11 Acute Spine Trauma in Adults and Children: Evidence-Based Emergency Imaging

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Key Points

- The NEXUS and Canadian cervical spine rules are validated clinical prediction rules that can identify subjects at risk for cervical spine fracture, in whom imaging is appropriate (strong evidence).
- Cervical spine CT is the best imaging modality in high- and intermediate-risk patients (moderate evidence).
- In low-risk trauma victims not undergoing head CT, radiography is an acceptable cervical spine imaging approach (limited evidence).
- Selection of subjects for thoracolumbar spine imaging can be made based on clinical criteria (moderate evidence).
- CT, including reformations from CT scans performed of the chest, abdomen, and pelvis, is more accurate than radiographs in the thoracic and lumbar spine, but radiography may still be appropriate in low-risk subjects (limited evidence).

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Definition and Pathophysiology

Spinal trauma can lead to permanent neurologic damage. In addition to the neurological deficit, spinal cord injury has additional important ramifications. This includes a precipitous decline in probability of employment, educational achievement, and intact marriage [1]. Therefore, although spinal cord injury is relatively uncommon, spine imaging is frequently performed to exclude suspected and occult fractures. As a result of wide spread utilization, the positive yield of spine imaging is estimated to be only 2.4% in the cervical spine when all patient populations are included [2]. Using the best available evidence, this chapter addresses diagnostic imaging of the spine in trauma including clinical prediction rules and cost-effectiveness.

Spinal fractures are estimated to account for 3–6% of all skeletal injuries in the USA. A Canadian study in 2006 estimated that 56% of spinal fractures are associated with spinal cord injuries and there is a general mortality rate of 8% [3]. Although no recent epidemiologic studies were identified, the annual incidence of cervical spine fracture was estimated at 10,000 per year in the USA in 1992 [4]. Better statistics are maintained for spinal cord injury of all causes and available from the National Spinal Cord Injury Statistical Center, Birmingham, Alabama. From this database the annual incidence of spinal cord

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injury is estimated at 40 cases per million per year in the USA or 12,000–20,000 per year when on scene fatalities are excluded [1]. The incidence of cervical spine fracture was recently estimated at 118 per million per year in Norway [5].

Spinal cord injury is predominantly a disease of young (average age 33.7 years) males (80.8%). The most common causes are traffic accidents, falls, and violence in decreasing frequency [1]. The hospital mortality for acute spinal injuries is high, up to 17%, reflecting the presence of other severe injuries.

The cervical spine is both the most commonly fractured region in spinal trauma and the area where risk of cord injury is greatest compared to that of thoracic, lumbar, or sacral fractures [6]. Though generally symptomatic, spine fractures may be clinically occult in trauma victims with other distracting injuries or who are unexaminable from obtundation, medication, or intoxication. In patients suffering from blunt trauma resulting in trauma team activation, the prevalence of cervical fracture is greater, 3.7%, and up to 7.7% in unexaminable patients. Once detected, between 42% and 57% of all cervical spine injuries are potentially unstable [7, 8].

Elderly patients have approximately doubled risk of significant injury, which may result from relatively low-energy mechanisms of injury [9]. The elderly spine has altered biomechanics, including decreased range of motion, lower muscular strength, and increased rigidity from degenerative changes, including ankylosis. In addition, degenerative changes may contribute to narrowing of the spinal canal with associated increased risk of cord injury [9].

Overall Cost to Society

Cervical spine injuries cause an estimated 6000 deaths and 5000 new cases of quadriplegia each year [1]. The total number of people with spinal cord injuries in the USA is estimated to be 265,000 persons, with a range of 232,000 to 316,000 persons [1]. The cost of care is dependent on severity of injury and is highest during the first year following injury. In 2010 dollars the average annual expense for cervical spine injury resulting in incomplete motor function at any level was $321,720 in the first year and $39,077 for each subsequent year of life. In cases of high tetraplegia (C1–4), the first year cost of care averages $985,774 and $171,183 for each subsequent year of life [1]. The most recent comprehensive analysis of spinal cord injuries performed in 1996 concluded that the estimated total annual cost of all cervical spinal cord injuries was $9.7 billion per year [10].

Goals of Imaging

The primary goals of imaging are to (1) detect potentially unstable injuries to enable immobilization or stabilization and prevent development or progression of neurologic injury and (2) inform prognosis and guide surgical intervention for unstable fractures.

Methodology

A PubMed (National Library of Medicine, Bethesda, Maryland) search for original research publications discussing diagnostic performance and clinical predictors of cervical and thoracic spine injury was performed. This includes publications from 1966 to May 6, 2015. The search strategy employed different combinations of the following terms: (1) spine, (2) radiography or imaging or computed tomography or magnetic resonance imaging, and (3) fracture or injury. MeSH headings included (1) spine and diagnosis, (2) imaging and spine, and (3) magnetic resonance imaging. Bibliographies of identified articles were reviewed for further papers. The articles were limited to human studies published in the English language. An initial review of the titles and abstracts of identified articles was followed by review of the full text of articles that were relevant.

Discussion of Issues

Who Should Undergo Cervical Spine Imaging After Blunt Trauma?

Summary of Evidence The NEXUS [2] and Canadian C-spine [11] rules are two clinical prediction rules that have undergone multicenter validation, with the intent of determining which patients should undergo cervical spine imaging in blunt trauma. Both clinical prediction rules report sensitivity greater than 99%, with specificity of 42.5% for the Canadian C-spine rule and 12.9% for NEXUS (Table 11.1). A single randomized trial was implemented applying the Canadian C-spine rule which found that adherence to the decision rule demonstrated efficacy at reducing imaging of the cervical spine (strong evidence).

