults, but DSA remains the reference standard [68]. When compared to DSA, CTA has the benefit of being less time intensive, having a lower risk of iatrogenic injury, and having fewer complications than those associated with DSA (such as stroke or death, arterial dissection, and vasospasm) [68,78]. CTA can also be easily performed in conjunction with other CT examinations, and the noninvasive nature of CTA makes it better suited as a screening tool in cervical trauma patients [68,78-80]. Both CTA and MRA may be considered in children with cervical trauma [68]. Certain risk factors can indicate the need for vascular screening, such as fractures involving the transverse foramen, traumatic facet dislocations (with or without fracture), ligamentous injury, neurological deficits, and fractures of C1-C3 [68,80-82]. Injury patterns at C2 that are specifically associated with vertebral artery injury in adults are dens fractures and traumatic spondylolisthesis [83]. Cerebrovascular injury after blunt trauma was diagnosed with CTA in 5.8% of 137 children with blunt trauma [84]. Scoring systems to identify adult patients that should undergo vascular imaging exist, but they have not been validated in children [85].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
E. MRA Neck

In adults, the role of MRA relative to DSA is less well established [68]. Studies comparing CTA,

MRA, and DSA have found that CTA has comparable accuracy compared to DSA, while MRA tended to overestimate stenosis and occlusion [68]. Lower-grade vascular injuries may be missed with CTA but not with DSA, even though they are usually asymptomatic [80]. A benefit of MRA over CTA and DSA is its ability to identify intramural hematomas and early ischemic injuries [68]. To date, despite the benefits of MRI as a noninvasive examination, the Eastern Association for the Surgery of Trauma states that MRA should not be considered as the sole imaging modality for blunt cerebrovascular injury based on lower sensitivity of MRA relative to DSA in detecting traumatic vascular injuries in adults [86].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
F. Arteriography Cervicocerebral

DSA remains the reference standard for cerebrovascular injury in adults [68]. There is no recent scientific literature evaluating the use of DSA in children with spinal trauma. DSA is more time consuming and associated with severe risks that include thrombosis that could lead to stroke or death, arterial dissection, and vasospasm [68,78].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
G. US Cervical Spine

The value of US has only recently been explored in pediatric cervical spine trauma and is not yet established [87]. Integrity of the posterior ligamentous complex plays an integral role for stability of the spine, and presence of posterior ligamentous complex injury may indicate more severe damage and change treatment interventions [88]. MRI is the modality of choice for evaluation of the posterior ligamentous complex, but it was shown that its sensitivity and specificity are lower than previously thought [89].

Variant 3: Child, younger than 3 years of age, acute cervical spine trauma, Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points. Initial imaging.
H. CT Myelography Cervical Spine

CT myelography is rarely performed and has been largely replaced with MRI. Exceptional indications may exist for patients with contraindications to MRI and in whom impending cord compression is suspected [90].

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
A. Radiography Thoracic and Lumbar Spine

It was estimated that only 0.6% to 0.9% of all pediatric spinal injuries affect the thoracolumbar supine [93]. There are currently no national guidelines to inform clinicians whether an imaging examination would be beneficial for an individual patient or not [93]. Thoracic and lumbar spine injuries are most commonly seen in children >9 years of age [3].

The clinical diagnosis of thoracolumbar spine fractures in children is frequently difficult because the clinical assessment has only 81% sensitivity and 68% specificity [24]. This argues in favor of screening children with thoracolumbar trauma with radiographs, regardless of clinical symptoms. However, a prospective study in 50 children with thoracolumbar trauma showed that AP and lateral

radiographs missed 22% of fractures when compared to MRI [24]. As shown in adults, it may be useful to screen for thoracolumbar fractures by using reconstructed spine images from chest, abdomen, and pelvis MDCT when available [94-96].

Sacral fractures account for only 0.16% of all pediatric trauma patients [3]. In a retrospective study of 89 patients, only 5% sacral fractures were found, all of which were Denis zone 1 fractures [3], which are located lateral to the neural elements and commonly involve the sacral alae [29]. Another study reported that adequate radiographs miss 35% of sacral fractures and, therefore, CT and MRI are superior to radiography in the diagnosis of sacral fractures [29].

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
B. CT Thoracic and Lumbar Spine

CT spine may be of value as a follow-up examination in patients who had radiographs with abnormal or ambiguous findings.

