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	Relative Radiation Level
Radiography cervical spine	Usually Not Appropriate	☢☢
Arteriography cervicocerebral	Usually Not Appropriate	☢☢☢☢
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	☢☢☢☢
CT myelography cervical spine	Usually Not Appropriate	☢☢☢
CTA neck with IV contrast	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
US cervical spine	Usually Not Appropriate	O

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

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

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

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

SUSPECTED SPINE TRAUMA–CHILD

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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].

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The American College of Radiology seeks and encourages collaboration with other organizations on the development of the ACR Appropriateness Criteria through society representation on expert panels. Participation by representatives from collaborating societies on the expert panel does not necessarily imply individual or society endorsement of the final document.

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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.

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).

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].

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).

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).

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).

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.

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].

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].

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].

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].

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].

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].

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].

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.

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].

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].

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].

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].

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].

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].

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].

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, acute thoracolumbar spine trauma. Initial imaging.

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].

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].

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].

CTA Thoracic and Lumbar Spine
CTA is not routinely used in the evaluation of children with thoracolumbar trauma.

MRA Thoracic and Lumbar Spine
MRA is not routinely used in the evaluation of children with thoracolumbar trauma.

Arteriography Thoracic and Lumbar Spine
Arteriography is not routinely used in the evaluation of children with thoracolumbar trauma.

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].

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 Recommendations

- **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 go to www.acr.org/ac.

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 [100].

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 (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."		

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Appendix 1. Clinical Rules.

Name of Rule	Study Age Group	Criteria
PECARN [18]	0 to <16 years	High risk for cervical spine injury (do imaging) if one or more of the following are present: 1. Altered mental status 2. Focal neurologic findings 3. Neck pain 4. Torticollis 5. Substantial torso injury 6. Conditions predisposing to cervical spine injury 7. Diving 8. High-risk motor vehicle crash
NEXUS [15]	2 to 100 years	Low risk for cervical spine injury (no imaging) if patients have all of the following: 1. Absence of tenderness at the posterior midline of the C-spine* 2. Absence of a focal neurologic deficit 3. Normal level of alertness 4. No evidence of intoxication 5. Absence of clinically apparent pain that might distract the patient from the pain of a C-spine injury
Pieretti-Vanmarcke [19]	≤3 years	Low risk: Weighted score 0 to 1 points (negative predictive value 99.83%) High Risk: Weighted score ≥2 to 8 points GCS <14 (3 points) GCS_{EYE} = 1 (2 points) Motor vehicle crash (2 points) Age 25-36 months (1 point)

*Based on the panel's expert opinion, the finding of midline tenderness in children with cervical trauma is very prevalent and its relevance as a predictor of cervical injury has been questioned. The PECARN study did not find midline tenderness to be a relevant predictor of cervical injury and it was therefore not included in the PECARN criteria.
GCS = Glasgow Coma Score