Supporting Evidence

Nexus Prediction Rule

The National Emergency X-Radiography Utilization Study (NEXUS) was a multicenter observational study involving 23 diverse emergency departments throughout the USA in the 1990s. Based on identified best practices at the time, the NEXUS study was designed to assess the validity of four predetermined clinical criteria for prediction of cervical spine injury. The presence of any of the four criteria would indicate that imaging should be performed in case of (1) altered neurologic status, (2) intoxication, (3) midline posterior bony cervical spine tenderness,

Table 11.1 Diagnostic performance of the clinical prediction rules and diagnostic imaging modalities in suspected blunt spine trauma

		Sensitivity%	Specificity%	Potential decrease in radiography%
C-spine prediction rules				
NEXUS[a]		99.6	12.9	12.6
Canadian C-spine rule[b]		100	42.5	41.8
TL-spine prediction rules				
Hsu et al.[c]		100	11.3	Not reported
Holmes et al.[d]		100	3.9	3.7
Inaba et al.[e]		98.9	29.0	26.6
C-spine radiography[f]				
	Overall	89–94	95.3	N/A
	Low risk		96.4	N/A
	High risk		78.1–89.3	N/A
CT[g]	Overall	99.0	93.1	N/A
TL-spine radiography[h]				
Conventional imaging		63.0	94.6	N/A
CT		97.8	99.6	N/A

[a]From reference [2]
[b]From reference [11]
[c]From reference [78]. Has not been validated
[d]From reference [79]. Has not been validated
[e]From reference [69]. Has not been validated
[f]Older references with clinical reference standard. It is unclear if these results are still valid. Adapted from references [17–19]
[g]Adapted from references [19–22, 38–42]
[h]Pooled from references [72, 81–87]
N/A: not applicable
Adapted from Springer Science + Business Media from Blackmore CC, Avey GD. Imaging of the Spine in Victims of Trauma. In Medina LS, Blackmore CC (eds): Evidence-Based Imaging: Optimizing Imaging in Patient Care. New York: Springer Science + Business Media, 2006

or (4) distracting injury (meaning an injury of sufficient pain to potentially distract the patient from noticing a cervical spine injury). In the NEXUS prospective validation study, 34,069 patients underwent radiography of the cervical spine following blunt trauma. The NEXUS criteria had a sensitivity of 99.6% and specificity of 12.9% for clinically significant injury [2]. In the participant population, 818 (2.4% of total) had a cervical spine injury. It was estimated that adherence to the NEXUS criteria would reduce utilization of radiographs by 12.6% (strong evidence).

Though validated in multiple different emergency departments, the NEXUS has been questioned in high-energy trauma patients in whom the trauma team is activated. There is limited evidence that the NEXUS criteria determined on patients with a normal Glasgow Coma Scale (GCS) cannot be used to exclude cervical spine fracture in victims of major trauma. In a 2007 study of major trauma victims, Duane et al. prospectively evaluated 534 patients imaged by cervical spine CT, and the performance of clinical exam was compared to that of CT [12]. In evaluable patients with GCS of 15 or greater who were not intoxicated and did not have a distracting injury, 17 patients had cervical spine fractures, 7 of which had a negative clinical exam. Of the seven fractures undetected clinically, three were transverse process fractures requiring no further intervention (and of uncertain clinical importance), and four required treatment with extended use of a rigid cervical collar. In follow-up studies in 2011 and 2013, by Duane et al., both the NEXUS and Canadian C-spine criteria were determined to be insufficient to exclude fracture in trauma team activation patients [13, 14].

There are no implementation studies documenting the efficacy of NEXUS for reducing overall utilization of imaging.

Table 11.2 NEXUS criteria. Imaging of the cervical spine is not necessary if all five of the NEXUS criteria are met

1.	Absence of posterior midline tenderness
2.	Absence of focal neurological deficit
3.	Normal level of alertness
4.	No evidence of intoxication
5.	Absence of painful injury distracting attention from the spine

Data from 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. N Engl J Med. 2000 Jul 13;343(2):94–9

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Canadian Cervical Spine Prediction Rule

The Canadian C-spine rule is similar to the NEXUS study in attempting to identify valid clinical predictors of patients who do not need imaging. The Canadian C-spine study, published subsequent to NEXUS, was a prospective cohort study of 8924 subjects from 10 community and university hospitals across Canada. The Canadian C-spine study was derived from an initial observational study which evaluated 20 potential predictive factors. According to the Canadian C-spine rule (Table 11.3), imaging is not indicated if all of the following three determinations are made: (1) absence of high-risk factor (age >65, dangerous mechanism, paresthesia's in extremities), (2) presence of a low-risk factor (simple rear end motor vehicle collision, sitting position in ED, ambulatory at any time since injury, delayed onset of neck pain, or absence of midline cervical C-spine tenderness), or (3) patient who is able to actively rotate neck 45 degrees to left and right. The Canadian C-spine rule has reported sensitivity of 100% and specificity of 42.5% with the rate of requested radiography estimated to be reduced by 58.2% (strong evidence) [11].

The implementation of the Canadian C-spine rule has also been investigated through a cluster randomized trial involving 12 Canadian emergency departments. A total of 11,824 alert and stable adults were included. The intervention group showed a relative reduction in cervical spine imaging of 12.8% and the control group a relative increase of 12.5% of cervical spine imaging [15].