There are not sufficient data to support the routine use of MDCT without IV contrast in the clearance of pediatric blunt spinal trauma. As shown in adults, it may be useful to screen for thoracolumbar fractures by using reconstructed spine images from chest, abdomen, and pelvis MDCT, when available [94-96]. Adequate radiographs miss 35% of sacral fractures; therefore, CT and MRI are superior to radiography in the diagnosis of sacral fractures [29]. A recent study in adults showed that CT can identify posterior ligament complex injuries with satisfactory reliability, which can be useful for the classification of thoracolumbar fractures [97].

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
C. MRI Thoracic and Lumbar Spine

MRI of the spine may be of value as a follow-up examination in patients who have an abnormal neurological examination.

MRI without IV contrast has become the modality of choice for imaging of children with thoracolumbar trauma and is especially useful in detecting injuries that require surgical intervention and that may be missed on CT, such as epidural hematoma or traumatic disk herniation [93]. SCIWORA is more common in children <8 years of age and mostly affects the cervical spine, but thoracic spine involvement is seen in 13% of cases [93]. It has been reported that SCIWORA was found in up to 38% of pediatric patients with myelopathy and no fracture or ligamentous injury on radiographs or CT [91]. In adults with SCIWORA, MRI screening did not yield positive findings in a substantial number of patients [98], but examinations in children were able to diagnose cord transection, contusion, and concussion in children <8 years of age with significant prognostic correlations [59]. In addition, children may have cartilaginous injuries that are not visualized on radiographs but are better detected with MRI [24]. It was shown that MRI facilitates the ability to classify thoracolumbar fractures in adults and children to aid in clinical decision making [27,28]. Adequate radiographs miss 35% of sacral fractures; therefore, CT and MRI are superior to radiography in the diagnosis of sacral fractures [29].

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
D. CTA Thoracic and Lumbar Spine

CTA is not routinely used in the evaluation of children with thoracolumbar trauma.

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
E. MRA Thoracic and Lumbar Spine

MRA is not routinely used in the evaluation of children with thoracolumbar trauma.

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
F. Arteriography Thoracic and Lumbar Spine

Arteriography is not routinely used in the evaluation of children with thoracolumbar trauma.

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
G. US Thoracic and Lumbar Spine

Integrity of the posterior ligamentous complex plays an integral role for stability of the spine, and presence of posterior ligamentous complex injury may indicate more severe damage and change treatment interventions [88]. MRI is the modality of choice for evaluation of the posterior ligamentous complex, but it was shown that its sensitivity and specificity are lower than previously thought [89]. In a prospective study of 18 adult patients with acute thoracolumbar burst fractures, US was used to assess the posterior ligament complex and achieved a sensitivity of 99% and a specificity of 75% ($P < .05$) when compared to operative results and preoperative radiographs, CT, and MRI [99].

Variant 4: Child, younger than 16 years of age, suspected thoracolumbar spine trauma. Initial imaging.
H. CT Myelography Thoracic and Lumbar Spine

CT myelography is rarely performed and has been largely replaced with MRI. Exceptional indications may exist for patients with contraindications to MRI and in whom impending cord compression is suspected [90].

Summary of Highlights

- **Variant 1:** Imaging is not recommended for the initial imaging of children 3 to 16 years of age with acute cervical spine trauma that meets low risk criteria (based on PECARN or NEXUS).
- **Variant 2:** Radiographs of the cervical spine are usually appropriate for the initial imaging of children 3 to 16 years of age with acute cervical spine trauma with at least one risk factor with reliable clinical examination (based on PECARN or NEXUS). The panel did not agree on recommending CT cervical spine without IV contrast or MRI cervical spine without IV contrast in children 3 to 16 years of age with this clinical condition. There is insufficient medical literature to conclude whether or not these patients would benefit from these procedures. CT cervical spine without IV contrast or MRI cervical spine without IV contrast as the initial imaging of children 3 to 16 years of age with acute cervical spine trauma and at least one risk factor with reliable clinical examination (based on PECARN or NEXUS) is controversial but may be appropriate.
- **Variant 3:** Radiographs of the cervical spine are usually appropriate for the initial imaging of children younger than 3 years of age with acute cervical spine trauma with a Pieretti-

Vanmarcke weighted score greater than or equal to 2 to 8 points. The panel did not agree on recommending MRI cervical spine without IV contrast in children younger than 3 years of age with this clinical condition. There is insufficient medical literature to conclude whether or not these patients would benefit from these procedures. MRI cervical spine without IV contrast as the initial imaging of children younger than 3 years of age with acute cervical spine trauma with a Pieretti-Vanmarcke weighted score greater than or equal to 2 to 8 points is controversial but may be appropriate.

