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Triage tools for detecting cervical spine injury in paediatric trauma patients (Review)

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[Diagnostic Test Accuracy Review]

Triage tools for detecting cervical spine injury in paediatric trauma patients

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ABSTRACT

Background

Paediatric cervical spine injury (CSI) after blunt trauma is rare but can have severe consequences. Clinical decision rules (CDRs) have been developed to guide clinical decision-making, minimise unnecessary tests and associated risks, whilst detecting all significant CSIs. Several validated CDRs are used to guide imaging decision-making in adults following blunt trauma and clinical criteria have been proposed as possible paediatric-specific CDRs. Little information is known about their accuracy.

Objectives

To assess and compare the diagnostic accuracy of CDRs or sets of clinical criteria, alone or in comparison with each other, for the evaluation of CSI following blunt trauma in children.

Search methods

For this update, we searched CENTRAL, MEDLINE, Embase, and six other databases from 1 January 2015 to 13 December 2022. As we expanded the index test eligibility for this review update, we searched the excluded studies from the previous version of the review for eligibility. We contacted field experts to identify ongoing studies and studies potentially missed by the search. There were no language restrictions.

Selection criteria

We included cross-sectional or cohort designs (retrospective and prospective) and randomised controlled trials that compared the diagnostic accuracy of any CDR or clinical criteria compared with a reference standard for the evaluation of paediatric CSI following blunt trauma. We included studies evaluating one CDR or comparing two or more CDRs (directly and indirectly). We considered X-ray, computed tomography (CT) or magnetic resonance imaging (MRI) of the cervical spine, and clinical clearance/follow-up as adequate reference standards.

Data collection and analysis

Two review authors independently screened titles and abstracts for relevance, and carried out eligibility, data extraction and quality assessment. A third review author arbitrated. We extracted data on study design, participant characteristics, inclusion/exclusion criteria, index test, target condition, reference standard and data (diagnostic two-by-two tables) and calculated and plotted sensitivity and

specificity on forest plots for visual examination of variation in test accuracy. We assessed methodological quality using the Quality Assessment of Diagnostic Accuracy Studies Version 2 tool. We graded the certainty of the evidence using the GRADE approach.

Main results

We included five studies with 21,379 enrolled participants, published between 2001 and 2021. Prevalence of CSI ranged from 0.5% to 1.85%. Seven CDRs were evaluated.

Three studies reported on direct comparisons of CDRs. One study (973 participants) directly compared the accuracy of three index tests with the sensitivities of NEXUS, Canadian C-Spine Rule and the PECARN retrospective criteria being 1.00 (95% confidence interval (CI) 0.48 to 1.00), 1.00 (95% CI 0.48 to 1.00) and 1.00 (95% CI 0.48 to 1.00), respectively. The specificities were 0.56 (95% CI 0.53 to 0.59), 0.52 (95% CI 0.49 to 0.55) and 0.32 (95% CI 0.29 to 0.35), respectively (moderate-certainty evidence). One study (4091 participants) compared the accuracy of the PECARN retrospective criteria with the Leonard de novo model; the sensitivities were 0.91 (95% CI 0.81 to 0.96) and 0.92 (95% CI 0.83 to 0.97), respectively. The specificities were 0.46 (95% CI 0.44 to 0.47) and 0.50 (95% CI 0.49 to 0.52) (moderate- and low-certainty evidence, respectively). One study (270 participants) compared the accuracy of two NICE (National Institute for Health and Care Excellence) head injury guidelines; the sensitivity of the CG56 guideline was 1.00 (95% CI 0.48 to 1.00) compared to 1.00 (95% CI 0.48 to 1.00) with the CG176 guideline. The specificities were 0.46 (95% CI 0.40 to 0.52) and 0.07 (95% CI 0.04 to 0.11), respectively (very low-certainty evidence).

Two additional studies were indirect comparison studies. One study (3065 participants) tested the accuracy of the NEXUS criteria; the sensitivity was 1.00 (95% CI 0.88 to 1.00) and specificity was 0.20 (95% CI 0.18 to 0.21) (low-certainty evidence). One retrospective study (12,537 participants) evaluated the PEDSPINE criteria and found a sensitivity of 0.93 (95% CI 0.78 to 0.99) and specificity of 0.70 (95% CI 0.69 to 0.72) (very low-certainty evidence).

We did not pool data within the broader CDR categories or investigate heterogeneity due to the small quantity of data and the clinical heterogeneity of studies. Two studies were at high risk of bias.

We identified two studies that are awaiting classification pending further information and two ongoing studies.

Authors' conclusions

There is insufficient evidence to determine the diagnostic test accuracy of CDRs to detect CSIs in children following blunt trauma, particularly for children under eight years of age. Although most studies had a high sensitivity, this was often achieved at the expense of low specificity and should be interpreted with caution due to a small number of CSIs and wide CIs. Well-designed, large studies are required to evaluate the accuracy of CDRs for the cervical spine clearance in children following blunt trauma, ideally in direct comparison with each other.

PLAIN LANGUAGE SUMMARY

Clinical tools for detecting cervical spine injury (CSI) in children with injuries

Key message

– There is currently insufficient evidence to determine which clinical decision tools should be used to assist in deciding whether children with potential cervical spine injuries (CSI) require imaging tests to aid diagnosis.

What is a cervical spine injury and how is it detected?

The cervical spine is the upper part of the spine between the head and shoulders (the neck). The incidence of traumatic CSI in children is very low. However, it is very important not to miss this injury as the consequences can be devastating, including death or lifelong disability. To detect CSI, several types of imaging techniques can be used: computed tomography (CT), magnetic resonance imaging (MRI) and X-rays. A CT scan uses detailed X-rays to produce cross-sectional images of the body and MRI uses radio waves and a powerful magnet to generate the images. While CT scans and X-rays are useful in detecting bone injuries, they do use radiation that can increase the risk of developing cancer, especially in children. To avoid exposing children to unnecessary radiation, it is important to find clinical tests that can determine whether children are at risk for CSI, how accurate they are (called diagnostic accuracy) and whether radiographic imaging is needed.

What was the aim of this review?

Clinical decision rules (CDRs) are tools that clinicians use to decide whether a diagnostic test is needed or another clinical action should be taken. We wanted to find out which CDRs are useful in determining which children are at risk for CSI after blunt trauma (for example, in motor vehicle-related accidents and falls), and whether radiographic imaging should be used to help diagnosis. Tools that have been developed for adults are also often used for children, but little information is known about their accuracy in children. The aim of this review was to evaluate all CDRs and tools used in this decision-making process and if they can be used safely and effectively in children.

What did we do?

We searched medical databases for studies that compared the diagnostic accuracy of any CDR with another CDR for the evaluation of CSI following blunt trauma in children.

What did we find?

We included five studies recruiting 21,379 children, published between 2001 and 2021, that assessed the accuracy of seven CDRs (NEXUS, Canadian C-Spine Rule, PECARN retrospective criteria, NICE guidelines CG56 and CG176, Leonard de novo model and PEDSPINE) to evaluate CSIs following blunt trauma in children.

Main results

There is currently insufficient evidence to determine which CDRs are most effective at detecting CSIs following blunt trauma in children, particularly for those younger than eight years of age. Although most CDRs accurately identified children who had a CSI (called high sensitivity), they frequently did not correctly identify children who did not have a CSI (called low specificity). If these CDRs were applied as a rule, a large proportion of children without CSI attending the emergency department for a blunt trauma assessment would receive imaging potentially exposing them to unnecessary radiation. These CDRs are at best a guide to clinical assessment with current evidence not supporting strict use of CDRs in trauma care for children. More research is needed to evaluate the accuracy of CDRs for use in cervical spine assessment in children.

What are the limitations of the evidence?

The quality of the studies was variable as there were differences in the children recruited, the number of CSIs, and the methods used making us uncertain about the results. There are currently two large ongoing studies that should contribute to the evidence of the accuracy of CDRs in children.

How up to date is the evidence?

The evidence is up to date to 13 December 2022.

SUMMARY OF FINDINGS

Summary of findings 1. Direct comparisons of clinical decision rules (CDRs) or sets of clinical criteria

Question: what is the diagnostic accuracy of clinical decision rules or sets of clinical criteria used to evaluate for cervical spine injury in the emergency department following blunt trauma in children?

Population: children (aged 0 to < 18 years) who underwent blunt trauma evaluation in the emergency department

Index test: CDRs or sets of clinical criteria that compared the diagnostic accuracy of the test for cervical spine injury with the reference standard

Comparator: studies comparing ≥ 2 CDRs (directly)

Reference standard: X-ray, CT, MRI or clinical clearance/follow-up in low-risk children

Study types: diagnostic studies with cross-sectional or cohort designs (retrospective or prospective) and randomised controlled trials

Study	Participants (CSI, %)	Sensitivity (95% CI)	Specificity (95% CI)	Certainty of the evidence
Phillips 2021	973 (0.5%)	NEXUS: 1.00 (0.48 to 1.00)	NEXUS: 0.56 (0.53 to 0.59)	**Moderate**[a]
		Canadian C-Spine Rule: 1.00 (0.48 to 1.00)	Canadian C-Spine Rule: 0.52 (0.49 to 0.55)	
		PECARN retrospective: 1.00 (0.48 to 1.00)	PECARN retrospective: 0.32 (0.29 to 0.35)	
Leonard 2019	4091 (1.8%)	PECARN retrospective: 0.91 (0.81 to 0.96)	PECARN retrospective: 0.46 (0.44 to 0.47)	**Moderate**[a]
		Leonard de novo: 0.92 (0.83 to 0.97)	Leonard de novo: 0.50 (0.49 to 0.52)	**Low**[b]
Davies 2016	270 (1.85%)	NICE CG56: 1.00 (0.48 to 1.00)	NICE CG56: 0.46 (0.40 to 0.52)	**Very low**[c]
		NICE CG176: 1.00 (0.48 to 1.00)	NICE CG176: 0.07 (0.04 to 0.11)	

CDR: clinical decision rule; **CI:** confidence interval; **CSI:** cervical spine injury; **CT:** computed tomography; **MRI:** magnetic resonance imaging; **NEXUS:** National Emergency X-Radiography Utilization Study; **NICE:** National Institute for Health and Care Excellence; **PECARN:** Pediatric Emergency Care Applied Research Network.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited; the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect.

[a] Downgraded one level due to study limitations (unclear risk of bias for the index test and reference standard).
[b] Downgraded one level due to study limitations (unclear risk of bias for the index test and reference standard) and one level due to indirectness (no existing validation data).
[c] Downgraded two levels due to study limitations (retrospective study design) and one level due to indirectness (only children with cervical spine imaging were included).

Summary of findings 2. Indirect comparisons of clinical decision rules (CDRs) or sets of clinical criteria

Question: what is the diagnostic accuracy of clinical decision rules or sets of clinical criteria used to evaluate for cervical spine injury in the emergency department following blunt trauma in children?

Population: children (aged 0 to < 18 years) who underwent blunt trauma evaluation in the emergency department

Index test: CDRs that compared the diagnostic accuracy of the test for cervical spine injury with the reference standard

Comparator: studies evaluating 1 single CDR or ≥ 2 CDRs (indirectly)

Reference standard: X-ray, CT, MRI or clinical clearance/follow-up in low-risk children

Study types: diagnostic studies with cross-sectional or cohort designs (retrospective or prospective) and randomised controlled trials

Study	Participants (CSI, %)	Sensitivity (95% CI)	Specificity (95% CI)	Certainty of the Evidence
NEXUS	2 studies 4038 (0.5% and 0.98%)	Phillips: 1.00 (0.48 to 1.00) Viccellio: 1.00 (0.88 to 1.00)	Phillips: 0.56 (0.53 to 0.59) Viccellio: 0.20 (0.18 to 0.21)	**Low**[a]
Canadian C-Spine Rule	1 study 973 (0.5%)	Phillips: 1.00 (0.48 to 1.00)	Phillips: 0.52 (0.49 to 0.55)	**Moderate**[b]
PECARN retrospective	2 studies 5064 (0.5% and 1.8%)	Phillips: 1.00 (0.48 to 1.00) Leonard: 0.91 (0.81 to 0.96)	Phillips: 0.32 (0.29 to 0.35) Leonard: 0.46 (0.44 to 0.47)	**Moderate**[b]
Leonard de novo	1 study 4091 (1.8%)	Leonard: 0.92 (0.83 to 0.97)	Leonard: 0.50 (0.49 to 0.52)	**Low**[c]
PEDSPINE criteria	1 study 12,537 (0.66%)	Pierretti: 0.93 (0.78 to 0.99)	Pierretti: 0.70 (0.69 to 0.72)	**Very low**[d]
NICE CG56	1 study 270 (1.85%)	NICE CG56: 1.00 (95% CI 0.48 to 1.00)	NICE CG56: 0.46 (95% CI 0.40 to 0.52)	**Very low**[e]
NICE CG176	1 study 270 (1.85%)	NICE CG176: 1.00 (95% CI 0.48 to 1.00)	NICE CG176: 0.07 (95% CI 0.04 to 0.11)	**Very low**[e]

CDR: clinical decision rule; **CI:** confidence interval; **CSI:** cervical spine injury; **CT:** computed tomography; **MRI:** magnetic resonance imaging; **NEXUS:** National Emergency X-Radiography Utilization Study; **NICE:** National Institute for Health and Care Excellence; **PECARN:** Pediatric Emergency Care Applied Research Network.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited; the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect.