There is no head-to-head trial supporting the adoption of either cervical spine prediction rule over the other, and a strong recommendation cannot be made of one clinical prediction rule over

Table 11.3 The Canadian C-spine rule

If the following three determinations are made, then imaging is not indicated
1. No high-risk factor, including:
Age > 64 years
Dangerous mechanism, including:
Fall from >3 m/5 stairs
Axial load to head (diving)
High-speed vehicular crash (60 MPH, rollover, ejection)
Bicycle collision
Motorized recreational vehicle
Paresthesia in extremities
2. Low-risk factor is present
Simple rear end vehicular crash, excluding:
Pushed into oncoming traffic
Hit by bus/large truck
Rollover
Hit by high-speed vehicle
Sitting position in emergency department
Ambulatory at any time
Delayed onset of neck pain
Absence of midline cervical tenderness
3. Able to actively rotate neck (45 degrees left and right)

Adapted with permission from Bandiera G, Stiell IG, Wells GA, et al. The Canadian C-spine rule performs better than unstructured physician judgment. Ann Emerg Med. 2003 Sep;42(3):395–402

the other. A retrospective analysis comparing Canadian C-spine and NEXUS prediction rules was attempted. However, for this analysis, altered level of consciousness was not used as a criterion [16, 17], potentially biasing against the NEXUS rule, as this was a NEXUS criterion. In addition, the Canadian C-spine rule requires the active evaluation of cervical spine rotational range of motion, an approach which may not be acceptable in many US emergency departments.

What Imaging Modality Should Be Used for the Cervical Spine in Blunt Trauma?

Summary of Evidence Cervical spine CT is both more sensitive and specific than radiography for identifying cervical spine fractures (Table 11.1). In addition, cost-effectiveness analysis supports the use of CT as the initial modality in patient populations at high and moderate risk of cervical fracture. Use of CT has been shown to reduce repeat imaging and identify the rare fractures which may have been missed from radiography with the potential to lead to severe neurological deficit (moderate evidence). In patient populations with low probability for cervical fracture, properly performed cervical spine radiography remains a reasonable imaging choice (limited evidence). MRI is not recommended in the acute setting as the initial evaluation of the cervical spine (moderate evidence).

Supporting Evidence

Accuracy of Imaging

Historically, the sensitivity of cervical spine radiography has been reported in the 89–94% range, when adequate three view radiographs were obtained on all patients [2, 18–20]. Weighted pooling of the larger studies using a clinical gold standard suggests that radiography is relatively accurate with a sensitivity of 94% and a specificity of 95% when all trauma patients are included (Table 11.1) [20]. Distressingly, however, more recently performed observational studies have reported much lower sensitivity for cervical spine radiography. The discrepancy seems related at least in part to choice of reference standard and adequacy of cervical spine radiographs. A representative in 2003 study performed by Griffen et al. in a level I trauma center concluded that the sensitivity of radiography was 65%, using CT follow-up as the reference standard [21]. In a 2014 systematic review, the sensitivity of cervical spine radiography for fractures was estimated to be between 36 and 65% using CT as the reference standard [22]. As with all diagnostic accuracy studies, using one modality as the reference standard biases strongly in favor of that modality, in this case with strong bias in favor of CT and against radiography. Accordingly, studies using fractures that become apparent clinically as the reference standard are probably more relevant for clinical practice. In addition, many recent studies are biased by comparing CT to inadequate radiography examinations that did not include all necessary views or did not visualize the entire cervical spine. Furthermore, inadequate visualization is often seen as rationale for proceeding to CT imaging increasing bias against radiography. In a 2009 study, Bailitz et al. included 1583 consecutive major trauma patients that were evaluated with both cervical spine CT and 3-view cervical radiography [23]. In this particular study, the final diagnosis in the medical record at discharge was used as the gold standard for cervical spine injury, and a clinically significant injury was one defined as requiring either an operative procedure, halo application, or rigid cervical collar application. Of the 78 patients with radiographic evidence of fracture, 50 (3.3%) were determined to have clinically significant injuries, and 42% of the 50 required operative intervention or halo application. Using the risk stratification criteria defined by Blackmore et al. [24], 16 clinically significant cervical fractures were present in the low-risk patients of which only 4 were identified by cervical spine radiography (25% sensitivity). It should be noted however that of the 32 clinically significant injuries "missed" by cervical spine radiography, only 6 had adequate radiography.

The disconnect between historical estimates of radiography sensitivity of 89–94% and current estimates of 36–65% confounds determination of appropriate imaging. It is likely that the methodological limitations in the more recent literature, including consideration of inadequate radiographs as normal, use of an imaging rather than a clinical reference standard, and inclusion of only high-risk trauma patients, explain much of this difference. Historical data indicating that missed cervical spine injuries were in fact rare prior to widespread use of CT also calls into question recent low estimates of radiograph sensitivity. However, with decreased utilization of cervical spine radiographs comes decreased proficiency at performance and interpretation, and sensitivity today may actually be lower as a consequence.

High- and Moderate-Risk Patients

Cervical spine radiography is less accurate in patients at moderate and high risk of cervical fracture (probability >4%) [20]. These patients are commonly immobilized on backboards, have multiple injuries, and are unable to cooperate. These factors result in lower specificity, more inadequate radiographs and repeat imaging, greater utilization of hospital resources, and ultimately higher cost [25]. Additionally, CT evaluation has been shown to be more time efficient when compared to radiography, allowing for faster disposition of patients from the emergency department [26, 27]. This is particularly true when evaluation of the cervical spine follows CT scan of the head [28]. The decreased sensitivity of radiography in the major trauma population, time efficiency, and increased prevalence of cervical fracture support initial evaluation of the cervical spine utilizing CT in moderate- and high-risk patients. Cost-effectiveness analysis supports use of CT in this population. In a 1999 study, Blackmore performed a cost-effectiveness analysis from the societal perspective comparing cervical radiography to that of CT and found that CT was cost-effective in high and moderate risk [18]. This was confirmed by Grogan et al. in 2005 (moderate evidence) [29].