- **Variant 4:** Radiographs of the thoracic and lumbar spine are usually appropriate for the initial imaging of children younger than 16 years of age with suspected thoracolumbar spine trauma. The panel did not agree on recommending CT thoracic and lumbar spine without IV contrast or MRI thoracic and lumbar spine without IV contrast in children younger than 16 years of age with this clinical condition. There is insufficient medical literature to conclude whether or not these patients would benefit from these procedures. CT thoracic and lumbar spine without IV contrast or MRI thoracic and lumbar spine without IV contrast as the initial imaging of children younger than 16 years of age with suspected thoracolumbar spine trauma is controversial but may be appropriate.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be

		unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as “Varies.”

References

1. American College of Radiology. ACR Appropriateness Criteria®: Suspected Physical Abuse — Child. Available at: https://acsearch.acr.org/docs/69443/Narrative/.
2. American College of Radiology. ACR Appropriateness Criteria®: Suspected Spine Trauma. Available at: https://acsearch.acr.org/docs/69359/Narrative/.
3. Dogan S, Safavi-Abbasi S, Theodore N, et al. Thoracolumbar and sacral spinal injuries in children and adolescents: a review of 89 cases. J Neurosurg. 2007;106(6 Suppl):426-433.
4. Katz JS, Oluigbo CO, Wilkinson CC, McNatt S, Handler MH. Prevalence of cervical spine injury in infants with head trauma. J Neurosurg Pediatrics. 5(5):470-3, 2010 May.
5. Ryan ME, Palasis S, Saigal G, et al. ACR Appropriateness Criteria head trauma--child. J. Am. Coll. Radiol.. 11(10):939-47, 2014 Oct.
6. Madura CJ, Johnston JM, Jr. Classification and Management of Pediatric Subaxial Cervical Spine Injuries. Neurosurg Clin N Am. 2017;28(1):91-102.
7. Adams JM, Cockburn MI, Difazio LT, Garcia FA, Siegel BK, Bilaniuk JW. Spinal clearance in the difficult trauma patient: a role for screening MRI of the spine. Am Surg. 2006;72(1):101-105.

8. Halpern CH, Milby AH, Guo W, Schuster JM, Gracias VH, Stein SC. Clearance of the cervical spine in clinically unevaluable trauma patients. [Review]. Spine. 35(18):1721-8, 2010 Aug 15.

9. Egloff AM, Kadom N, Vezina G, Bulas D. Pediatric cervical spine trauma imaging: a practical approach. Pediatr Radiol. 2009;39(5):447-456.

10. Pang D, Wilberger JE, Jr. Spinal cord injury without radiographic abnormalities in children. J Neurosurg 1982;57:114-29.

11. Babcock L, Olsen CS, Jaffe DM, Leonard JC, Cervical Spine Study Group for the Pediatric Emergency Care Applied Research N. Cervical Spine Injuries in Children Associated With Sports and Recreational Activities. Pediatr Emerg Care 2016.

12. Adelgais KM, Browne L, Holsti M, Metzger RR, Murphy SC, Dudley N. Cervical spine computed tomography utilization in pediatric trauma patients. J Pediatr Surg. 2014;49(2):333-337.

13. Hoffman JR, Schriger DL, Mower W, Luo JS, Zucker M. Low-risk criteria for cervical-spine radiography in blunt trauma: a prospective study. Ann Emerg Med. 1992;21(12):1454-1460.

14. Stiell IG, Clement CM, McKnight RD, et al. The Canadian C-spine rule versus the NEXUS low-risk criteria in patients with trauma. N Engl J Med. 2003; 349(26):2510-2518.

15. Hoffman JR, Mower WR, Wolfson AB, Todd KH, Zucker MI. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National Emergency X-Radiography Utilization Study Group.[Erratum appears in N Engl J Med 2001 Feb 8;344(6):464]. N Engl J Med. 343(2):94-9, 2000 Jul 13.

16. Viccellio P, Simon H, Pressman BD, Shah MN, Mower WR, Hoffman JR. A prospective multicenter study of cervical spine injury in children. Pediatrics. 108(2):E20, 2001 Aug.

17. Garton HJ, Hammer MR. Detection of pediatric cervical spine injury. Neurosurgery. 2008;62(3):700-708; discussion 700-708.