[a]Downgraded one level due to study limitations (unclear risk of bias for the index test in two studies and reference standard in one study) and one level due to inconsistency.
[b]Downgraded one level due to study limitations (unclear risk of bias for the index test and reference standard).
[c]Downgraded one level due to study limitations (unclear risk of bias for the index test and reference standard) and one level due to indirectness (no existing validation data).
[d]Downgraded three levels due to study limitations (retrospective study design and children with no imaging were not followed up, increasing the risk of missed cervical spine injuries) and one level due to indirectness (no existing validation data).
[e]Downgraded two levels due to study limitations (retrospective study design) and one level due to indirectness (only children with cervical spine imaging were included).

BACKGROUND

Target condition being diagnosed

Paediatric cervical spine injury (CSI) after blunt trauma is rare, accounting for an estimated 1% to 2% of trauma presentations in children (Garton 2008; Leonard 2019; Mohseni 2011; Patel 2001; Shin 2016; Viccellio 2001). However, the consequences of CSI can be devastating and include death or life-changing neurological damage (Cirak 2004; Hutchings 2009; Kokoska 2001; Leonard 2014; Mohseni 2011; Parent 2011; Patel 2001; Platzer 2007). Concern also exists that undiagnosed CSIs may lead to worsening of neurological symptoms and outcomes (Mortazavi 2011; Ravichandran 1982; Schuster 2005).The long-term prognosis for children who sustain cervical spinal cord injury and survive the first 24 hours is poor; life expectancy is reduced by eight to 53 years, depending on the anatomical level of injury and the degree of spinal cord involvement (NSCISC 2019). Due to prolonged hospital stay, the large number of treatments and associated long-term assistance required, severe paediatric CSI is associated with very high medical, psychological and societal costs (Shavelle 2007; Vogel 2002a; Vogel 2002b; Vogel 2002c). Therefore, in children presenting after blunt trauma, physicians seek to identify all CSIs promptly through a combination of clinical features and imaging tests.

Paediatric CSIs differ from the adult pattern of injury, particularly at younger ages (Junewick 2010; Kreykes 2010; Mohseni 2011; Mortazavi 2011; Parent 2011; Viccellio 2001). Anatomical and behavioural differences account for this. A higher proportion of injuries occur in the upper or axial cervical spine (Occiput to C2) at the younger ages (Kokoska 2001; Leonard 2014; Mohseni 2011; Patel 2001). Injuries of the upper cervical spine are associated with higher morbidity and mortality than those of the lower cervical spine (Leonard 2014; Patel 2001). A more adult pattern of injury is established by late childhood/early teenage years with equal proportions or slightly higher numbers of subaxial CSIs described at older ages (Leonard 2014; Mohseni 2011). A cut-off around eight years of age has often been used to separate injury patterns in older and younger children; some series also separate children under two or three years of age (Kokoska 2001; Leonard 2014; Leonard 2015; Viccellio 2001). At younger ages, the flexibility of the vertebral column also considerably outweighs the capacity for stretch of the spinal cord proper, and spinal cord injury may occur without bony injury. Reported spinal cord injury incidence rates in paediatric CSI vary between 17% and 35% (Gargas 2013; Leonard 2014; Patel 2001).

Several blunt trauma mechanisms can cause paediatric CSI. At all ages, motor vehicle-related accidents account for the largest proportion of injuries, with falls generally described as the second most common mechanism (Leonard 2014; Leonard 2019; Mohseni 2011; Nunn 2021; Patel 2001; Polk-Williams 2008; Shin 2016). In older children, sporting and other recreational activities account for a significant proportion of CSIs (Babcock 2018; Cirak 2004; Leonard 2014; Mortazavi 2011); in younger children, pedestrian accidents and inflicted injuries are also described (Leonard 2014; Mortazavi 2011). Specific mechanisms that involve an axial load, or head-first impact, such as diving may predispose to CSI (Leonard 2011; Leonard 2019).

Clinical features associated with CSI have been described in adult and paediatric studies (Hoffman 2000; Leonard 2011; Leonard 2019; Stiell 2001). These factors may include features of examination (e.g. posterior neck tenderness, torticollis, abnormal neurology, altered level of consciousness, significant other injury), and history (e.g. neck pain, previous CSI, underlying predisposing conditions such as Down's syndrome). Clinical assessment in children may be further complicated by the child's ability to both communicate and co-operate with clinical examination and their ability to discriminate symptoms suspicious for CSI, such as midline neck tenderness from discomfort, anxiety and other injury complaints. Neck pain rather than specific posterior midline tenderness has been described as a factor associated with CSI in children(Leonard 2011).Age-related differences in factors associated within children have also been described (Leonard 2015).

Given the consequences of CSIs, physicians seek to identify all injuries, generally through the use of imaging modalities such as plain radiography (X-ray), computed tomography (CT) or magnetic resonance imaging (MRI). X-ray and CT are the most common initial imaging tests used by physicians to diagnose or rule out paediatric CSI. In contrast to adult practice where CT is considered the gold standard (National Clinical Guideline Centre 2014; Ryken 2013), X-ray is often advocated as the first-line investigation in children (Browne 2003; Burns 2011; Chaudhry 2016; Chung 2011; Hannon 2015; Herman 2019; National Clinical Guideline Centre 2014; Nigrovic 2012; Slaar 2017). Some guidelines and publications suggest a combination of X-ray and targeted upper cervical spine CT (Chung 2011; Garton 2008; Sun 2013); others recommend CT in children deemed to be at higher risk, such as those with altered levels of consciousness, although this definition of "higher risk" often varies (Easter 2011; Hannon 2015; Herman 2019; Mortazavi 2011; National Clinical Guideline Centre 2014).

X-rays are associated with significantly lower radiation doses than CT scans (Booth 2012; Jimenez 2008); however, missed CSI rates of 10% to 25% have been reported with plain X-rays in children (Chung 2011; Garton 2008; Nigrovic 2012; Rana 2009). CT, while superior to X-ray in detecting bony CSI (Parizel 2010; Ryken 2013), may also not show all paediatric CSIs or their extent (Rozzelle 2013). One study reported a sensitivity of 23% (specificity 100%) in detecting soft tissue abnormalities in children (Henry 2013); other retrospective reviews have found 17% (Gargas 2013) and 20% (Nunn 2021) of paediatric CSIs not to be apparent on CT.

MRI is often used as a second- or third-line test, particularly where neurological symptoms are present, the patient is unable to be clinically assessed or there are ongoing concerns of CSI. While a superior modality for spinal cord and spinal soft tissue abnormalities (Parizel 2010) and free of ionising radiation, it has several limitations including availability, cost, time to perform the scan and possible need for sedation or general anaesthesia due to the prolonged immobilisation required in young or unco-operative children. It may also be less ideal than CT scan for bony injuries. These factors have limited consideration of MRI use in screening after blunt trauma to date. In addition, the clinical significance of the injuries detected on MRI is also sometimes unclear (Booth 2012).

Spinal cord injury without radiographic abnormalities (SCIWORA) has been described in children with spinal cord injury, with incidence varying greatly between studies (Bosch 2002; Brown 2001; Cirak 2004; Farrell 2017; Gore 2009; Kreykes 2010; Leonard 2014; Mahajan 2013; Mortazavi 2011; Pang 2004; Polk-Williams 2008; Yucesoy 2008). One review reported rates between 5% and 67%, with an overall incidence estimated at around 35% (Pang

2004). The SCIWORA terminology predates the widespread use and availability of MRI (Pang 1982), and there is ongoing definitional debate as to whether the term should include MRI detectable injury or not (Farrell 2017; Yucesoy 2008). Some more recent studies have divided SCIWORA into two categories, those with MRI abnormalities and those with a normal MRI, with more favourable clinical outcomes described in the latter group (Farrell 2017; Mahajan 2013).

It is unethical and unfeasible to image all children presenting with blunt trauma for possible CSI given concerns about unnecessary exposure to ionising radiation (X-ray, CT) and increased lifetime cancer risk (Brenner 2007; Chen 2014; Mathews 2013; Miglioretti 2013; Pearce 2012), the risks of sedation (CT, MRI) (Cutler 2007; Goldwasser 2015; Hoyle 2014), resource implications (cost, time, bed space*)* and patient discomfort with prolonged assessments (Chan 1994; Leonard 2012; March 2002; Sundstrom 2014). Physicians are thus faced with the decision of which children require imaging and in whom it can be safely avoided (i.e. which children are considered at very low risk of CSI and can be "clinically cleared" without imaging). Ideally, a well-evidenced clinical decision rule (CDR) or tool would be administered during the initial clinical assessment to guide this clinical decision-making process, and minimise unnecessary tests and their associated risks, whilst detecting all significant CSIs.

Index test(s)

The tools under evaluation are any CDRs or sets of clinical criteria used to evaluate CSI in children and adolescents following blunt trauma that provide guidance on whether imaging is required, or whether it can be safely avoided. CDRs are composed of at least three variables of history, examination findings or simple tests, and are applied during the initial clinical assessment, prior to any imaging. The definition of a positive result is dependent on whether the rule aims to identify children at high risk of CSI, who require further imaging, or at very low risk of CSI, where imaging is not required. These tools may be prospectively or retrospectively derived.

The development of a CDR is a three-step process involving derivation, validation and impact analysis (assessing the impact of the rule on clinician behaviour) (Laupacis 1997; McGinn 2000; Stiell 1999). The thresholds for a positive result are dependent on the nature of the CDR, whether the CDR is intended to identify children at high risk of CSI, who require further imaging, or at very low risk of CSI, where imaging is not required.

Tools derived for adults that are commonly used for children, such as the National Emergency X-Radiography Utilization Study (NEXUS) (Viccellio 2001) and the Canadian C-Spine Rule (Stiell 2001), were also evaluated providing their use was assessed in children. Tools evaluated were not limited by primary imaging modality recommended (if any).

Clinical pathway

The clinical pathway for assessment of possible CSIs is part of the standard trauma workup for children presenting with blunt trauma to the emergency department (ED). Clinical features such as history, mechanism of injury and examination findings are considered to determine whether radiographic imaging of the cervical spine is indicated. A well-evidenced CDR or set of clinical criteria guiding clinicians on whether a child is at higher or lower risk of CSI would assist in this decision-making process. It would allow those at higher risk of CSI to be more accurately identified and unnecessary tests with their incumbent risks, such as exposure to ionising radiation, and costs, to be avoided. Children are also usually immobilised during assessment for CSI with their movements heavily restricted (often confined to lying still on a bed) and they may wear a cervical spine collar or neck brace (Chan 1994; Leonard 2012; March 2002; Sundstrom 2014). Early identification of children at low risk and suitable for clinical clearance (i.e. clearance without imaging) would also minimise these discomforts and free hospital resources, benefiting both the patient and healthcare system.

Rationale

Paediatric CSIs, while rare, can have devastating consequences, including death and long-term disability. Radiographic imaging is used to identify CSIs but has significant risks and costs including exposure to ionising radiation and increased lifetime cancer risks. Physicians aim to identify all CSIs in children whilst minimising unnecessary imaging in children deemed low risk for CSI. CDRs or tools can assist in this decision-making process, but evidence to support their use in paediatric populations has been limited.

Well-established adult rules to guide the decision to image in possible CSI exist (Hoffman 2000; Stiell 2001); however, the validity of their use in children, particularly at younger ages, has been questioned (Garton 2008; Slaar 2017; Viccellio 2001). In more recent years, clinical criteria or risk factors derived from specific paediatric cohorts have been proposed as possible CDRs or tools specifically for children (Leonard 2011; Leonard 2019).

This review seeks to expand the previous Cochrane review (Slaar 2017) beyond examining NEXUS and Canadian C-Spine Rule tests to include all CDRs or sets of clinical criteria used to evaluate CSI (and guide the decision to image) in children and adolescents following blunt trauma. It will also ascertain whether any new evidence exists to inform the use of these well-established adult rules in children.

OBJECTIVES

To assess and compare the diagnostic accuracy of clinical decision rules (CDRs) or sets of clinical criteria, alone or in comparison with each other, for the evaluation of CSI following blunt trauma in children.

Secondary objectives

We were unable to explore heterogeneity in this review due to the small number of studies for each CDR. However, we will explore the following types of heterogeneity in the estimates of diagnostic test accuracy in subsequent reviews if the number of studies increases, including:

- differences in the healthcare setting and study design: previous studies stated that CSI is seen less often in general EDs than in paediatric trauma hospitals, and that a CT of the neck is more common in general EDs (Adelgais 2014);
- study quality, as assessed by the Quality Assessment of Diagnostic Accuracy Studies Version 2 (QUADAS-2) checklist (Whiting 2011);
- age-related differences: we hypothesised that both the applicability of the CDRs and the type of injury would differ

according to age in children younger than eight years and eight years or older (Leonard 2014).