Low-Risk Patients

There is neither strong evidence nor consensus on the appropriate approach to cervical spine imaging in trauma victims who require imaging under the NEXUS or the Canadian C-spine rule but who are at low risk of injury. The standard has been radiography, but more recently, CT has been promoted as an initial imaging strategy, even in low-risk individuals. Recent societal consensus guidelines in the USA, including the ACR Appropriateness Criteria [30] and Eastern Association for the Surgery of Trauma [31], have advocated for use of CT for all patients who undergo cervical spine imaging in trauma. However, guidelines supporting the use of CT in low-risk patients generally rely on recent estimates of accuracy, despite the methodological limitations discussed above. In addition, such guidelines do not consider the fact that use of CT carries much greater radiation risk and societal cost.

Radiography may be most appropriate in the evaluation of patients who cannot be cleared clinically but have low-risk factors for significant cervical trauma such as young age, low-impact trauma, and no distracting injuries [20, 24, 32]. Inability to obtain technically adequate radiographs due to incomplete visualization or suboptimal quality (low specificity) is the single biggest limitation of radiography (Table 11.1) [22]. In the very low-risk patient population, adequate images are more easily obtained. CT is indicated when adequate radiographs cannot be obtained.

Radiation risks are difficult to estimate with any precision due to the need for extrapolation of radiation effects from higher administered doses to the very low doses found in diagnostic imaging. However, the use of CT rather than radiography for evaluation of the cervical spine comes with an estimated 14-fold greater patient exposure to ionizing radiation (26 mGy compared to 1.8 mGy) [33], resulting in increased risk of radiation-induced malignancy [34]. Thyroid doses in particular from cervical CT are high, ranging from 4.4 to 66.5 mGy [35].

Reconciliation of the higher sensitivity of CT versus the lower cost and radiation dose of radiography is challenging. From 2002 to 2007, there was a significant increase in the use of CT and plain radiographs in the management of trauma patients, leading to significantly higher radiation exposure with no demonstrable improvements in the diagnosis of missed injuries, mortality, or length of stay [36].

Table 11.4 makes the trade-offs explicit through a crude estimation of the number needed to treat and the number needed to harm when substituting CT for radiography in low-risk patients. There is substantial uncertainty in the estimates of both benefits and harms from CT. However, it is likely that the rate of cancer mortality is at least an order of magnitude greater than the probability of preventing paralysis through use of CT in low-risk trauma patients. Accordingly, radiography, when adequately performed, should be considered as the initial imaging approach in patients at low risk (limited evidence).

Table 11.4 Number needed to treat and harm for cervical spine imaging in low-risk patients

Variable	Estimate	Range	Source (references)
Risk of fracture	0.005	0.002–0.02	[2, 11, 37]
Chance of missing fracture (1-sensitivity)	0.1	0.06–0.20	[2, 18–20, 23]
Chance of paralysis (from missed fracture)	0.05	0.01–0.15	[20, 34]
Number needed to treat[a] (to prevent one case of paralysis)	40,000	10,000–200,000	
Number needed to harm[b] (to cause one case of fatal cancer)	2000	1000–20,000	[33, 34, 35]

Notes: [a]Number needed to treat is number of patients who have to undergo CT instead of radiography to prevent one case of paralysis in this population (equal to risk of fracture × chance of missing fracture × chance of paralysis)
[b]Number needed to harm is the number of patients who would have to undergo CT instead of radiography to cause one case of fatal cancer in the course of their lifetime
Used with permission from Blackmore CC, Smith JB: Spine Trauma: Evidence-Based Neuroimaging. Medina LS et al. (eds): Evidence-Based Neuroimaging Diagnosis and Treatment. New York: Springer Science + Business Media, 2013

Cost-effectiveness analysis also supports radiography as initial imaging strategy in low-risk patients. The threshold for when CT becomes cost-effective is somewhat uncertain. In the original cost-effectiveness analysis, Blackmore found a risk threshold of 4% to be the criterion for use of CT. However, subsequent investigators have proposed lower thresholds. Grogan suggested 0.9%, though this was based on extremely low estimates of radiograph sensitivity (64%) found in severely injured patients. Likely, however, the appropriate threshold is lower than the original 4% estimate, due to lower current estimates of performance of radiography detailed above.

Determination of appropriate imaging therefore requires stratification of patients into low- and

Table 11.5 Harborview high-risk cervical spine criteria

1.	High-energy injury mechanism
	High-speed (>35mph) motor vehicle or motorcycle crash
	Motor vehicle crash with death at scene
	Fall from height greater than 10 feet
2.	High-risk clinical parameter
	Significant head injury, including intracranial hemorrhage or unconscious in Emergency Department
	Neurological signs or symptoms referable to the cervical spine
	Pelvic or multiple extremity fractures

Presence of any of the following criteria indicates a subject at sufficiently high risk to warrant initial use of CT to evaluate the cervical spine

Adapted with permission from Hanson JA, Blackmore CC, Mann FA, Wilson AJ. Cervical spine screening: A decision rule can identify high-risk patients to undergo screening helical CT of the cervical spine. AJR. 2000;174:713–8

higher-risk cohorts. Blackmore [24] and Hanson [37] developed and validated a clinical prediction rule to identify subjects at high risk (Table 11.5). In the validation cohort, subjects lacking any of the high-risk factors had a risk of cervical spine fracture of only 0.2%, indicating that radiography was the preferred imaging approach. In the NEXUS study, the probability of fracture was 2.4% overall but 0.4% in the low-risk patients [2], again confirming that a group can be identified where adequate cervical spine radiography is appropriate as the initial screening tool.