18. Leonard JC, Kuppermann N, Olsen C, et al. Factors associated with cervical spine injury in children after blunt trauma. Ann Emerg Med. 2011;58(2):145-155.

19. Pieretti-Vanmarcke R, Velmahos GC, Nance ML, et al. Clinical clearance of the cervical spine in blunt trauma patients younger than 3 years: a multi-center study of the american association for the surgery of trauma. Journal of Trauma-Injury Infection & Critical Care. 67(3):543-9; discussion 549-50, 2009 Sep.

20. Jagannathan J, Dumont AS, Prevedello DM, Shaffrey CI, Jane JA, Jr. Cervical spine injuries in pediatric athletes: mechanisms and management. Neurosurg Focus. 2006;21(4):E6.

21. Huber AM, Gaboury I, Cabral DA, et al. Prevalent vertebral fractures among children initiating glucocorticoid therapy for the treatment of rheumatic disorders. Arthritis Care Res (Hoboken). 2010;62(4):516-526.

22. Rodd C, Lang B, Ramsay T, et al. Incident vertebral fractures among children with rheumatic disorders 12 months after glucocorticoid initiation: a national observational study. Arthritis Care Res (Hoboken). 2012;64(1):122-131.

23. Inaba K, Nosanov L, Menaker J, et al. Prospective derivation of a clinical decision rule for thoracolumbar spine evaluation after blunt trauma: An American Association for the Surgery of Trauma Multi-Institutional Trials Group Study. J Trauma Acute Care Surg.

78(3):459-65; discussion 465-7, 2015 Mar.

24. Leroux J, Vivier PH, Ould Slimane M, et al. Early diagnosis of thoracolumbar spine fractures in children. A prospective study. Orthop Traumatol Surg Res. 99(1):60-5, 2013 Feb.

25. Diaz JJ Jr, Cullinane DC, Altman DT, et al. Practice management guidelines for the screening of thoracolumbar spine fracture. J Trauma. 63(3):709-18, 2007 Sep.

26. Joaquim AF, Ghizoni E, Tedeschi H, Batista UC, Patel AA. Clinical results of patients with thoracolumbar spine trauma treated according to the Thoracolumbar Injury Classification and Severity Score. Journal of Neurosurgery Spine. 20(5):562-7, 2014 May.

27. de Gauzy JS, Jouve JL, Violas P, et al. Classification of chance fracture in children using magnetic resonance imaging. Spine (Phila Pa 1976). 2007;32(2):E89-92.

28. Salgado A, Pizones J, Sanchez-Mariscal F, Alvarez P, Zuniga L, Izquierdo E. MRI reliability in classifying thoracolumbar fractures according to AO classification. Orthopedics. 2013;36(1):e75-78.

29. White JH, Hague C, Nicolaou S, Gee R, Marchinkow LO, Munk PL. Imaging of sacral fractures. Clin Radiol. 2003;58(12):914-921.

30. Holmes JF, Akkinepalli R. Computed tomography versus plain radiography to screen for cervical spine injury: a meta-analysis. [Review] [21 refs]. Journal of Trauma-Injury Infection & Critical Care. 58(5):902-5, 2005 May.

31. Corcoran B, Linscott LL, Leach JL, Vadivelu S. Application of Normative Occipital Condyle-C1 Interval Measurements to Detect Atlanto-Occipital Injury in Children. AJNR Am J Neuroradiol 2016;37:958-62.

32. Smith P, Linscott LL, Vadivelu S, Zhang B, Leach JL. Normal Development and Measurements of the Occipital Condyle-C1 Interval in Children and Young Adults. AJNR Am J Neuroradiol 2016;37:952-7.

33. Avellino AM, Mann FA, Grady MS, et al. The misdiagnosis of acute cervical spine injuries and fractures in infants and children: the 12-year experience of a level I pediatric and adult trauma center. Childs Nerv Syst. 2005;21(2):122-127.

34. Sundgren PC, Philipp M, Maly PV. Spinal trauma. Neuroimaging Clin N Am. 2007;17(1):73-85.

35. Nigrovic LE, Rogers AJ, Adelgais KM, et al. Utility of plain radiographs in detecting traumatic injuries of the cervical spine in children. Pediatr Emerg Care. 28(5):426-32, 2012 May.

36. Silva CT, Doria AS, Traubici J, Moineddin R, Davila J, Shroff M. Do additional views improve the diagnostic performance of cervical spine radiography in pediatric trauma? AJR. 2010; 194(2):500-508.