METHODS

Criteria for considering studies for this review

Types of studies

We included studies that compared the diagnostic accuracy of any CDR or clinical criteria compared with a reference standard for the evaluation of CSI in children presenting to EDs following blunt trauma. De novo CDRs and validated CDRs were included; however, de novo CDRs were considered at high risk of bias due to the lack of validation data. Eligible study designs included diagnostic studies with cross-sectional or cohort designs (retrospective or prospective) and randomised controlled trials. We included studies evaluating one CDR or comparing two or more CDRs (directly and indirectly). We only included results from full reports. We excluded case-control studies because of the bias they might introduce and reports that evaluated predictor finding models.

Participants

We included children (aged 0 to less than 18 years) who underwent blunt trauma evaluation in the ED. We excluded studies specifically focused on children with a history of previous surgery of the cervical spine or congenital cervical spine anomalies, or both.

In studies with mixed populations where data related to participants aged less than 18 years could not be separated from older participants, we attempted to contact the study authors for more information. If we were unable to contact study authors to request additional data, we listed them in the Studies awaiting classification table. However, if study authors confirmed that age disaggregated data were unavailable, we excluded the studies.

Index tests

The tests under evaluation were any CDR or set of clinical criteria that compared the diagnostic accuracy of the test for the target condition with the reference standard.

Target conditions

The target condition was clinically important CSI, defined as any fracture, dislocation, ligamentous injury or spinal cord injury (either detectable by diagnostic imaging or spinal cord injury without radiographic association) involving the cervical region and attached ligamentous structures.

Reference standards

Evaluation for CSI in the ED requires expert clinical assessment and often diagnostic imaging. X-ray, CT and MRI can be used in the assessment of CSI with each modality having different strengths and weaknesses. Therefore, we included studies in which participants were diagnosed with CSI using any reference standard, that is, X-ray, CT or MRI, following presentation to the ED.

In children who are low risk for CSI, it may not be feasible or ethical to perform diagnostic imaging for reasons described in the Background. As such, we also included studies where children received follow-up in the ED to clinically clear the cervical spine in individuals deemed at lower-risk by the treating clinician. Clinical follow-up in the ED was defined as clinical evaluation of the neck after removal of the neck collar (if worn) in these children.

To reduce the risk of incorrectly classifying children as positive or negative for CSI, children who received only clinical follow-up in the ED and no imaging should have had an additional follow-up some time after discharge. This additional follow-up may have involved clinical evaluation of the neck by a treating clinician, review of the medical record for additional imaging of the cervical spine, telephone follow-up to verify the absence of CSI or other systems to ensure initially missed CSI were diagnosed.

We included studies with participants who did not receive imaging or an additional clinical follow-up after discharge from the ED; however, this was considered a source of bias in the QUADAS-2 assessment.

We included children who underwent an eligible reference standard or obtained clinical follow-up within 72 hours of presentation at the ED following blunt trauma.

Search methods for identification of studies

Electronic searches

The Information Specialist of the Cochrane Back and Neck Review Group developed the initial search strategy for the previous version of the review (Slaar 2017). For the update, a specialist librarian reviewed and modified the search strategy when necessary, based on updates to thesaurus terms for each database listed below. The search strategies for identifying diagnostic test accuracy studies consisted of controlled vocabulary and keyword terms for each of the following concepts: the index or reference test, the target condition and the patient description.

We searched the following databases from 1 January 2015 to 13 December 2022 to capture any studies published since the previous version of the review (Slaar 2017).

- Cochrane Central Register of Controlled Trials (CENTRAL, in the Cochrane Library) Issue 12, 2022
- MEDLINE Ovid
- Embase Ovid
- ProQuest Dissertations & Theses Database for relevant conference proceedings, dissertations, and theses
- PubMed (www.ncbi.nlm.nih.gov/pubmed)
- OpenGrey for 'grey literature' (www.opengrey.eu/)
- ClinicalTrials.gov (clinicaltrials.gov/)
- Science Citation Index (Web of Science, Core Collection)
- World Health Organization International Clinical Trials Registry Platform (ICTRP) (www.who.int/clinical-trials-registry-platform)

The search strategies can be found in Appendix 1.

Searching other resources

We re-examined all studies excluded from the previous version of the review to determine if any studies should now be included based on our expanded index test eligibility criteria to include all CDRs. We sought to identify additional studies through searching reference lists of primary studies and relevant systematic reviews. We also contacted authors to request information of

any unpublished or ongoing studies. There were no language restrictions. In non-English full-text studies, we first examined the English abstract and title for eligibility. If the abstract was potentially relevant, we planned to translate the full text.

Data collection and analysis

Selection of studies

For this review update, we uploaded and screened references in Covidence. Pairs of review authors (NE, ET, VR, JW) independently screened each title and abstract identified in the search. We retrieved full texts for potentially relevant references, and two review authors independently screened them. We resolved disagreements by recourse to a third review author. Two review authors were authors of one of the included studies. They were not involved in the screening and selection of papers.

Data extraction and management

Two review authors (ET, NE) independently extracted data using a piloted data extraction form, resolving disagreements by consultation with a third review author if necessary. We contacted study authors to request additional information.

Data collected included:

- study ID (year of publication, author, citation);
- study design (consecutive/random, retrospective/prospective, cohort, cross-sectional, randomised controlled trials);
- sample characteristics (number of participants and children enrolled and analysed, age, sex);
- setting (type of acute care setting(s), location);
- inclusion and exclusion criteria;
- index test(s) used (name, clinical criteria, interpretation);
- target condition (definition, prevalence in sample);
- reference standard (definition, any information related to execution or interpretation);
- results (data to populate a two-by-two table).

This information was documented for each study in the Characteristics of included studies table.

Two review authors were authors of one of the included studies. They were not involved in the data extraction.

Assessment of methodological quality

Two review authors (ET, NE), independently and in duplicate, assessed the methodological quality of each study, using the QUADAS-2 tool (Whiting 2011). We resolved disagreements by consensus.

The QUADAS-2 tool consists of four domains: patient selection, index tests, reference standard, and flow and timing. For this update, we modified the patient selection domains by removing one core signalling question that was addressed by the eligibility criteria; "was a case-control design avoided?" and added an additional signalling question to check if the data were collected prospectively. Retrospective data are prone to selective and incomplete recording. We clarified the meaning of the flow and timing domain signalling question "did all patients receive the same reference standard?" to be more clinically appropriate. The same reference standard could be either all patients underwent the same type of imaging or all patients underwent follow-up after discharge. The tailored version of the tool is provided in Table 1.

Studies that evaluated de novo CDRs were rated as high risk of bias in the index test domain because of the lack of existing validation data. In the current review update, the reference standards were radiographic imaging. However, the decision to obtain imaging was at the treating clinicians' discretion, and some children received clinical clearance of the cervical spine without imaging. We preferred if children who did not receive imaging underwent a follow-up some time after discharge to ensure no CSIs were missed. Therefore, we rated studies with children who did not receive imaging or follow-up after discharge as high risk of bias in the reference standard domain. If studies only included those children that received imaging, excluding those who presented with blunt trauma and were cleared clinically, this was recorded as high risk for the applicability question in the patient selection domain.

The risk of bias judgement ('high', 'low' or 'unclear') for each domain was dependent on the signalling questions. If the answers to all signalling questions within a domain were judged as 'yes' (indicating low risk of bias for each question), then the domain was judged at low risk of bias. If any signalling question was judged as 'no' (indicating a high risk of bias), the overall domain was also categorised at high risk of bias.

Statistical analysis and data synthesis

We extracted indices of the diagnostic performance of all clinical tools from data presented in each study. We generated diagnostic two-by-two tables, from which we calculated sensitivities and specificities for each index test with 95% confidence intervals (CI), and presented them in forest plots and also in a receiver operator curve (ROC) space. If data presented in trials were uninterpretable to generate two-by-two tables, we contacted the authors of the study requesting clarification.

We planned to perform meta-analyses of sensitivity and specificity employing a bivariate logistic normal model using a hierarchical approach (Reitsma 2005). This approach would enable us to calculate summary estimates of sensitivity and specificity while dealing with sources of variation within and between studies and any correlation that might exist between sensitivity and specificity. With the model estimates, we aimed to plot sensitivities and specificities in forest plots and in ROC space. If we had identified a sufficient number of studies with direct or indirect comparison between two or more index tests, we planned to use the methods proposed by Nyaga 2018 for meta-analysis. These methods will be used for randomised controlled trials and studies that used both direct and indirect comparisons.

We also planned to compare the different index tests and tried to find whether these tests had different sensitivities or specificities, employing a bivariate model.

We planned to compare tests by adding covariates for different types of index tests into the bivariate model and testing the significance (P = 0.05) of the parameters of covariates. If almost none of the primary studies directly compared these tools, we would have included all studies that evaluated at least one of the index tests into the test comparison. In other words, test comparison would not be limited to direct comparisons, but would have used all the evidence available. We planned to compare them

qualitatively if data were insufficient for comparison by statistical tests. Verification bias is to be expected, since we included the use of different types of reference standards in test-positive (X-ray, CT scan, or MRI) and test-negative (clinical follow-up). All the statistical analyses were performed using the analysis functions of Review Manager 5 (Review Manager 2014).

Investigations of heterogeneity

We intended to investigate sources of heterogeneity in terms of differences in the healthcare setting, study design, study quality and age-related differences. However, we were unable to formally explore heterogeneity, due to a lack of relevant studies. If sufficient data becomes available in future updates, we will use forest plots and sensitivities and specificities plotted in ROC space for visual examination of heterogeneity between studies. We will add covariates, for example, age groups (less than eight years of age versus eight years and older) and QUADAS-2 items bivariate model to investigate the heterogeneity between studies in the meta-analysis (Whiting 2011). We could only have investigated heterogeneity if there was a sufficient number of studies providing adequate information on the factor of interest.

Sensitivity analyses

We planned to undertake sensitivity analysis by removing studies at high risk of bias. However, we were unable to conduct sensitivity analyses because there were too few studies.

Assessment of reporting bias

As yet there are no quantitative methods for reporting bias in diagnostic test accuracy studies; therefore, we did not assess reporting bias.

Summary of findings and assessment of the certainty of the evidence

We summarised key findings in Summary of findings 1 and Summary of findings 2. We assessed the certainty of evidence using the GRADE approach, which evaluates five domains: risk of bias, indirectness, inconsistency, imprecision and publication bias (Schünemann 2020). We explained our decisions to downgrade the certainty of evidence in the footnotes of the summary of findings tables.