Special Cases

Obtunded Patients

Summary of Evidence A normal cervical CT in obtunded patients with blunt trauma essentially excludes unstable cervical spine injuries. MRI is unlikely to change management when there is no neurological deficit or abnormality by cervical spine CT and is therefore not routinely recommended given risks and benefits (limited evidence).

Supporting Evidence There are several valid cohort studies of the accuracy of cervical spine CT in excluding unstable injuries in obtunded or clinically unexaminable patients. Hennessy in 2010 reported a prospective cohort study of 402 intubated, unexaminable blunt trauma patients with normal CT. Using flexion-extension radiography and clinical follow-up as a reference standard, one patient was found to have an unstable injury missed by the CT (negative predictive value 99.7%) [38]. Hogan et al. retrospectively examined 366 patients with negative CT, using MR and clinical follow-up as the reference standard. The authors concluded that the negative predictive value of CT for ligamentous injury was 98.9% and 100% for unstable cervical spine (CS) injury [39]. Harris and colleagues evaluated a retrospective cohort of 367 obtunded patients using a clinical and radiographic reference standard. A normal multi-detector row CT scan of the cervical spine in obtunded patients with blunt trauma had a negative predictive value of 99.7% [40]. Brohi and colleagues prospectively evaluated 442 consecutive unconscious trauma patients and defined the sensitivity of CT at 98.1% (51/52), with a negative predictive value of 99.7% [41]. In addition, a 2005 retrospective cohort study by Schuster et al. included 93 patients with a normal motor examination and a negative cervical spine CT with MR as the reference standard. In this study all patients had negative MRI examinations unless there was a neurological deficit or a positive CT [42]. Como evaluated 197 patients who were obtunded by moving all four extremities and reported no missed injuries on CT, with clinical or MRI follow-up [43]. The recent recommendations of the Eastern Association for the Surgery of Trauma based on evidence review also now recommend CT alone in obtunded patients (moderate evidence) [44].

However, it is also clear that CT is imperfect. As an example, Schoenfeld and colleagues culled from the medical literature multiple cases (particularly of ligamentous injuries) missed at CT but discovered on subsequent MRI [45]. However, in a common failing of the literature on this topic, the authors omitted to mention the number of true-negative CT scans, instead only reporting the number of false-negative CT scans among the group who went on to MRI. This verification bias, due to selection of the cohort based on performance of the reference standard, makes calculation of negative predictive value meaningless [46].

Finally, there are potential risks related to the use of MRI in obtunded patients, related to the transfer of patients to the MRI suite, and related to the limited ability to monitor patients while in the MRI scanner. In addition, delay in clearance of the cervical spine, with prolonged immobilization, may lead to complications including pressure ulcers, increased intracranial pressure, thromboembolism, and pulmonary aspiration [47–49].

Elderly Patients

Summary of Evidence Elderly individuals are at higher risk of cervical spine injury from both high- and low-energy mechanisms. However, no prediction rules have been validated to identify differential predictors of injury in the elderly. The same predictors in younger patients appear to work in the elderly [50]; however, clinical examination may not be as reliable [51]. Accordingly, the same approach to imaging may be applied in the elderly as in younger patients but with a lower threshold for use of CT due to the higher overall probability of fracture (limited evidence).

Children

Summary of the Evidence The NEXUS clinical prediction rule is a reasonable method of identifying which older children and adolescents should undergo cervical spine imaging after trauma. Imaging should be performed in subjects with (1) altered neurologic function, (2) intoxication, (3) midline posterior bony cervical spine tenderness, and (4) distracting injury (moderate evidence). In children under the age of 3 years, cervical spine imaging may be limited to subjects with high-energy mechanism (motor vehicle crash) or a Glasgow Coma Scale of less than 14 (limited evidence). Radiography can appropriately be used to exclude cervical spine fracture in children, though cervical spine CT may be useful in high-risk subjects. In younger children, when indicated, CT should be limited to the upper cervical spine (limited evidence).

Supporting Evidence Evidence for who should undergo imaging is less complete in children than in adults. Determination of clinical predictors of injury in pediatric subjects is complicated by the decreased incidence of injury in children, requiring larger sample size for adequate study [52–54]. In addition, children may sustain serious cervical cord injuries that are not radiographically apparent [52, 53]. Among adult clinical prediction rules, the Canadian clinical prediction rule development study excluded children [11]. The NEXUS trial included children, but there were only 30 injuries in subjects under age 18 and only 4 in subjects under age 9 [2]. Although no pediatric injuries were missed in the NEXUS study, the sample size was too small to adequately assess the sensitivity of the prediction rule in this group. Further validation of a pediatric version of the NEXUS was performed at a single academic pediatric trauma center in the USA. In 647 trauma victims age 3 or older, injuries were found in approximately 2%, of whom, 4 required operative fixation. No missed injuries were reported [55].