37. Kulaylat AN, Tice JG, Levin M, Kunselman AR, Methratta ST, Cilley RE. Reduction of radiation exposure in pediatric patients with trauma: cephalic stabilization improves adequacy of lateral cervical spine radiographs. J Pediatr Surg. 2012;47(5):984-990.

38. Nasir S, Hussain M, Mahmud R. Flexion/extension cervical spine views in blunt cervical trauma. Chinese Journal of Traumatology. 15(3):166-9, 2012.

39. Pollack CV Jr, Hendey GW, Martin DR, Hoffman JR, Mower WR. Use of flexion-extension

radiographs of the cervical spine in blunt trauma. Annals of Emergency Medicine. 38(1):8-11, 2001 Jul.

40. Rana AR, Drongowski R, Breckner G, Ehrlich PF. Traumatic cervical spine injuries: characteristics of missed injuries. J Pediatr Surg. 2009;44(1):151-155; discussion 155.

41. Sierink JC, van Lieshout WA, Beenen LF, Schep NW, Vandertop WP, Goslings JC. Systematic review of flexion/extension radiography of the cervical spine in trauma patients. [Review]. European Journal of Radiology. 82(6):974-81, 2013 Jun.

42. Anderson RC, Kan P, Vanaman M, et al. Utility of a cervical spine clearance protocol after trauma in children between 0 and 3 years of age. J Neurosurg Pediatrics. 5(3):292-6, 2010 Mar.

43. Brohi K, Healy M, Fotheringham T, et al. Helical computed tomographic scanning for the evaluation of the cervical spine in the unconscious, intubated trauma patient. J Trauma. 2005; 58(5):897-901.

44. Brockmeyer DL, Ragel BT, Kestle JR. The pediatric cervical spine instability study. A pilot study assessing the prognostic value of four imaging modalities in clearing the cervical spine for children with severe traumatic injuries. Childs Nerv Syst. 28(5):699-705, 2012 May.

45. Zhuge W, Ben-Galim P, Hipp JA, Reitman CA. Efficacy of MRI for assessment of spinal trauma: correlation with intraoperative findings. J Spinal Disord Tech. 28(4):147-51, 2015 May.

46. Brown CV, Antevil JL, Sise MJ, Sack DI. Spiral computed tomography for the diagnosis of cervical, thoracic, and lumbar spine fractures: its time has come. J Trauma. 2005; 58(5):890-895; discussion 895-896.

47. Sixta S, Moore FO, Ditillo MF, et al. Screening for thoracolumbar spinal injuries in blunt trauma: an Eastern Association for the Surgery of Trauma practice management guideline. The Journal of Trauma and Acute Care Surgery. 73(5 Suppl 4):S326-32, 2012 Nov.

48. Henry M, Riesenburger RI, Kryzanski J, Jea A, Hwang SW. A retrospective comparison of CT and MRI in detecting pediatric cervical spine injury. Childs Nerv Syst. 29(8):1333-8, 2013 Aug.

49. Diaz JJ, Jr., Aulino JM, Collier B, et al. The early work-up for isolated ligamentous injury of the cervical spine: does computed tomography scan have a role? J Trauma. 2005; 59(4):897-903; discussion 903-894.

50. Mascarenhas D, Dreizin D, Bodanapally UK, Stein DM. Parsing the Utility of CT and MRI in the Subaxial Cervical Spine Injury Classification (SLIC) System: Is CT SLIC Enough?. AJR Am J Roentgenol. 206(6):1292-7, 2016 Jun.

51. Junewick JJ, Meesa IR, Luttenton CR, Hinman JM. Occult injury of the pediatric craniocervical junction. EMERG. RADIOL.. 16(6):483-8, 2009 Nov.

52. Gargas J, Yaszay B, Kruk P, Bastrom T, Shellington D, Khanna S. An analysis of cervical spine magnetic resonance imaging findings after normal computed tomographic imaging findings in pediatric trauma patients: ten-year experience of a level I pediatric trauma center. The Journal of Trauma and Acute Care Surgery. 74(4):1102-7, 2013 Apr.

53. Beenen LF, Sierink JC, Kolkman S, et al. Split bolus technique in polytrauma: a prospective study on scan protocols for trauma analysis. Acta Radiol. 56(7):873-80, 2015 Jul.

54. Kreykes NS, Letton RW Jr. Current issues in the diagnosis of pediatric cervical spine injury. [Review]. Semin Pediatr Surg. 19(4):257-64, 2010 Nov.