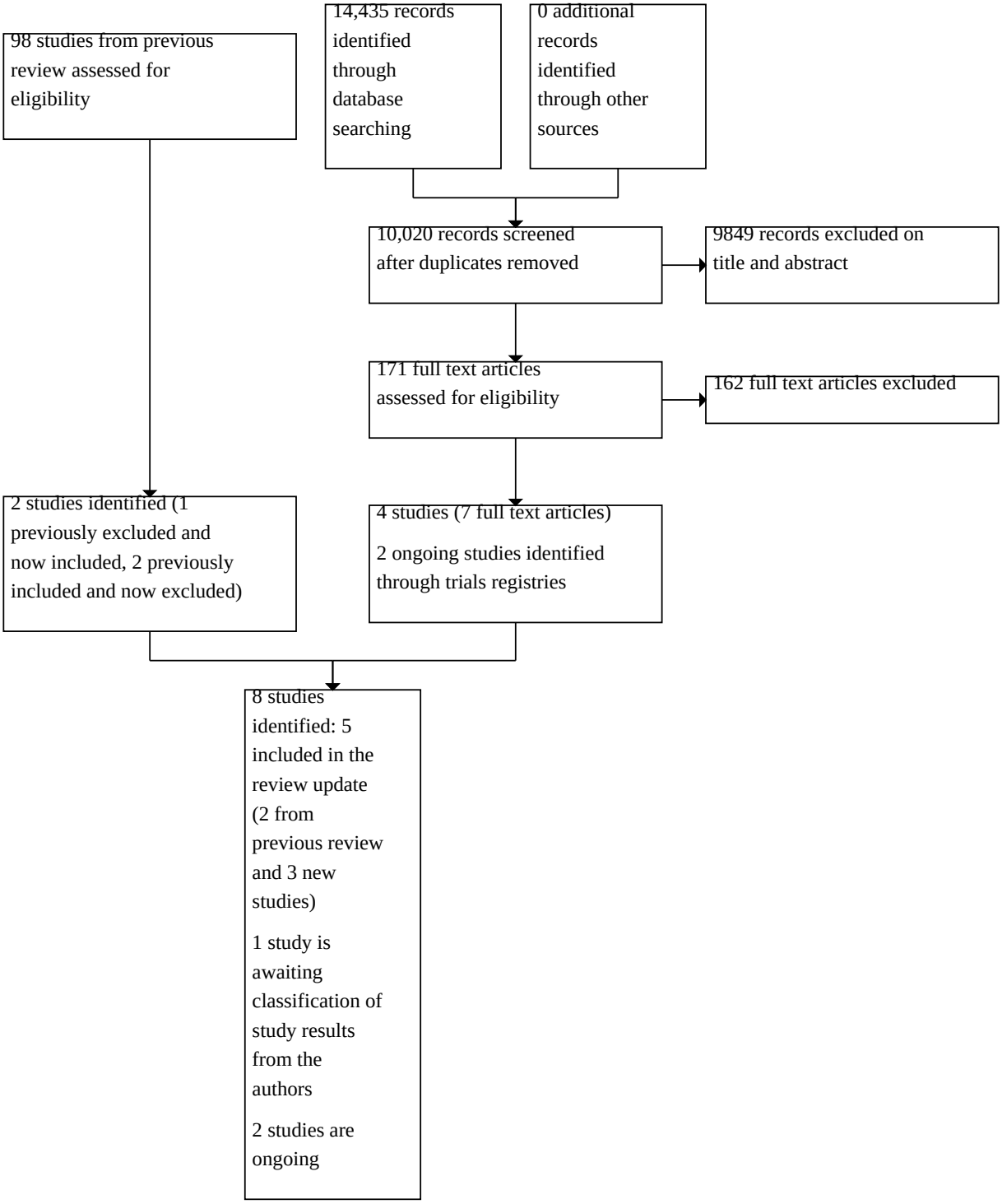
RESULTS

Results of the search

We identified 14,435 citations in the search update on 13 December 2022. The number of citations by search engine is shown in Table 2. After removal of duplicates, we screened 10,020 records by title and abstract and excluded 9849. Due to changes in the inclusion criteria for this review update, we evaluated the 98 full-text articles assessed for eligibility in the previous version of the review (included and excluded studies), in addition to the 171 full-text articles identified in the search update. We excluded 162/171 full-text articles identified through the updated search. The main reasons for exclusion were irrelevant index tests or different study population (e.g. prehospital or adult study sample). We excluded two studies evaluated in the previous review (Ehrlich 2009; Jaffe 1987). We excluded Jaffe 1987 because it included a second non-consecutive cohort of participants with CSI, and Ehrlich 2009 because of the case-matched study design. Further details are provided in the Characteristics of excluded studies table.

This update includes five studies: one study evaluated in the previous review (Viccellio 2001); one study excluded from the previous review and now included (Pieretti-Vanmarcke 2009); and three new studies identified in the updated search (Davies 2016; Leonard 2019; Phillips 2021). Two studies are awaiting classification, with authors contacted for further eligibility information (Arbuthnot 2017; Vargas 2022), and we identified two ongoing studies (ACTRN12621001050842; NCT05049330). Refer to Figure 1 for the PRISMA flow diagram of search results and screening results.

Figure 1. Study flow diagram.



Included studies

We reported the main characteristics of the five studies in the Characteristics of included studies table. All studies were reported in full-text publications.

Included studies reported on the diagnostic accuracy of seven CDRs, summarised in Table 3; five previously described CDRs (NEXUS, Canadian C-Spine Rule, PECARN retrospective criteria, National Institute for Health and Care Excellence (NICE) clinical guideline 56 (CG56) and 176 (CG176)) and two derived CDRs (Leonard de novo (Leonard 2019), PEDSPINE (Pieretti-Vanmarcke 2009)). One study directly compared the accuracy of three index tests (Phillips 2021), two studies directly compared the accuracy of two index tests (Davies 2016; Leonard 2019), and two studies reported the accuracy of one index test (Pieretti-Vanmarcke 2009; Viccellio 2001). The inclusion criteria for age of children were: less than 10 years of age following blunt trauma (Davies 2016), younger than 18 years of age (Leonard 2019; Viccellio 2001), under 16 years of age (Phillips 2021), and three years of age and younger (Pieretti-Vanmarcke 2009).

The total number of children enrolled in the included studies was 21,379 and ranged from 278 (Davies 2016) to 12,882 (Pieretti-Vanmarcke 2009). The prevalence of CSI ranged from 0.5% (Phillips 2021) to 1.85% (Davies 2016). Studies were conducted in the USA (Leonard 2019; Viccellio 2001); the UK (Davies 2016); Australia (Phillips 2021); and across the USA, Canada and Brazil (Pieretti-Vanmarcke 2009). The studies were published between 2001 and 2021.

Excluded studies

We excluded 164 reports with reasons (Characteristics of excluded studies table).

Studies awaiting classification

Two studies are awaiting classification while we await replies from authors (Arbuthnot 2017; Vargas 2022; Characteristics of studies awaiting classification table).

Ongoing studies

We identified two ongoing studies (ACTRN12621001050842; NCT05049330; Characteristics of ongoing studies table).

Methodological quality of included studies

We reported the results of the methodological quality assessment of included studies in the Characteristics of included studies table. Figure 2 summarises the results of the quality assessment of the included studies and an individual assessment for each study is provided in Figure 3.

Figure 2. Risk of bias and applicability concerns graph: review authors' judgements about each domain presented as percentages across included studies.

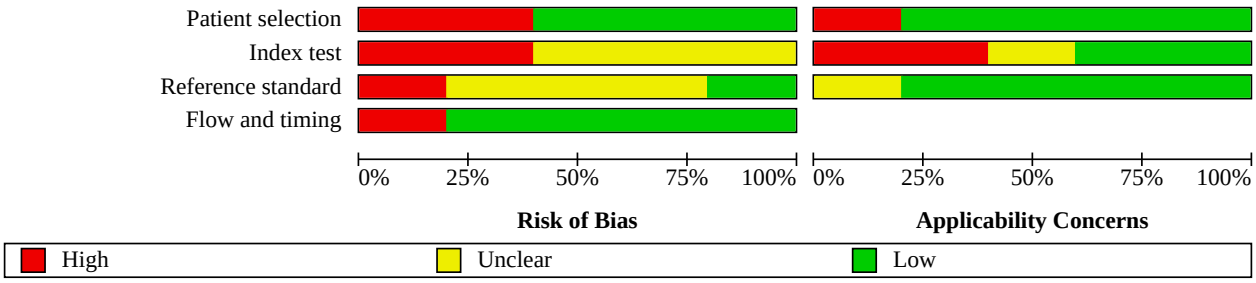
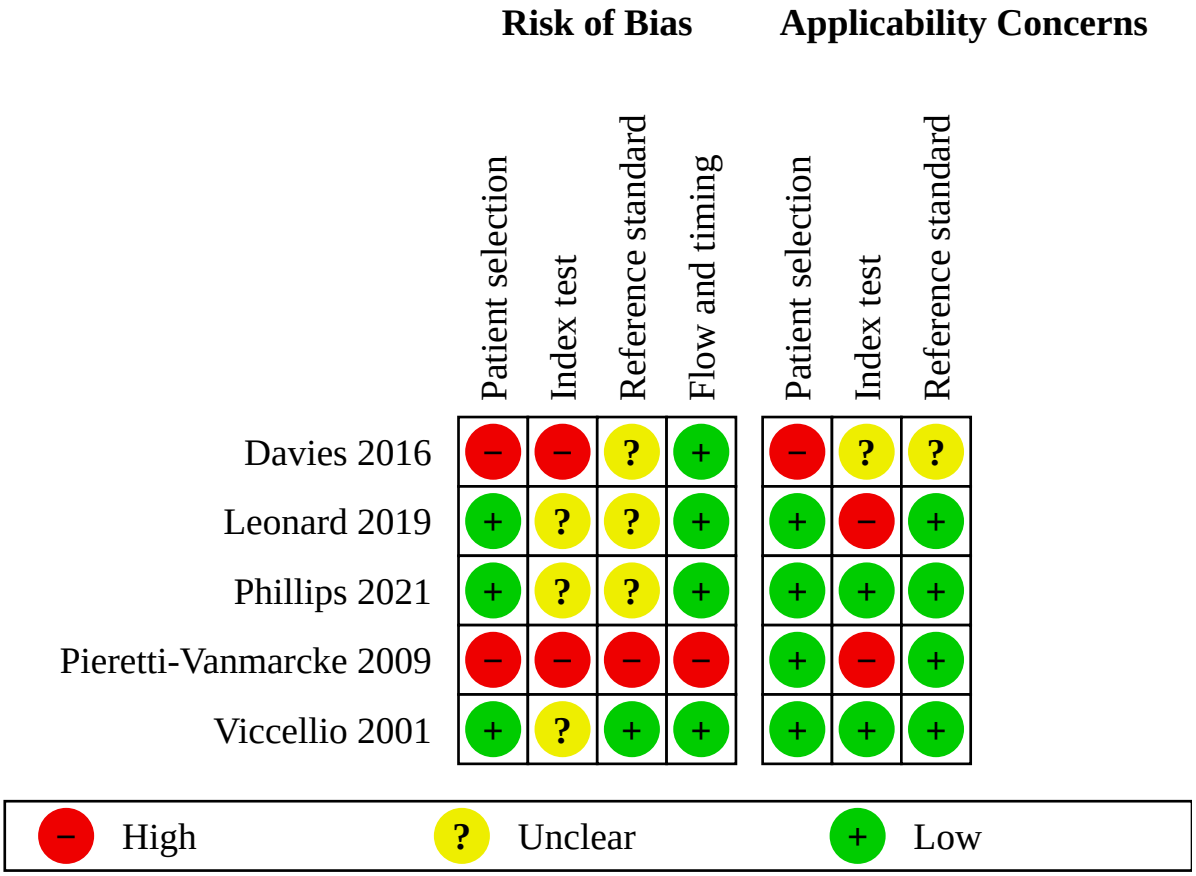


Figure 3. Risk of bias and applicability concerns summary: review authors' judgements about each domain for each included study.



Patient selection

We considered two studies at high risk of bias in the patient selection domain as they were retrospective studies of medical records or trauma registries (Davies 2016; Pieretti-Vanmarcke 2009), with the remaining studies rated at low risk of bias. Davies 2016 was rated as high concern of applicability as they included only those children who presented and had imaging of the cervical spine. Retrospective studies rely on routinely collected data and are, therefore, susceptible to selective and incomplete recording. Davies 2016 excluded eight children due to incomplete data. Four studies were at low concern of applicability because they were of prospective cohort design, included a consecutive or random sample of participants and avoided inappropriate exclusions.

Index test

Two studies applied the index test retrospectively, after the reference standard was interpreted and were rated at high risk of bias (Davies 2016; Pieretti-Vanmarcke 2009). Three studies of prospective design collected data on rule predictor variables prior to radiographic imaging (Leonard 2019; Phillips 2021; Viccellio 2001). However, there were insufficient details on the blinding of imaging results prior to index tests being interpreted. Therefore, they were assessed at unclear risk of bias. All studies reported the use of a prespecified threshold.

Two studies derived a new CDR (Leonard de novo and PEDSPINE) and were, therefore, rated as high concern for applicability due to an absence of existing validation data (Leonard 2019; Pieretti-Vanmarcke 2009). However, Leonard 2019 also validated an existing CDR, the PECARN retrospective criteria, and, for this rule, we had low concerns for its applicability. Davies 2016 was rated as unclear applicability concerns because of their retrospective study design. We had low concern for applicability in the index test domain for Phillips 2021 and Viccellio 2001 because they applied validated CDRs prospectively.

Reference standard

In two studies, the reference standard was radiographic imaging (X-ray, CT or MRI) in all children (Davies 2016; Viccellio 2001). Two studies had a reference standard of radiographic imaging or for those who did not receive imaging, clinical clearance in the ED with subsequent telephone follow-up after discharge for all children (Leonard 2019; Phillips 2021). The final study had radiographic imaging for some children and clinical clearance in the ED for others (Pieretti-Vanmarcke 2009).

The reference standard domain was at low risk of bias in one study (Viccellio 2001), unclear risk of bias in three studies (Davies 2016; Leonard 2019; Phillips 2021), and high risk of bias in one study (Pieretti-Vanmarcke 2009). Pieretti-Vanmarcke 2009 was at high risk of bias because it did not follow up after discharge for children

who did not receive imaging. Therefore, there was a risk that the target condition may have been incorrectly classified for these children. Although Leonard 2019 and Phillips 2021 both included follow-up after discharge for children who did not receive imaging, there was insufficient information provided on whether those who interpreted the reference standard (radiologists) had knowledge of the index test results or data collection forms. Davies 2016 was at unclear risk of bias and unclear concern for applicability because the target condition, CSI, was not defined. All other studies were rated at low concern for applicability as the target condition was clearly defined.

Flow and timing

One study was at high risk of bias in the flow and timing domain (Pieretti-Vanmarcke 2009). There was an appropriate interval between presentation to the ED and conduct of the index test/reference standard and children included in the analysis were clearly defined and any exclusions were for appropriate reasons (e.g. child did not meet inclusion criteria or data were missing). However, children did not receive the same reference standard and those not receiving imaging were not followed up after discharge, increasing the risk of verification bias of the index test.