A pediatric adaptation of the NEXUS is a therefore reasonable approach in children over age 3, suggesting that imaging is only indicated when subjects have any of the following: (1) altered neurologic function, (2) intoxication, (3) midline posterior bony cervical spine tenderness, and (4) distracting injury (moderate evidence) [55].

Vanmarcke and colleagues performed a retrospective analysis of trauma registry data from multiple institutions, including 12,537 patients under the age of 3. They found that limiting imaging to subjects with decreased level of consciousness manifest by pediatric Glasgow Coma Scale of less than 14 or high-energy mechanism (motor vehicle crash) identified 78 of 83 (94%) clinically important injuries with a negative predictive value of 99.9%. The overall high negative predictive value was driven largely by the extremely low incidence of injury in this population (0.66%) even in subjects evaluated at major trauma centers [54]. This study has not yet been validated prospectively (limited evidence).

Comparison of CT versus radiography has not been well explored in children. Radiography has accuracy for cervical spine fracture of approximately 94% [56], similar to adults [19]. The odontoid view and flexion-extension radiographs contribute little in young children [57–60]. CT is likely more accurate than radiography but does encompass higher radiation doses and higher costs [61]. Most research studies and cost-effectiveness analyses excluded children [19, 23, 37]. Further, the lower frequency of injury in children [52, 62] and the increased radiosensitivity of pediatric subjects [63] suggest that cost-effectiveness results from adults may not be relevant.

A reasonable approach to pediatric cervical spine imaging is the Harborview protocol (Fig. 11.1 and Table 11.5). Overall, radiography is adequate to exclude cervical spine fracture in most young children (limited evidence) [61, 64]. However, the use of upper cervical CT in high-risk younger children [65] who are getting head CT is probably reasonable, as the time and cost are minimal, and the thyroid can be spared the CT radiation dose if imaging is limited to the upper cervical spine (insufficient evidence). In addition, upper cervical spine injuries are more common than lower cervical injuries in younger children [62, 66–68].

Who Should Undergo Imaging of the Thoracic and Lumbar Spine After Blunt Trauma?

Summary of Evidence There is no effective, validated clinical prediction rule to guide which patients should undergo thoracolumbar spine imaging. A recently developed prediction rule [69] has potential to identify nearly all fractures and reduce unnecessary imaging but has not yet been validated. Other prediction rules with high sensitivities for detecting thoracolumbar fractures have been reported, but their low specificities and low positive predictive values mean that the effect on imaging in patients without thoracolumbar injuries would be minimal and utilization essentially unchanged (moderate evidence).

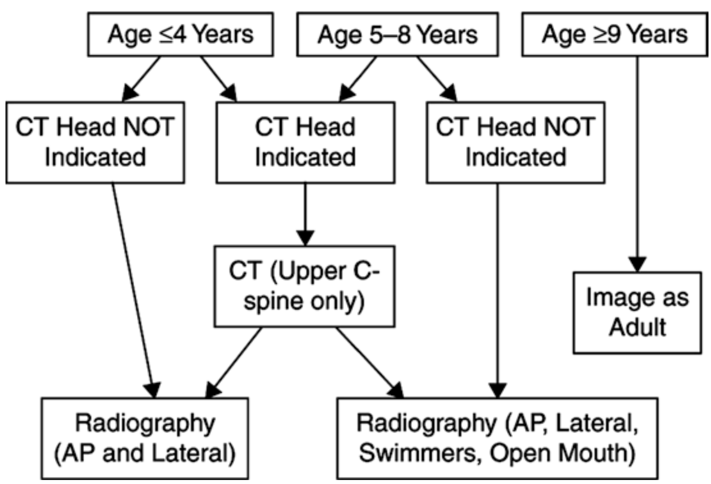

Fig. 11.1 Evidence-based decision tree for imaging of the cervical spine in child victims of trauma. The NEXUS or Canadian prediction rules are used to select patients for imaging. If imaging is appropriate, the selection of CT versus radiography is made based on whether the patient is also to undergo head CT. The radiography and CT protocols are age dependent (Reprinted with kind permission of Springer Science + Business Media from Blackmore CC, Avey GD. Imaging of the Spine in Victims of Trauma. In Medina LS, Blackmore CC (eds): Evidence-Based Imaging: Optimizing Imaging in Patient Care. New York: Springer Science + Business Media, 2006)

Supporting Evidence Several observational studies have examined potential risk factors for thoracolumbar fracture. These limited studies have identified associations between the risk of thoracolumbar injury and high-speed motor vehicle crash [70, 71], fall from a significant height [60–62], complaint of back pain [72–76], elevated injury score [72, 73], decreased level of consciousness [73–75, 77], and abnormal neurological exam (limited evidence) [74, 75].

Three different clinical prediction rules to guide use of thoracolumbar spine imaging have been developed, although neither prediction rule has been validated. In 2003, Hsu et al. examined the effect of six clinical criteria on two retrospective groups [78]. The first group consisted of a cohort of 100 patients with known thoracolumbar fracture, while the second group consisted of 100 randomly selected multi-trauma patients. The criteria evaluated were (1) back pain/midline tenderness, (2) local signs of injury, (3) neurological deficit, (4) cervical spine fracture, (5) distracting injury, and (6) intoxication. The results of this small-scale, retrospective trial found that 100% of the patients in the known thoracolumbar fracture group would have been imaged appropriately using the proposed criteria. This proposed pathway was then tested retrospectively in the group of randomly selected blunt trauma patients and was found to have a sensitivity of 100%, a specificity of 11.3%, and a negative predictive value of 100%. Implementing these criteria would still require imaging the thoracolumbar spine in 92% of the selected multi-trauma patients.