55. Yaniv G, Portnoy O, Simon D, Bader S, Konen E, Guranda L. Revised protocol for whole-body CT for multi-trauma patients applying triphasic injection followed by a single-pass scan on a 64-MDCT. Clin Radiol. 68(7):668-75, 2013 Jul.

56. Morais DF, de Melo Neto JS, Meguins LC, Mussi SE, Filho JR, Tognola WA. Clinical applicability of magnetic resonance imaging in acute spinal cord trauma. Eur Spine J. 2014;23(7):1457-1463.

57. Bagley LJ. Imaging of spinal trauma. [Review] [56 refs]. Radiologic Clinics of North America. 44(1):1-12, vii, 2006 Jan.

58. Easter JS, Barkin R, Rosen CL, Ban K. Cervical spine injuries in children, part II: management and special considerations. [Review]. J Emerg Med. 41(3):252-6, 2011 Sep.

59. Liao CC, Lui TN, Chen LR, Chuang CC, Huang YC. Spinal cord injury without radiological abnormality in preschool-aged children: correlation of magnetic resonance imaging findings with neurological outcomes. Journal of Neurosurgery. 103(1 Suppl):17-23, 2005 Jul.

60. Khanna P, Chau C, Dublin A, Kim K, Wisner D. The value of cervical magnetic resonance imaging in the evaluation of the obtunded or comatose patient with cervical trauma, no other abnormal neurological findings, and a normal cervical computed tomography. J Trauma Acute Care Surg. 72(3):699-702, 2012 Mar.

61. Qualls D, Leonard JR, Keller M, Pineda J, Leonard JC. Utility of magnetic resonance imaging in diagnosing cervical spine injury in children with severe traumatic brain injury. The Journal of Trauma and Acute Care Surgery. 78(6):1122-8, 2015 Jun.

62. Satahoo SS, Davis JS, Garcia GD, et al. Sticking our neck out: is magnetic resonance imaging needed to clear an obtunded patient's cervical spine? J Surg Res. 2014;187(1):225-229.

63. Steigelman M, Lopez P, Dent D, et al. Screening cervical spine MRI after normal cervical spine CT scans in patients in whom cervical spine injury cannot be excluded by physical examination. Am J Surg. 2008;196(6):857-862; discussion 862-853.

64. Tomycz ND, Chew BG, Chang YF, et al. MRI is unnecessary to clear the cervical spine in obtunded/comatose trauma patients: the four-year experience of a level I trauma center. J Trauma. 2008; 64(5):1258-1263.

65. Menaker J, Philp A, Boswell S, Scalea TM. Computed tomography alone for cervical spine clearance in the unreliable patient--are we there yet? J Trauma. 2008; 64(4):898-903; discussion 903-894.

66. Russin JJ, Attenello FJ, Amar AP, Liu CY, Apuzzo ML, Hsieh PC. Computed tomography for clearance of cervical spine injury in the unevaluable patient. World Neurosurg. 80(3-4):405-13, 2013 Sep-Oct.

67. Malhotra A, Wu X, Kalra VB, et al. Utility of MRI for cervical spine clearance after blunt traumatic injury: a meta-analysis. [Review]. European Radiology. 27(3):1148-1160, 2017 Mar.

68. Tolhurst SR, Vanderhave KL, Caird MS, et al. Cervical arterial injury after blunt trauma in

children: characterization and advanced imaging. Journal of Pediatric Orthopedics. 33(1):37-42, 2013 Jan.

69. Fisher BM, Cowles S, Matulich JR, Evanson BG, Vega D, Dissanaike S. Is magnetic resonance imaging in addition to a computed tomographic scan necessary to identify clinically significant cervical spine injuries in obtunded blunt trauma patients?. American Journal of Surgery. 206(6):987-93; discussion 993-4, 2013 Dec.

70. Muchow RD, Resnick DK, Abdel MP, Munoz A, Anderson PA. Magnetic resonance imaging (MRI) in the clearance of the cervical spine in blunt trauma: a meta-analysis. J Trauma. 64(1):179-89, 2008 Jan.

71. Flynn JM, Closkey RF, Mahboubi S, Dormans JP. Role of magnetic resonance imaging in the assessment of pediatric cervical spine injuries. J Pediatr Orthop 2002;22:573-7.

72. Hutchings L, Atijosan O, Burgess C, Willett K. Developing a spinal clearance protocol for unconscious pediatric trauma patients. J Trauma. 2009;67(4):681-686.