Findings

We evaluated five studies, which enrolled 21,379 children, for the presence of CSI using the NEXUS criteria, Canadian C-Spine Rule, PECARN retrospective criteria, NICE CG56 and CG176 and assessment of the certainty of the evidence (Davies 2016; Leonard 2019; Phillips 2021; Pieretti-Vanmarcke 2009; Viccellio 2001), and two derived CDRs (Leonard de novo (Leonard 2019) and PEDSPINE (Pieretti-Vanmarcke 2009)). The average incidence of CSI in these five studies was 1.16% with a median prevalence of CSI of 0.98% (interquartile range (IQR) 0.50% to 1.85%). Since the number of eligible studies for each CDR was fewer than four, and the inclusion criteria and outcomes of those studies were too diverse, we did not conduct a meta-analysis and therefore presented no summary estimates in this review. Instead, we interpreted sensitivity and specificity from each primary study separately. Since there were few data, we were unable to investigate heterogeneity. We generated diagnostic two-by-two tables, from which we calculated sensitivities and specificities for each index test with 95% CIs, and presented them in forest plots (see Figure 4 and Summary of findings 1). We could not perform sensitivity analyses because there were too few studies.

Figure 4. Forest plot of NEXUS, Canadian C-spine Rule, NICE Guidelines (CG56 and CG176), PECARN Retrospective, Leonard de novo and PEDSPINE.

NEXUS

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Phillips 2021	5	425	0	543	1.00 [0.48, 1.00]	0.56 [0.53, 0.59]
Viccellio 2001	30	2432	0	603	1.00 [0.88, 1.00]	0.20 [0.18, 0.21]

Canadian C-Spine Rule

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Phillips 2021	5	467	0	501	1.00 [0.48, 1.00]	0.52 [0.49, 0.55]

PECARN Retrospective

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Leonard 2019	67	2186	7	1831	0.91 [0.81, 0.96]	0.46 [0.44, 0.47]
Phillips 2021	5	658	0	310	1.00 [0.48, 1.00]	0.32 [0.29, 0.35]

Leonard de novo

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Leonard 2019	68	1998	6	2019	0.92 [0.83, 0.97]	0.50 [0.49, 0.52]

PEDSPINE

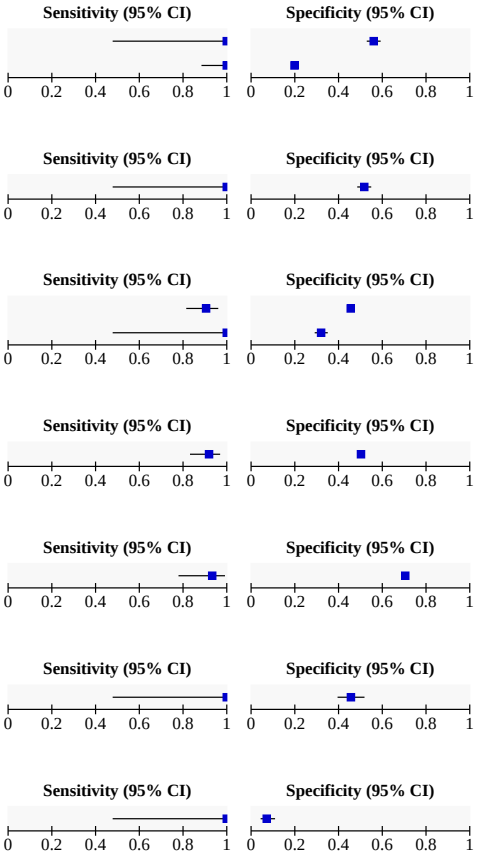
Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Pieretti-Vanmarcke 2009	28	1224	2	2925	0.93 [0.78, 0.99]	0.70 [0.69, 0.72]

NICE guideline (CG56)

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Davies 2016	5	144	0	121	1.00 [0.48, 1.00]	0.46 [0.40, 0.52]

NICE guideline (CG176)

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Davies 2016	5	246	0	19	1.00 [0.48, 1.00]	0.07 [0.04, 0.11]



Direct comparisons

NEXUS, Canadian C-Spine Rule and PECARN retrospective criteria

Phillips 2021, a prospective single-centre study, directly compared the accuracy of NEXUS, Canadian C-Spine Rule and the PECARN retrospective criteria in an enrolled cohort of 1010 children aged under 16 years who were immobilised before arrival to the ED for possible CSI, presented with neck pain in the context of trauma or considered at risk of neck injury by the ED team. The reference standard was imaging (X-ray, CT or MRI) or clinical clearance with all children followed up by telephone to ensure no CSIs were missed. The CSI prevalence in the children included in the analysis (973 children) was 0.5%. The sensitivities of NEXUS, Canadian C-Spine Rule and the PECARN retrospective criteria were 1.00 (95% CI 0.48 to 1.00), 1.00 (95% CI 0.48 to 1.00) and 1.00 (95% CI 0.48 to 1.00), respectively. The sensitivities of the three CDRs were not provided in the paper, with the authors deeming a formal validation inappropriate due to the low incidence of CSI (0.5%). The specificities for NEXUS, Canadian C-Spine Rule and the PECARN retrospective criteria were 0.56 (95% CI 0.53 to 0.59), 0.52 (95% CI 0.49 to 0.55) and 0.32 (95% CI 0.29 to 0.35), respectively. We considered the evidence for the estimates of sensitivity and specificity to be moderate certainty, downgraded one level for risk of bias.

Pediatric Emergency Care Applied Research Network (PECARN) retrospective criteria and Leonard de novo

Leonard 2019, a prospective multicentre study, evaluated the accuracy of the PECARN retrospective criteria in comparison to a de novo model (Leonard de novo) in 4091 children younger than 18 years of age, who presented to the ED for blunt trauma and were transported from the scene of the injury by emergency medical services in spinal motion restriction devices, underwent trauma team evaluation, had cervical spine imaging ordered in the ED, or combinations of these. The reference standard was imaging (X-ray, CT or MRI), medical record review 21 days later for subsequent imaging and a follow-up call if no imaging was noted to ensure no CSIs were missed. The prevalence of CSI was 1.8%.

The PECARN retrospective criteria were derived from a multicentre retrospective case-control study in children with blunt trauma and described eight variables associated with paediatric CSI which, if applied as a CDR, would have detected 98% of CSIs in their retrospective derivation cohort (Leonard 2011). The Leonard de novo model included CSI risk factors from the prospective study with good test accuracy in identifying CSIs (see Table 3 for details) (Leonard 2019). The sensitivities for the PECARN retrospective criteria and the Leonard de novo model were 0.91 (95% CI 0.81 to 0.96) and 0.92 (95% CI 0.83 to 0.97), respectively. The specificities for the PECARN retrospective criteria and the Leonard de novo model were 0.46 (95% CI 0.44 to 0.47) and 0.50 (95% CI 0.49 to 0.52), respectively. Although the sensitivity and specificity of the Leonard de novo was greater than the PECARN retrospective criteria (moderate-certainty evidence), the certainty of evidence was rated as low, downgraded one level due to risk of bias and one level due to indirectness/high concern for applicability due to an absence of existing validation data.

National Institute for Health and Clinical Excellence (NICE) Head Injury clinical guideline 56 and NICE Head Injury clinical guideline 176

Davies 2016 evaluated the diagnostic accuracy of the NICE Head Injury CG56 in comparison with the NICE Head Injury CG176 in the detection of paediatric CSI. A retrospective review was undertaken of all children under 10 years of age who underwent emergency cervical spine imaging following blunt trauma at a Level 1 trauma centre in the UK. The total number of enrolled participants was 278 and the prevalence of CSI in the children included in the analysis (270 children) was 1.85%. Davies 2016 was at high risk of bias in the patient selection domain as it was a retrospective study of medical records and rated at high concerns of applicability as only those children who presented and had imaging of the cervical spine were included. As the index test was applied retrospectively, after the reference standard was interpreted, it was also rated as high risk of bias in the index test domain.

The sensitivity of the CG56 guideline was 1.00 (95% CI 0.48 to 1.00) and specificity was 0.46 (95% CI 0.40 to 0.52). The sensitivity of the CG176 guideline was 1.00 (95% CI 0.48 to 1.00) and specificity was 0.07 (95% CI 0.04 to 0.11). We considered the evidence for the estimates of sensitivity and specificity to be very low certainty, downgraded two levels for risk of bias and one level for indirectness.

Indirect comparisons

National Emergency X-Radiography Utilization Study (NEXUS)

The NEXUS study was validated in a prospective, observational study in 21 EDs of 34,069 children who underwent radiography of the cervical spine after blunt trauma (2.5% were eight years old or younger) (Hoffman 2000). Two studies evaluated the diagnostic accuracy of the NEXUS criteria to evaluate for CSI in children following blunt trauma (Phillips 2021; Viccellio 2001). The total number of participants was 4038. The prevalences of CSI in the target populations were 0.5% (Phillips 2021) and 0.98% (Viccellio 2001).

Viccellio 2001, a prospective multicentre study and the paediatric cohort of the original NEXUS cohort, tested the accuracy of the NEXUS criteria in 3065 blunt trauma patients younger than 18 years who received cervical spine imaging (X-ray, CT, MRI or a combination of these). The number of children for whom a CT was obtained was unclear. Phillips 2021, a prospective single-centre study, tested the accuracy of NEXUS in direct comparison to the Canadian C-Spine Rule and to the PECARN retrospective criteria in an enrolled cohort of 1010 children aged under 16 years who were immobilised before arrival in the ED for possible CSI, presented with neck pain in the context of trauma or considered at risk of neck injury by the ED team. The reference standard was imaging (X-ray, CT or MRI) or clinical clearance with all children followed up by telephone to ensure no CSIs were missed. The sensitivity of the NEXUS criteria was calculated for Phillips 2021, as it was not provided in the paper. The authors deemed a formal validation inappropriate due to the low incidence of CSI (0.5%) in the 973 children included in the analysis.

The sensitivity of the NEXUS criteria in the studies was 1.00 (95% CI 0.88 to 1.00) (Viccellio 2001) and 1.00 (95% CI 0.48 to 1.00) (Phillips 2021). The specificity of the NEXUS criteria varied in the studies and was 0.20 (95% CI 0.18 to 0.21) (Viccellio 2001)

and 0.56 (95% CI 0.53 to 0.59) (Phillips 2021). We considered the evidence for the estimates of sensitivity and specificity to be low certainty, downgraded one level for risk of bias and one level for inconsistency.

Canadian C-Spine Rule

While the original Canadian C-Spine Rule study was never validated in children (Stiell 2001), one study evaluated its diagnostic accuracy for CSI in children following blunt trauma (Phillips 2021). Phillips 2021, a prospective single-centre study, tested the accuracy of the Canadian C-Spine Rule in direct comparison to the NEXUS criteria and the PECARN retrospective criteria in 973 children aged under 16 years who were immobilised before arrival in the ED for possible CSI, presented with neck pain in the context of trauma or considered at risk of neck injury by the ED team. The reference standard was imaging (X-ray, CT or MRI) or clinical clearance with all children followed up by telephone to ensure no CSIs were missed.

The sensitivity of the Canadian C-Spine Rule in the study was 1.00 (95% CI 0.48 to 1.00) and the specificity was 0.52 (95% CI 0.49 to 0.55) (Phillips 2021). We calculated the sensitivity as it was not provided in the paper. The CIs for sensitivity were wide due to the small number of injuries (5/973 children had confirmed CSI (0.5%)). We considered the evidence for the estimates of sensitivity and specificity to be moderate certainty, downgraded one level for risk of bias.

Pediatric Emergency Care Applied Research Network (PECARN) retrospective criteria

The PECARN criteria were derived from a retrospective case-control study and described eight variables associated with paediatric CSI which, if applied as a CDR, would have detected 98% of CSIs in their retrospective derivation cohort (Leonard 2011). Two studies evaluated the diagnostic accuracy of the PECARN retrospective criteria to evaluate for CSI in children following blunt trauma (Phillips 2021; Leonard 2019). The total number of participants was 5064 and the prevalence of CSI was 1.8% in Leonard 2019 and 0.5% in Phillips 2021. Leonard 2019, a prospective multicentre study, evaluated the accuracy of the PECARN retrospective criteria in 4091 children younger than 18 years of age, that presented to the ED for blunt trauma and were transported from the scene of the injury by emergency medical services in spinal motion restriction devices, underwent trauma team evaluation, had cervical spine imaging ordered in the ED, or a combination of these. The reference standard was imaging (X-ray, CT or MRI), medical record review 21 days later for subsequent imaging and a follow-up call if no imaging was noted to ensure no CSIs were missed. Phillips 2021, a prospective single-centre study, tested the accuracy of PECARN retrospective criteria in direct comparison to the Canadian C-Spine Rule and to the NEXUS criteria in 973 children aged under 16 years who were either immobilised before arrival in the ED for possible CSI, presented with neck pain in the context of trauma or considered at risk of neck injury by the ED team. The reference standard was imaging (X-ray, CT or MRI) or clinical clearance with all children followed up by telephone to ensure no CSIs were missed. The sensitivity of the PECARN retrospective criteria was calculated for Phillips 2021, as it was not provided in the paper. The authors deemed a formal validation not appropriate due to the low incidence of CSI (0.5%).