A second, much larger prospective, single-center study by Holmes et al. evaluated similar criteria in 2003 consecutive blunt trauma patients who underwent thoracolumbar imaging [79]. These clinical criteria (Table 11.5) were (1) complaints of thoracolumbar spine pain, (2) thoracolumbar spine pain on midline palpation, (3) decreased level of consciousness, (4) abnormal peripheral nerve examination, (5) distracting injury, and (6) intoxication. This prediction rule had 100% sensitivity for detecting thoracolumbar fracture, however, with specificity of only 3.9%. Due to this low specificity, implementing this prediction rule in this patient population would have decreased the rate of thoracolumbar imaging by just 4% (moderate evidence).

More recently, a multicenter study at 13 trauma centers in the USA developed a clinical prediction rule based on clinical exam findings, age over 60 years, and high-energy mechanism. This rule had sensitivity of 98.9% with specificity of 29.0% for clinically important injuries. The authors identified that clinical exam alone, without age and mechanism, was not of sufficient sensitivity. This study has also not yet been validated (Table 11.1) [69].

Though not specifically evaluating a clinical prediction rule, Sava and colleagues did identify that clinical exam may not be sufficiently reliable to exclude fracture in subjects with substantial blunt trauma and altered sensorium [80].

What Is the Optimal Thoracic and Lumbar Imaging Approach in Blunt Trauma?

Summary of Evidence Multiple studies have shown that some CT protocols used for imaging the chest and abdominal visceral organs, when performed with sagittal reformations, are more sensitive and specific for detecting thoracolumbar spine fracture than conventional radiography. In patients undergoing such scans, conventional radiography may be eliminated (limited evidence). The effect of primary screening with CT scan on cost and radiation exposure has not been thoroughly studied for the thoracolumbar spine.

Supporting Evidence Multiple limited evidence studies examine the possibility of eliminating conventional radiography in those patients who are candidates for both conventional thoracolumbar radiographs and CT evaluation of the chest or abdominal viscera; however, many of these trials are hampered by small sample sizes and/or verification bias [81–86]. Studies that combine the results of both CT and conventional radiography as the reference standard suggest that CT has a sensitivity of 78.1–100%, while conventional radiographs have a sensitivity of 29.9–74% for detecting thoracolumbar fracture (Table 11.1) [82–84, 87]. The clinical importance of thoracolumbar fractures not found with conventional radiography is unknown, as no studies with clinically based outcome measures were located.

A single limited evidence trial examined the use of CT as an initial evaluation in patients for which a CT scan is not indicated for other reasons [83]. This prospective, single-center trial examined 222 trauma patients with both CT and conventional radiographs as initial screening exams. The reported sensitivity was 97% for CT examination and 58% for conventional radiographs. The results of this trial are limited in that only 36 patients were diagnosed with thoracolumbar fracture during the course of the trial.

Applicability to Children

Summary of Evidence There are no clinical prediction rules validated in children for the determination of when imaging is indicated. However, a reasonable approach in older children is to image when any of the following are present: (1) complaints of thoracolumbar spine pain, (2) thoracolumbar spine pain on midline palpation, (3) decreased level of consciousness, (4) abnormal peripheral nerve examination, (5) distracting injury, and (6) intoxication (limited evidence). No reliable data exists on when to image in younger children (insufficient evidence). Compared to adults, younger children are less likely to localize pain and may have pain referred to the spine from intra-abdominal causes, particularly renal (infection and obstruction).

Supporting Evidence Data on appropriate indications for thoracolumbar spine imaging in children is limited. The adult clinical prediction rule from Holmes and colleagues did enroll children. However, the actual number of children in the study is not reported [79]. The youngest patient enrolled in the small clinical prediction rule validation trial by Hsu et al. was 14 years of age [78]. Given the 100% sensitivity in adults, it is reasonable to employ the Holmes clinical prediction rule in older children (limited evidence). In younger children, the criteria would have to be modified ad hoc to meet the clinical perception of the child's ability to provide reasonable responses and the clinical picture (insufficient evidence). The specificity of the Holmes prediction rule in adults was low (3.9%), so it is not expected that the use of this prediction rule would decrease unnecessary imaging [79]. The Inaba study excluded children [69].

Take Home Tables and Figure

Tables 11.1 through 11.6 and Fig. 11.1 serve to highlight key recommendations, supporting evidence, and imaging decisions.

Imaging Case Studies

Case 1

Figure 11.2a, b presents a victim of a motor vehicle crash who has met criteria for cervical spine imaging with CT scan due to a potentially unstable C6–7 facet and pars interarticularis fracture.

Case 2

Figure 11.3a, b presents a victim for a motor vehicle crash who has met criteria for initial cervical spine imaging with CT scan due to fracture of the right skull base (foramen magnum) and dislocation/dissociation at the atlanto-occipital joint.