73. Panczykowski DM, Tomycz ND, Okonkwo DO. Comparative effectiveness of using computed tomography alone to exclude cervical spine injuries in obtunded or intubated patients: meta-analysis of 14,327 patients with blunt trauma. [Review]. J Neurosurg. 115(3):541-9, 2011 Sep.

74. Raza M, Elkhodair S, Zaheer A, Yousaf S. Safe cervical spine clearance in adult obtunded blunt trauma patients on the basis of a normal multidetector CT scan--a meta-analysis and cohort study. [Review]. Injury. 44(11):1589-95, 2013 Nov.

75. Schoenwaelder M, Maclaurin W, Varma D. Assessing potential spinal injury in the intubated multitrauma patient: does MRI add value?. EMERG. RADIOL.. 16(2):129-32, 2009 Mar.

76. National Institute for Health and Care Excellence. Spinal injury: assessment and initial management. NICE guideline [NG41]. Available at: https://www.nice.org.uk/guidance/ng41.

77. Ghasemi A, Haddadi K, Shad AA. Comparison of Diagnostic Accuracy of MRI with and Without Contrast in Diagnosis of Traumatic Spinal Cord Injuries. Medicine. 94(43):e1942, 2015 Oct.

78. Eastman AL, Chason DP, Perez CL, McAnulty AL, Minei JP. Computed tomographic angiography for the diagnosis of blunt cervical vascular injury: is it ready for primetime? J Trauma. 2006;60(5):925-929; discussion 929.

79. Fleck SK, Langner S, Baldauf J, Kirsch M, Rosenstengel C, Schroeder HW. Blunt craniocervical artery injury in cervical spine lesions: the value of CT angiography. Acta Neurochir (Wien). 2010;152(10):1679-1686.

80. Payabvash S, McKinney AM, McKinney ZJ, Palmer CS, Truwit CL. Screening and detection of blunt vertebral artery injury in patients with upper cervical fractures: the role of cervical CT and CT angiography. Eur J Radiol. 83(3):571-7, 2014 Mar.

81. Chung D, Sung JK, Cho DC, Kang DH. Vertebral artery injury in destabilized midcervical spine trauma; predisposing factors and proposed mechanism. Acta Neurochir (Wien). 154(11):2091-8; discussion 2098, 2012 Nov.

82. Kopelman TR, Leeds S, Berardoni NE, et al. Incidence of blunt cerebrovascular injury in low-

risk cervical spine fractures. American Journal of Surgery. 202(6):684-8; discussion 688-9, 2011 Dec.

83. Durand D, Wu X, Kalra VB, Abbed KM, Malhotra A. Predictors of Vertebral Artery Injury in Isolated C2 Fractures Based on Fracture Morphology Using CT Angiography. Spine (Phila Pa 1976). 2015;40(12):E713-718.

84. Desai NK, Kang J, Chokshi FH. Screening CT angiography for pediatric blunt cerebrovascular injury with emphasis on the cervical "seatbelt sign". Ajnr: American Journal of Neuroradiology. 35(9):1836-40, 2014 Sep.

85. Delgado Almandoz JE, Schaefer PW, Kelly HR, Lev MH, Gonzalez RG, Romero JM. Multidetector CT angiography in the evaluation of acute blunt head and neck trauma: a proposed acute craniocervical trauma scoring system. Radiology. 254(1):236-44, 2010 Jan.

86. Bromberg WJ, Collier BC, Diebel LN, et al. Blunt cerebrovascular injury practice management guidelines: the Eastern Association for the Surgery of Trauma. J Trauma. 68(2):471-7, 2010 Feb.

87. Agrawal D, Sinha TP, Bhoi S. Assessment of ultrasound as a diagnostic modality for detecting potentially unstable cervical spine fractures in pediatric severe traumatic brain injury: A feasibility study. J Pediatr Neurosci. 2015;10(2):119-122.

88. Machino M, Yukawa Y, Ito K, Kanbara S, Morita D, Kato F. Posterior ligamentous complex injuries are related to fracture severity and neurological damage in patients with acute thoracic and lumbar burst fractures. Yonsei Med J. 2013;54(4):1020-1025.

89. Vaccaro AR, Rihn JA, Saravanja D, et al. Injury of the posterior ligamentous complex of the thoracolumbar spine: a prospective evaluation of the diagnostic accuracy of magnetic resonance imaging. Spine. 34(23):E841-7, 2009 Nov 01.