The sensitivities of the PECARN retrospective criteria in the studies were 0.91 (95% CI 0.81 to 0.96) (Leonard 2019) and 1.00 (95% CI 0.48 to 1.00) (Phillips 2021). The specificities of the PECARN retrospective criteria were 0.46 (95% CI 0.44 to 0.47) (Leonard 2019) and 0.32 (95% CI 0.29 to 0.35) (Phillips 2021). We considered the evidence for the estimates of sensitivity and specificity to be moderate certainty, downgraded one level for risk of bias.

PEDSPINE criteria

Pieretti-Vanmarcke 2009 was a multicentre retrospective study developed and validated the PEDSPINE CSI criteria for children aged three years and younger who sustained blunt trauma. Trauma registries from 22 institutions located in the USA, Canada and Brazil were reviewed over a 10-year period. The total number of participants analysed was 12,537 and the prevalence of CSI was 0.66%. The reference standard was X-rays, CT, MRI or clinical clearance. X-rays were obtained in 32.3% of children, CT in 30.6% and MRI in 3.8%. Imaging was not undertaken in 33.3% of children. Two-thirds of the sample (8354 children) was used to evaluate and develop the PEDSPINE clinical predictors of CSI and one-third (4179 children) was used to validate the criteria. The validation set results were reported. Pieretti-Vanmarcke 2009 was at high risk of bias in the patient selection domain as it was a retrospective study and as the index test was applied retrospectively, after the reference standard was interpreted. It was also rated at high risk of bias in the index test domain.

The sensitivity of the PEDSPINE criteria was 0.93 (95% CI 0.78 to 0.99) and specificity was 0.70 (95% CI 0.69 to 0.72). We considered the evidence for the estimates of sensitivity and specificity to be very low certainty, downgraded three levels for risk of bias and one level for indirectness.

DISCUSSION

Summary of main results

We included five studies evaluating the diagnostic accuracy of seven CDRs (NEXUS, Canadian C-Spine Rule, PECARN retrospective criteria, NICE CG56 and CG176, Leonard de novo and PEDSPINE) to evaluate children with blunt trauma for CSI. One study reported on three index tests (Phillips 2021), two studies reported on two index tests (Davies 2016; Leonard 2019), and two studies reported on one index test (Pieretti-Vanmarcke 2009; Viccellio 2001). The inclusion criteria for age of children were: less than 10 years following blunt trauma (Davies 2016), younger than 18 years (Leonard 2019; Viccellio 2001), under 16 years (Phillips 2021), and three years and younger (Pieretti-Vanmarcke 2009). The total number of enrolled participants in the included studies was 21,379 and ranged from 278 (Davies 2016) to 12,882 (Pieretti-Vanmarcke 2009). The incidence of CSI ranged from 0.5% (Phillips 2021) to 1.85% (Davies 2016). Studies were conducted in the USA (Leonard 2019; Viccellio 2001); the UK (Davies 2016); Australia (Phillips 2021); and across the USA, Canada and Brazil (Pieretti-Vanmarcke 2009). The studies were published between 2001 and 2021.

We assessed the five studies using the four QUADAS-2 risk of bias domains, and assessed the certainty of evidence using the GRADE approach.

For those studies that assessed direct comparisons of CDRs, the evidence for the estimates of sensitivity and specificity for Phillips 2021 (NEXUS, Canadian C-Spine Rule and PECARN retrospective criteria) and Leonard 2019 (PECARN retrospective) were considered moderate certainty, as both studies were downgraded for risk of

bias (unclear risk of bias for the index test and reference standard). The evidence was of low certainty for the new CDR (Leonard de novo) due to risk of bias (unclear risk of bias for the index test and reference standard) and indirectness (no existing validation data). Davies 2016 (NICE guidelines CG56 and CG176) was assessed as very low certainty of evidence, downgraded due to high risk of bias (retrospective study design) and indirectness (only included those children who had imaging of the cervical spine and excluded eight children due to incomplete data).

The additional two indirect comparison studies assessed NEXUS (Viccellio 2001) and PEDSPINE (Pieretti-Vanmarcke 2009). The evidence for the estimates of sensitivity and specificity of NEXUS were low certainty due to risk of bias and inconsistency. Pieretti-Vanmarcke 2009 (PEDSPINE) was assessed as very low-certainty evidence, downgraded due to high risk of bias (retrospective study design and no follow-up) and indirectness (absence of existing validation data).

Since the number of eligible studies for each CDR was fewer than four, and the inclusion criteria and outcomes of those studies were too diverse, we did not conduct a meta-analysis and, therefore, presented no summary estimates in this review. Instead, we interpreted sensitivity and specificity from each primary study separately.

All studies demonstrated high CDR sensitivity in identifying children at risk of CSI (greater than 90%), albeit with relatively wide and varied CIs. However, there is debate about what is considered an acceptable sensitivity, given the potential consequences of missing CSI such as death and lifetime disability. Any CDR considered for clinical use should have a very high sensitivity in detecting people at risk, and ideally narrow CIs. Wider CIs suggest that studies may be underpowered, and in fact two studies are in progress with much larger sample sizes to address this question more accurately (ACTRN12621001050842; NCT05049330). Furthermore, the question remains of what lower sensitivity limit is acceptable for such a potentially devastating condition. The original NEXUS cohort study demonstrated a sensitivity of 1.00, with narrower CIs (95% CI 0.88 to 1.00) (Viccellio 2001); however, other concerns such as the median age of the paediatric population, the small number of injuries under the age of nine years and the potential for missed injuries at younger ages described in some retrospective studies caution interpretation of these findings (Ehrlich 2009; Garton 2008).

Sensitivity and specificity are generally paired outcomes and often inversely associated (i.e. choosing a threshold with higher sensitivity will result in lower specificity). Most included studies described low specificity of the cervical spine CDRs. CDRs for use in the assessment of possible CSI aim to either identify children at higher risk of injury and thus in need of imaging, or children at very low risk for whom imaging can be safely avoided. Imaging itself is not without risks and costs, including exposure to ionising radiation. If CDRs are applied to guide the use of imaging, the lower the specificity, the higher the imaging rate may be, and thus CDRs could actually increase baseline imaging rates without necessarily improving injury detection. This unintended consequence of CDRs has been previously described (Weber 2019). The impact of CDR/tool use (and CDR specificity) may differ depending on baseline population imaging rates; one Australian study suggested that strict tool use could increase imaging rates from a baseline imaging rate of 41% to between 44% and 68% (Phillips 2021), whereas US data suggest the reverse may apply with Leonard 2019 describing a baseline imaging rate of 78%, and Leonard 2011 calculating that the PECARN retrospective criteria could potentially decrease imaging rates by up to 25%.

Several CDRs have been proposed for use in children to aid in the assessment of possible CSI. While high sensitivity has been reported, findings should be interpreted with caution given the wide CIs. The potential impacts on baseline imaging rates also warrants consideration.

Strengths and weaknesses of the review

This is an update of a systematic review on the diagnostic accuracy of CDRs or sets of clinical criteria used to evaluate for CSI following blunt trauma in children. One strength of this review update was the expanded inclusion criterion to include all CDRs compared to the previous review that assessed only NEXUS and the Canadian C-Spine Rule. We performed an extensive search in numerous databases and selected articles using clear inclusion and exclusion criteria. Another strength of this review was that we evaluated the evidence using the QUADAS-2 tool (Whiting 2011). This tool provides important information about potential sources of bias and enables a simple and clear presentation of the assessment.

One of the limitations of our review was that only a few studies were eligible for inclusion. Therefore, we could not conduct sensitivity analyses or formally investigate potential sources of heterogeneity. Only one study tested the accuracy of the NEXUS rule, Canadian C-Spine Rule and PECARN retrospective criteria by direct comparison (Phillips 2021), and the authors identified that low numbers of CSI in a single-centre precluded formal validation of any rule. Therefore, there is limited evidence for which CDR was superior to determine if imaging is indicated in detecting CSI in children following blunt trauma.

Another weakness of this review was that the results were based on a relatively low number of children diagnosed with CSI. A larger sample size would be desirable to better evaluate the accuracy of the CDRs, which should indirectly lead to a higher number of events (children with CSI).

Applicability of findings to the review question

The aim of this review was to evaluate if any CDRs are accurate decision tools for detecting CSI in children following blunt trauma.

All the included studies involved a paediatric cohort of participants, with all having a median age under 11 years except the earliest published (Viccellio 2001), which had a median age of 15 years. Two studies focused on the younger ages; Pieretti-Vanmarcke 2009 only included children aged under three years and Davies 2016 included children under 10 years. The inclusion of younger children is important because adolescent injuries are generally considered to follow a more adult pattern, and the greatest clinical concern of the applicability and accuracy of adult-derived CDRs such as Canadian C-Spine Rule and NEXUS, and thus the potential for missed injuries, exists at younger ages (Ehrlich 2009;Garton 2008).

All studies were conducted in largely well-resourced trauma or tertiary EDs across several countries. Resource access constraints may influence the threshold for imaging and CDR application.

Inclusion criteria also varied between studies; two included only those already considered at higher risk by ED clinicians (receiving imaging) (Davies 2016; Viccellio 2001); others included a broader population of ED participants. This is an important consideration when applying study results outside their original populations, as imaging rates vary across both time and healthcare system, depending on perceived risks of the prevalence of the condition, radiation exposure and medicolegal concerns (Babl 2017; Leonard 2019; Phillips 2021).

On the strength of currently available evidence, caution is advised with strictly applying the considered CDRs in practice to children. Future studies may offer better clarity. There are two ongoing studies; NCT05049330, which will validate a Pediatric CSI Risk Assessment Tool in more than 20,000 children younger than 18 years of age and ACTRN12621001050842 will validate three CDRs (NEXUS, Canadian C-Spine Rule and latest published PECARN criteria) in children aged less than 16 years with possible CSI after known or suspected blunt trauma in a large multicentre population.

AUTHORS' CONCLUSIONS

Implications for practice

Currently, there is insufficient evidence to determine which clinical decision rule (CDR) is the most accurate in detecting cervical spine injuries (CSIs) in children following blunt trauma and those available are at best a guide to clinical assessment. Current evidence does not support strict or protocolised adoption of any of the CDRs in paediatric trauma care. Although most studies had a high sensitivity, this was often achieved at the expense of specificity (and resulting high imaging rates). The specificities of the CDRs were generally low, ranging from 0.07 to 0.70. The main goal of CDRs is to identify all CSIs whilst minimising unnecessary imaging tests. Therefore, sensitivity needs to be high; the challenge is in improving specificity and maintaining high sensitivity. Data on children under the age of eight years of age are particularly sparse; therefore, there is currently no strong evidence to support the use of these CDRs in this age group. Although Pieretti-Vanmarcke 2009 assessed the accuracy of PEDSPINE for children aged three years and younger who sustained blunt trauma, as a retrospective study it was at high risk of bias in the patient selection domain as the index test was applied retrospectively, after the reference standard was interpreted and it was at high risk of bias in the index test domain.

Implications for research

Since the incidence of CSIs in children is low, a large cohort is needed to test the accuracy of CDRs. Hence, future research should focus on large adequately powered multicentre prospective trials to assess the accuracy of CDRs in children. Only then can we determine whether they are sufficiently sensitive and specific to be applied as a decision tool following blunt trauma. It would be important to include enough children younger than eight years of age to ensure the decision tools could be used in children of all ages. Also, there should be an adequate number of CSI events. Although PEDSPINE focuses on children aged three years and younger, this will need to be assessed prospectively. A study should optimally evaluate CDRs in direct comparison to others in all paediatric trauma populations. It is important that children are clinically followed up if radiographic imaging was not conducted to reduce the likelihood of missing CSIs. In planning the study, trialists should conduct a power analysis to determine how many children younger and older than eight years of age should be included, and how many events (children with CSI) would be required. There are currently two large ongoing multicentre prospective studies that should contribute to the evidence base of the accuracy of CDRs in children. NCT05049330 will validate a Pediatric CSI Risk Assessment Tool (derived in Leonard 2019) in children younger than 18 years of age and ACTRN12621001050842 will validate three CDRs (National Emergency X-Radiography Utilization Study (NEXUS), Canadian C-Spine Rule and the latest published Pediatric Emergency Care Applied Research Network (PECARN) criteria) in children aged less than 16 years.

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REFERENCES

References to studies included in this review

Davies 2016 *{published data only}*

Davies J, Cross S, Evanson J. Radiological assessment of paediatric cervical spine injury in blunt trauma: the potential impact of new NICE guidelines on the use of CT. *Clinical Radiology* 2016;**71**(9):844-53. [DOI: 10.1016/j.crad.2016.04.024]

Leonard 2019 *{published data only}*

Leonard JC, Browne LR, Ahmad FA, Schwartz H, Wallendorf M, Leonard JR, et al. Cervical spine injury risk factors in children with blunt trauma. *Pediatrics* 2019;**144**(1):e20183221. [DOI: 10.1542/peds.2018-3221]

Phillips 2021 *{published data only}*

Phillips N, Rasmussen K, McGuire S, Abel KA, Acworth J, Askin G, et al. Projected paediatric cervical spine imaging rates with application of NEXUS, Canadian C-Spine and PECARN clinical decision rules in a prospective Australian cohort. *Emergency Medicine Journal* 2021;**38**:330-7.