Table 11.6 Thoracolumbar spine imaging criteria

1.	Pain
2.	Tenderness to palpation
3.	Neurological deficit
4.	Deformity
5.	High-risk mechanism[a]
6.	Age ≥ 60 years

Adapted with permission from 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 2015;78:459–467

[a]Fall, crush injury, motor vehicle collision with rollover/ejection, unenclosed vehicle crash, automobile versus pedestrian

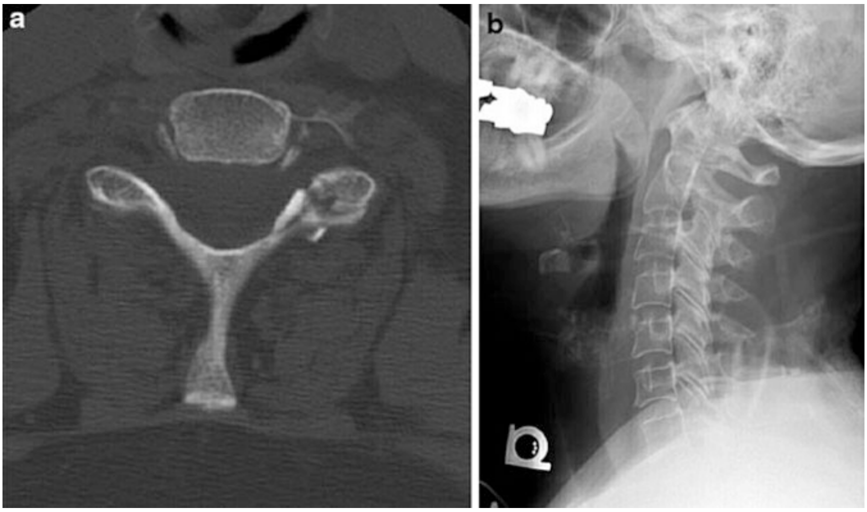

Fig. 11.2 Victim of a motor vehicle crash who met criteria for cervical spine imaging with CT scan. A potentially unstable C6–7 facet and pars interarticularis fracture is apparent on CT (**a**) but was missed on contemporaneous radiography (**b**). CT has higher sensitivity for fracture than radiography (Reprinted with kind permission of Springer Science + Business Media from Blackmore CC, Avey GD. Imaging of the spine in victims of trauma. In: Medina LS, Blackmore CC, editors. Evidence-based imaging: optimizing imaging in patient care. New York: Springer Science; 2006)

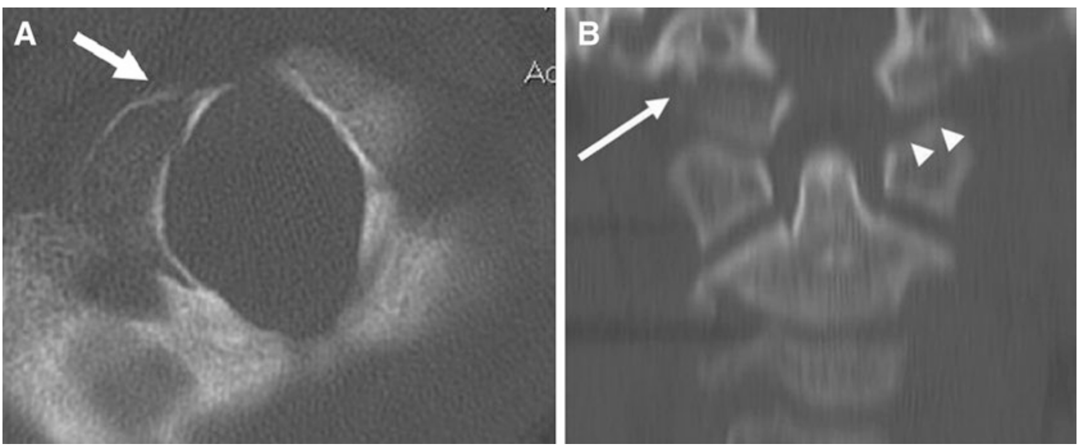

Fig. 11.3 Victim of a motor vehicle crash who met criteria for initial cervical spine imaging with CT scan. A fracture of the right skull base (foramen magnum) (**a**) and dislocation/dissociation at the atlanto-occipital joint (**b**) are apparent on CT but were not visible on contemporaneous radiography (Reprinted with kind permission of Springer Science + Business Media from Blackmore CC. Imaging of the spine for traumatic and nontraumatic etiologies. In: Medina LS, Applegate KE, Blackmore CC, editors. Evidence-based imaging in pediatrics: optimizing imaging in pediatric patient care. New York: Springer Science; 2010)

Recommended Imaging Protocols

Cervical Spine

CT protocol: Multi-detector CT with axial image reconstruction at 2.5 mm or less, in both bone and soft tissue algorithms, and with sagittal and coronal reformations in bone algorithm at 2 mm collimation.

Radiography protocol: AP, open mouth, lateral, and swimmers. Note that all images must be adequate for evaluation, and the entire region from skull base to T1 must be visible in both frontal and lateral projections. If adequate films cannot be obtained after repeat imaging, then CT should be performed.

Thoracic and Lumbar Spine

CT protocol: Axial images in bone algorithm through the area of concern, with 2.5 mm collimation. Must include sagittal reformations, and preferable coronal, in bone algorithm, at 2 mm collimation.

Radiography protocol: AP and lateral views covering the entire area of interest.

Future Research

- Studies in both cervical spine and thoracolumbar spine imaging indicate that CT is more sensitive than traditional radiography in detecting fractures. However, further clinical studies addressing the relevance of these fractures are needed.
- The applicability of cervical spine injury clinical prediction rules in pediatric patients is unknown. In addition, the sensitivity, specificity, and cost-effectiveness of the various imaging exams in the pediatric population are not well established.
- Clinical prediction rules for imaging of the thoracolumbar spine have been developed, but further research is necessary to validate such approaches. The effect of implementing these rules on cost, cost-effectiveness, and radiation exposure has not been determined.
- Appropriate imaging to detect unstable ligamentous injury, particularly in clinically unexaminable subjects, remains unresolved.

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