90. Heinemann U, Freund M. Diagnostic strategies in spinal trauma. Eur J Radiol. 2006;58(1):76-88.

91. Jones TM, Anderson PA, Noonan KJ. Pediatric cervical spine trauma. [Review]. J Am Acad Orthop Surg. 19(10):600-11, 2011 Oct.

92. Brand MC. Part 1: recognizing neonatal spinal cord injury. Adv Neonatal Care. 2006;6(1):15-24.

93. Srinivasan V, Jea A. Pediatric Thoracolumbar Spine Trauma. Neurosurg Clin N Am. 2017;28(1):103-114.

94. Kim S, Yoon CS, Ryu JA, et al. A comparison of the diagnostic performances of visceral organ-targeted versus spine-targeted protocols for the evaluation of spinal fractures using sixteen-channel multidetector row computed tomography: is additional spine-targeted computed tomography necessary to evaluate thoracolumbar spinal fractures in blunt trauma victims? J Trauma 2010;69:437-46.

95. Lucey BC, Stuhlfaut JW, Hochberg AR, Varghese JC, Soto JA. Evaluation of blunt abdominal trauma using PACS-based 2D and 3D MDCT reformations of the lumbar spine and pelvis. AJR. 2005; 185(6):1435-1440.

96. Roos JE, Hilfiker P, Platz A, et al. MDCT in emergency radiology: is a standardized chest or abdominal protocol sufficient for evaluation of thoracic and lumbar spine trauma? AJR Am J Roentgenol. 2004;183(4):959-968.

97. Barcelos AC, Joaquim AF, Botelho RV. Reliability of the evaluation of posterior ligamentous complex injury in thoracolumbar spine trauma with the use of computed tomography scan. Eur Spine J. 25(4):1135-43, 2016 Apr.

98. Boese CK, Nerlich M, Klein SM, Wirries A, Ruchholtz S, Lechler P. Early magnetic resonance imaging in spinal cord injury without radiological abnormality in adults: a retrospective study. J Trauma Acute Care Surg. 74(3):845-8, 2013 Mar.

99. Vordemvenne T, Hartensuer R, Lohrer L, Vieth V, Fuchs T, Raschke MJ. Is there a way to diagnose spinal instability in acute burst fractures by performing ultrasound? Eur Spine J. 2009;18(7):964-971.

100. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf.

Disclaimer

[a]Emory University and Children's of Atlanta (Egleston), Atlanta, Georgia. [b]Emory University and Children's Healthcare of Atlanta, Atlanta, Georgia. [c]Panel Vice-Chair, Vanderbilt Children's Hospital, Nashville, Tennessee. [d]Scripps Memorial Hospital La Jolla, La Jolla, California; American Association for the Surgery of Trauma. [e]Children's Health, Dallas and University of Texas Southwestern Medical Center, Dallas, Texas. [f]Texas Children's Hospital, Houston, Texas. [g]Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio; American Pediatric Surgical Association. [h]Texas Children's Hospital, Houston, Texas. [i]University of Florida College of Medicine Jacksonville, Jacksonville, Florida; American College of Emergency Physicians. [j]Hospital for Sick Children, Toronto, Ontario, Canada; American Association of Neurological Surgeons/Congress of Neurological Surgeons. [k]University of Pittsburgh, Children's Hospital of Pittsburgh, Pittsburgh, Pennsylvania; Society for Academic Emergency Medicine. [l]Emory University and Children's Healthcare of Atlanta, Atlanta, Georgia. [m]Children's Hospital Colorado, Aurora, Colorado. [n]Children's National Health System, Washington, District of Columbia; American Association of Neurological Surgeons/Congress of Neurological Surgeons. [o]Medical University of South Carolina, Charleston, South Carolina; North American Spine Society. [p]Boston Children's Hospital, Boston, Massachusetts. [q]Ann & Robert H. Lurie Children's Hospital of

Chicago, Chicago, Illinois. [r]Jackson Memorial Hospital, Miami, Florida. [s]Children's Hospital at Montefiore, Bronx, New York; American Academy of Pediatrics. [t]Johns Hopkins University School of Medicine, Baltimore, Maryland. [u]Johns Hopkins University School of Medicine, Baltimore, Maryland. [v]Cincinnati Children’s Hospital Medical Center, Cincinnati, Ohio; Commission on Nuclear Medicine and Molecular Imaging. [w]Children's National Health System, Washington, District of Columbia. [x]Specialty Chair, Riley Hospital for Children Indiana University, Indianapolis, Indiana.