Pieretti-Vanmarcke 2009 *{published and unpublished data}*

Pieretti-Vanmarcke R, Velmahos GC, Nance ML, Islam S, Falcone RA Jr, Wales PW, et al. Clinical clearance of the cervical spine in blunt trauma patients younger than 3 years: a multi-center study of the American Association for the Surgery of Trauma. *Journal of Trauma and Acute Care Surgery* 2009;**67**(3):543-50. [DOI: 10.1097/TA.0b013e3181b57aa1]

Viccellio 2001 *{published data only}*

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. *New England Journal of Medicine* 2000;**343**(2):94-9.

Simon H, Viccellio P, Pressman B, Shah M, Hoffman J, Mower W, et al. A prospective evaluation of cervical spine injuries in children and a decision model for radiography. *Pediatric Research* 2000;**47**(4):119A.

* Viccellio P, Simon H, Pressman BD, Shah MN, Mower WR, Hoffman JR. A prospective multicenter study of cervical spine injury in children. *Pediatrics* 2001;**108**(2):e20.

References to studies excluded from this review

Adelgais 2014 *{published data only}*

Adelgais KM, Browne L, Holsti M, Metzger RR, Murphy SC, Dudley N. Cervical spine computed tomography utilization in pediatric trauma patients. *Journal of Pediatric Surgery* 2014;**49**(2):333-7.

Ahmad 2017 *{published data only}***10.1111/acem.13144**

Ahmad FA, Schwartz H, Browne LR, Lassa-Claxton S, Wallendorf M, Brooke Lerner E, et al. Methods for collecting paired observations from emergency medical services and emergency department providers for pediatric cervical spine injury risk factors. *Academic Emergency Medicine* 2017;**24**(4):432-41.

Alas 2021 *{published data only}*

Alas H, Pierce KE, Brown A, Bortz C, Naessig S, Ahmad W, et al. Sports-related cervical spine fracture and spinal cord injury: a review of nationwide pediatric trends. *Spine (Phila Pa 1976)* 2021;**46**(1):22-8.

Al-Sarheed 2020 *{published data only}***10.1007/s00381-019-04440-5**

Al-Sarheed S, Alwatban J, Alkhaibary A, Babgi Y, Al-Mohamadi W, Masuadi EM, et al. Cervical spine clearance in unconscious pediatric trauma patients: a level l trauma center experience. *Childs Nervous System* 2020;**36**(4):811-7.

Anderson 2006 *{published data only}*

Anderson RC, Kan P, Hansen KW, Brockmeyer DL. Cervical spine clearance after trauma in children. *Neurosurgical Focus* 2006;**20**(2):E3.

Anderson 2010 *{published data only}*

Anderson RC, Kan P, Vanaman M, Rubsam J, Hansen KW, Scaife ER, et al. Utility of a cervical spine clearance protocol after trauma in children between 0 and 3 years of age. *Journal of Neurosurgery* 2010;**Pediatrics**(3):292-6.

Atesok 2018 *{published data only}***10.1155/2018/7060654**

Atesok K, Tanaka N, O'Brien A, Robinson Y, Pang D, Deinlein D, et al. Posttraumatic spinal cord injury without radiographic abnormality. *Advances in Orthopaedics* 2018;**Jan 4**:7060654.

Babcock 2018 *{published data only}***10.1097/PEC.0000000000000819**

Babcock L, Olsen CS, Jaffe DM, Leonard JC. Cervical spine study group for the Pediatric Emergency Care Applied Research Network (PECARN). Cervical spine injuries in children associated with sports and recreational activities. *Pediatric Emergency Care* 2018;**34**(10):677-86.

Babu 2016 *{published data only}***10.1159/000439540**

Babu RA, Arivazhagan A, Devi BI, Bhat DI, Sampath S, Chandramouli BA. Peculiarities and patterns of cervical spine injuries in children and adolescents: a retrospective series of 84 patients from a single institute. *Pediatric Neurosurgery* 2016;**51**(1):1-8.

Bailey 2022 *{published data only}*

Bailey RS, Klein R, de Los Cobos D, Geraud S, Puryear A. A retrospective look at a cervical spine clearance protocol in pediatric trauma patients at a level-1 trauma center. *Journal of Pediatric Orthopedics* 2022;**42**(6):e607-11.

Baker 1999 *{published data only}*

Baker C, Kadish H, Schunk JE. Evaluation of pediatric cervical spine injuries. *American Journal of Emergency Medicine* 1999;**17**(3):230-4.

Bandiera 2003 *{published data only}*

Bandiera G, Stiell IG, Wells GA, Clement C, De V Maio, Vandemheen KL, et al. The Canadian C-Spine Rule performs better than unstructured physician judgment. *Annals of Emergency Medicine* 2003;**42**(3):395-402.

Banit 2000 *{published data only}*

Banit DM, Grau G, Fisher JR. Evaluation of the acute cervical spine: a management algorithm. *Journal of Trauma-Injury Infection & Critical Care* 2000;**49**(3):450-6.

Bayless 1989 *{published data only}*

Bayless P, Ray VG. Incidence of cervical spine injuries in association with blunt head trauma. *American Journal of Emergency Medicine* 1989;**7**(2):139-42.

Benayoun 2016 *{published data only}***10.1097/TA.0000000000001073**

Benayoun MD, Allen JW, Lovasik BP, Uriell ML, Spandorfer RM, Holder CA. Utility of computed tomographic imaging of the cervical spine in trauma evaluation of ground-level fall. *Journal of Trauma & Acute Care Surgery* 2016;**81**(2):339-44.

Bennett 2015 *{published data only}***10.1097/PEC.0000000000000395**

Bennett TD, Bratton SL, Riva-Cambrin J, Scaife ER, Nance ML, Prince JS, et al. Cervical spine imaging in hospitalized children with traumatic brain injury. *Pediatric Emergency Care* 2015;**31**(4):243-9.

Blacksin 1995 *{published data only}*

Blacksin MF, Lee HJ. Frequency and significance of fractures of the upper cervical spine detected by CT in patients with severe neck trauma. *AJR. American Journal of Roentgenology* 1995;**165**(5):1201-4.

Boese 2015 *{published data only}***10.1097/TA.0000000000000579**

Boese CK, Oppermann J, Siewe J, Eysel P, Scheyerer MJ, Lechler P. Spinal cord injury without radiologic abnormality in children: a systematic review and meta-analysis. *Journal of Trauma & Acute Care Surgery* 2015;**78**(4):874-82.

Borock 1991 *{published data only}*

Borock EC, Gabram SG, Jacobs LM, Murphy MA. A prospective analysis of a two-year experience using computed tomography as an adjunct for cervical spine clearance. *Journal of Trauma* 1991;**31**(7):1001-6.

Boustani 2015 *{published data only}***https://doi.org/10.1016/j.annemergmed.2015.07.294**

Boustani AJ, Tubbs IR. Sensitivity of NEXUS criteria in the setting of facial fractures. *Annals of Emergency Medicine* 2015;**66**(4):S94.

Brockmeyer 2012 *{published data only}*

Brockmeyer DL, Ragel BT, Kestle JR. The pediatric cervical spine instability study. A pilot study assessing the prognostic value of four imaging modalities in clearing the cervical spine for children with severe traumatic injuries. *Child's Nervous System: ChNS* 2012;**28**(5):699-705.

Brooks 2001 *{published data only}*

Brooks RA, Willett KM. Evaluation of the Oxford protocol for total spinal clearance in the unconscious trauma patient. *Journal of Trauma – Injury Infection & Critical Care* 2001;**50**(5):862-7.

Brown 2001 *{published data only}*

Brown RL, Brunn MA, Garcia VF. Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center. *Journal of Pediatric Surgery* 2001;**36**(8):1107-14.

Browne 2003 *{published data only}*

Browne GJ, Lam LT, Barker RA. The usefulness of a modified adult protocol for the clearance of paediatric cervical spine injury in the emergency department. *Emergency Medicine (Fremantle, W.A.)* 2003;**15**(2):133-42.

Browne 2017 *{published data only}***10.1111/acem.13312**

Browne LR, Schwartz H, Ahmad FA, Wallendorf M, Kuppermann N, Lerner EB, et al. Interobserver agreement in pediatric cervical spine injury assessment between prehospital and emergency department providers. *Academic Emergency Medicine* 2017;**24**(12):1501-10.

Browne 2021 *{published data only}***10.1111/acem.14176**

Browne LR, Ahmad FA, Schwartz H, Wallendorf M, Kuppermann N, Lerner EB, et al. Prehospital factors associated with cervical spine injury in pediatric blunt trauma patients. *Academic Emergency Medicine* 2021;**28**(5):553-61.

Burns 2011 *{published data only}*

Burns EC, Yanchar NL. Using cervical spine clearance guidelines in a pediatric population: a survey of physician practices and opinions. *CJEM: Canadian Journal of Emergency Medical Care* 2011;**13**(1):1-6.

Caltili 2017 *{published data only}*

Caltili C, Ozturk D, Altinbilek E, Yapar N, Serin M, Gunduz H, et al. Canadian C-Spine criteria and nexus in the spinal trauma: comparison at a tertiary referral hospital in Turkey. *Biomedical Research* 2017;**28**(8):3598-602.

Carter 2017 *{published data only}***10.5339/jemtac.2017.5**

Carter AW, Jacups SP, Ackland HM, Wright A, Lawson A, Armit D, et al. Spinal clearance practices at a regional Australian hospital: a window to major trauma management performance outside metropolitan trauma centres. *Journal of Emergency Medicine, Trauma and Acute Care* 2017;**5**:1-9.

Chaudhry 2016 *{published data only}***10.1159/000444192**

Chaudhry AS, Prince J, Sorrentino C, Fasanya C, McGinn J, Atanassov KD, et al. Identification of risk factors for cervical spine injury from pediatric trauma registry. *Pediatric Neurosurgery* 2016;**51**(4):167-74.

Clayton 2012 *{published data only}*

Clayton JL, Harris MB, Weintraub SL, Marr AB, Timmer J, Stuke LE, et al. Risk factors for cervical spine injury. *Injury* 2012;**43**(4):431-5.

Coffey 2011 *{published data only}*

Coffey F, Hewitt S, Stiell I, Howarth N, Miller P, Clement C, et al. Validation of the Canadian C-Spine rule in the UK emergency department setting. *Emergency Medicine Journal* 2011;**28**(10):873-6.

Como 2011 *{published data only}*

Como JJ, Leukhardt WH, Anderson JS, Wilczewski PA, Samia H, Claridge JA. Computed tomography alone may clear the cervical spine in obtunded blunt trauma patients: a prospective evaluation of a revised protocol. *Journal of Trauma-Injury Infection & Critical Care* 2011;**70**(2):345-9.

Cui 2016 *{published data only}*10.1007/s10140-016-1417-y

Cui LW, Probst MA, Hoffman JR, Mower WR. Sensitivity of plain radiography for pediatric cervical spine injury. *Emergency Radiology* 2016;**23**(5):443-8.

Dahlquist 2013 *{published data only}*

Dahlquist RT, Fischer PE, Desai H, Rogers A, Christmas AB, Gibbs MA, et al. Is cervical spine imaging required in patients with femur fractures? *Academic Emergency Medicine* 2013;**20**(5 Suppl 1):S58.

Dalle 2022 *{published data only}*

Dalle DU, Sriram S, Bandyopadhyay S, Egiz A, Kotecha J, Kanmounye US, et al. Management and outcomes of traumatic pediatric spinal cord injuries in low- and middle-income countries: a scoping review. *World Neurosurgery* 2022;**165**:180-7.

Dickinson 2004 *{published data only}*

Dickinson G, Stiell IG, Schull M, Brison R, Clement CM, Vandemheen KL, et al. Retrospective application of the NEXUS low-risk criteria for cervical spine radiography in Canadian emergency departments. *Annals of Emergency Medicine* 2004;**43**(4):507-14.

DiGiacomo 2002 *{published data only}*

DiGiacomo JC, Frankel HL, Rotondo MF. Clearing the cervical spine in victims of blunt trauma. *Military Medicine* 2002;**167**(5):398-401.

Douglas 2022 *{published data only}*

Douglas GP, McNickle AG, Jones SA, Dugan MC, Kuhls DA, Fraser DR, et al. A pediatric cervical spine clearance guideline leads to fewer unnecessary computed tomography scans and decreased radiation exposure. *Pediatric Emergency Care* 2022;**39**(5):318-23.

Dranoff 2019 *{published data only}*

Dranoff EJ, Smith S, Gyftopoulos S, Wu T. 362 head computed tomography utilization for mild trauma in an academic medical center emergency department. *Annals of Emergency Medicine* 2019;**74**(4):S142-S3.

Dwyer 2019 *{published data only}*10.3233/PRM-180545

Dwyer R, Ward R, Richardson E, Davidson SA, Thetford A, Valentine J. Traumatic spinal cord injuries: a retrospective cohort study of children seen in Western Australia between 1996 and 2016. *Journal of Pediatric Rehabilitation Medicine* 2019;**12**(3):235-43.

Edwards 2001 *{published data only}*

Edwards MJ, Frankema SP, Kruit MC, Bode PJ, Breslau PJ, van Vugt AB. Routine cervical spine radiography for trauma victims: does everybody need it? *Journal of Trauma – Injury Infection & Critical Care* 2001;**50**(3):529-34.

Ehrlich 2009 *{published data only}*

Ehrlich PF, Wee C, Drongowski R, Rana AR. Canadian C-Spine Rule and the national emergency x-radiography utilization low-risk criteria for C-Spine radiography in young trauma patients. *Journal of Pediatric Surgery* 2009;**44**(5):987-91.

Ekhator 2022 *{published data only}*

Ekhator C, Nwankwo I, Nicol A. Implementation of National Emergency X-Radiography Utilization Study (NEXUS) criteria in pediatrics: a systematic review. *Cureus* 2022;**14**(10):e30065.

Eren 2020 *{published data only}*10.1111/ped.14064

Eren B, Karagoz Guzey F. Is spinal computed tomography necessary in pediatric trauma patients? *Pediatrics International* 2020;**65**(3):239-47.

Ersoy 1995 *{published data only}*

Ersoy G, Karcioglu O, Enginbas Y, Eray O, Ayrik C. Are cervical spine X-rays mandatory in all blunt trauma patients? *European Journal of Emergency Medicine* 1995;**2**(4):191-5.

Fischer 1984 *{published data only}*

Fischer RP. Cervical radiographic evaluation of alert patients following blunt trauma. *Annals of Emergency Medicine* 1984;**13**(10):905-7.

Flynn-O'Brien 2016 *{published data only}*10.1016/j.jpedsurg.2015.09.006

Flynn-O'Brien KT, Thompson LL, Gall CM, Fallat ME, Rice TB, Rivara FP. Variability in the structure and care processes for critically injured children: a multicenter survey of trauma bay and intensive care units. *Journal of Pediatric Surgery* 2016;**51**(3):490-8.

Gajera 2017 *{published data only}*10.1111/1754-9485.12658

Gajera J, Singh A. Protect your neck: what every radiologist should know about the clearance of cervical spinal column injury. *Journal of Medical Imaging and Radiation Oncology* 2017;**61**(S1):19-22.

Garton 2008 *{published data only}*

Garton HJ, Hammer MR. Detection of pediatric cervical spine injury. *Neurosurgery* 2008;**62**(3):700-8.

Gbaanador 1986 *{published data only}*

Gbaanador GB, Fruin AH, Taylon C. Role of routine emergency cervical radiography in head trauma. *American Journal of Surgery* 1986;**152**(6):643-8.

Ghelichkhani 2021 *{published data only}*10.1007/s11547-020-01288-7

Ghelichkhani P, Shahsavarinia K, Gharekhani A, Taghizadieh A, Baratloo A, Fattah FH, et al. Value of Canadian C-Spine Rule versus the NEXUS criteria in ruling out clinically important cervical spine injuries: derivation of modified Canadian C-Spine Rule. *La Radiologia Medica* 2021;**126**(3):414-20.

Gonzalez 1999 *{published data only}*

Gonzalez RP, Fried PO, Bukhalo M, Holevar MR, Falimirski ME. Role of clinical examination in screening for blunt cervical spine injury. *Journal of the American College of Surgeons* 1999;**189**(2):152-7.

Gonzalez 2009 *{published data only}*

Gonzalez RP, Cummings GR, Phelan HA, Bosarge PL, Rodning CB. Clinical examination in complement with computed tomography scan: an effective method for identification of cervical spine injury. *Journal of Trauma-Injury Infection & Critical Care* 2009;**67**(6):1297-304.

Gonzalez 2013 *{published data only}*

Gonzalez RP, Cummings GR, Baker JA, Frotan AM, Simmons JD, Brevard SB, et al. Prehospital clinical clearance of the cervical spine: a prospective study. *American Surgeon* 2013;**79**(11):1213-7.

Griffen 2003 *{published data only}*

Griffen MM, Frykberg ER, Kerwin AJ, Schinco MA, Tepas JJ, Rowe K, et al. Radiographic clearance of blunt cervical spine injury: plain radiograph or computed tomography scan? *Journal of Trauma – Injury Infection & Critical Care* 2003;**55**(2):222-6.

Griffith 2011 *{published data only}*

Griffith B, Bolton C, Goyal N, Brown ML, Jain R. Screening cervical spine CT in a level I trauma center: overutilization? *AJR: American Journal of Roentgenology* 2011;**197**(2):463-7.

Griffith 2013 *{published data only}*

Griffith B, Kelly M, Vallee P, Slezak M, Nagarwala J, Krupp S, et al. Screening cervical spine CT in the emergency department, Phase 2: a prospective assessment of use. *AJNR: American Journal of Neuroradiology* 2013;**34**(4):899-903.

Griffith 2014 *{published data only}*

Griffith B, Vallee P, Krupp S, Jung M, Slezak M, Nagarwala J, et al. Screening cervical spine CT in the emergency department, phase 3: increasing effectiveness of imaging. *Journal of the American College of Radiology* 2014;**11**(2):139-44.

Hale 2015 *{published data only}*10.1097/TA.0000000000000603

Hale DF, Fitzpatrick CM, Doski JJ, Stewart RM, Mueller DL. Absence of clinical findings reliably excludes unstable cervical spine injuries in children 5 years or younger. *Journal of Trauma & Acute Care Surgery* 2015;**78**(5):943-8.

Handler 2018 *{published data only}*10.1007/s00381-018-3756-3

Handler M, Greenan K, Mirksy D, Sarah G, Hubbell N, Stence N. MRI utility in C-spine clearance following pediatric trauma. *Child's Nervous System* 2018;**34**(5):1027.

Hannon 2015 *{published data only}*10.1016/j.annemergmed.2014.09.002

Hannon M, Mannix R, Dorney K, Mooney D, Hennelly K. Pediatric cervical spine injury evaluation after blunt trauma: a clinical decision analysis. *Annals of Emergency Medicine* 2015;**65**(3):239-47.

Hanson 2000a *{published data only}*

Hanson JA, Blackmore CC, Mann FA, Wilson AJ. Cervical spine injury: accuracy of helical CT used as a screening technique. *Emergency Radiology* 2000;**7**(1):31-5.

Hanson 2000b *{published data only}*

Hanson JA, Blackmore CC, Mann FA, Wilson AJ. Cervical spine injury: a clinical decision rule to identify high-risk patients for helical CT screening. *AJR. American Journal of Roentgenology* 2000;**174**(3):713-7.

Hasan 2022 *{published data only}*

Hasan S, Waheed M, Suhrawardy AK, Braithwaite C, Ahmed L, Zakko P, et al. Pediatric upper cervical spine trauma: a 10-year retrospective review at a pediatric trauma center. *Cureus* 2022;**14**(1):e20995.

Hasler 2011 *{published data only}*

Hasler RM, Exadaktylos AK, Bouamra O, Benneker LM, Clancy M, Sieber R, et al. Epidemiology and predictors of spinal injury in adult major trauma patients: European cohort study. *European Spine Journal* 2011;**20**(12):2174-80.

Hazboun 2021 *{published data only}*

Hazboun R, Muñoz A, Krafft PR, Harder S, Vannix R, Zouros A. Craniocervical dissociation in pediatric patients: pearls and pitfalls of diagnosis and management. *Pediatric Emergency Care* 2021;**37**:602-8. [DOI: 10.1097/PEC.0000000000001721]

Heffernan 2005 *{published data only}*

Heffernan DS, Schermer CR, Lu SW. What defines a distracting injury in cervical spine assessment? *Journal of Trauma – Injury Infection & Critical Care* 2005;**59**(6):1396-9.

Henry 2016 *{published data only}*10.1016/j.acap.2016.01.017

Henry MK, Zonfrillo MR, French B, Song L, Feudtner C, Wood JN. Hospital variation in cervical spine imaging of young children with traumatic brain injury. *Academic Pediatrics* 2016;**16**(7):684-91.

Henry 2021 *{published data only}*10.1097/PEC.0000000000001455

Henry MK, French B, Feudtner C, Zonfrillo MR, Lindberg DM, Anderst JD. Cervical spine imaging and injuries in young children with non-motor vehicle crash-associated traumatic brain injury. *Pediatric Emergency Care* 2021;**37**(1):e1-e6.

Herman 2019 *{published data only}*10.2106/JBJS.18.00217

Herman MJ, Brown KO, Sponseller PD, Phillips JH, Petrucelli PM, Parikh DJ, et al. Pediatric cervical spine clearance: a consensus statement and algorithm from the pediatric cervical spine clearance working group. *Journal of Bone and Joint Surgery* 2019;**101**(1):e1.

Hoffman 1992 *{published data only}*

Hoffman JR, Schriger DL, Mower W, Luo JS, Zucker M. Low-risk criteria for cervical-spine radiography in blunt trauma: a prospective study. *Annals of Emergency Medicine* 1992;**21**(12):1454-60.

Hollingshead 2000 *{published data only}*

Hollingshead MC, Keenan HT, Chung CJ, Ziglar MK. Use of screening neck/cervical spine CT in pediatric head trauma victims. *Radiology* 2000;**217**:340.

Hood 2015 *{published data only}*10.1016/j.aenj.2015.03.003

Hood N, Considine J. Spinal immobilisation in pre-hospital and emergency care: a systematic review of the literature. *Australasian Emergency Nursing Journal* 2015;**18**(3):118-37.

Hopper 2020 *{published data only}*10.1111/1742-6723.13351

Hopper SM, McKenna S, Williams A, Phillips N, Babl FE, Paediatric Research in Emergency Departments International Collaborative (PREDICT). Clinical clearance and imaging for possible cervical spine injury in children in the emergency department: a retrospective cohort study. *Emergency Medicine Australasia* 2020;**32**(1):93-9.

Hutchings 2009 *{published data only}*

Hutchings L, Atijosan O, Burgess C, Willett K. Developing a spinal clearance protocol for unconscious pediatric trauma patients. *Journal of Trauma – Injury Infection & Critical Care* 2009;**67**(4):681-6.

Ihalainen 2017 *{published data only}*10.1038/sc.2017.71

Ihalainen T, Rinta-Kiikka I, Luoto TM, Koskinen EA, Korpijaakko-Huuhka AM, Ronkainen A. Traumatic cervical spinal cord injury: a prospective clinical study of laryngeal penetration and aspiration. *Spinal Cord* 2017;**55**(11):979-84.

Inaba 2015 *{published data only}*10.1097/TA.0000000000000560

Inaba K, Nosanov L, Menaker J, Bosarge P, Williams L, Turay D, 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. *Journal of Trauma and Acute Care Surgery* 2015;**78**(3):465-7.

Inaba 2016 *{published data only}*10.1097/TA.0000000000001194

Inaba K, Byerly S, Bush LD, Martin MJ, Martin DT, Peck KA, et al. Cervical spine clearance: a prospective western trauma association multi-institutional trial. *Journal of Trauma and Acute Care Surgery* 2016;**81**(6):1122-30.

Jacob 2016 *{published data only}*10.3174/ajnr.A4817

Jacob R, Cox M, Koral K, Greenwell C, Xi Y, Vinson L, et al. MR imaging of the cervical spine in nonaccidental trauma: a tertiary institution experience. *American Journal of Neuroradiology* 2016;**37**(10):1944-50.

Jaffe 1987 *{published data only}*

Jaffe DM, Binns H, Radkowski MA, Barthel MJ, Engelhard HH 3rd. Developing a clinical algorithm for early management of cervical spine injury in child trauma victims. *Annals of Emergency Medicine* 1987;**16**(3):270-6.

Jakes 2015 *{published data only}*10.1136/bmj.h1275

Jakes AD, Phillips R, Scales M. Teenagers with back pain. *BMJ* 2015;**350**:h1275.

Jarvers 2020 *{published data only}*

Jarvers JS, Herren C, Jung MK, Blume C, Meinig H, Ruf M, et al. Pediatric spine trauma – results of a German national multicenter study including 367 patients. *Unfallchirurg* 2020;**4**:280-8.

Kadom 2019 *{published data only}*10.1016/j.jacr.2019.02.003

Kadom N, Palasis S, Pruthi S, Biffl WL, Booth TN, Desai NK, et al. ACR Appropriateness criteria suspected spine trauma – child. *Journal of the American College of Radiology* 2019;**16**(5S):S286-99.

Kaminski 2017 *{published data only}*10.1089/neu.2016.4955

Kaminski L, Cordemans V, Cernat E, M'Bra KI, Mac-Thiong JM. Functional outcome prediction after traumatic spinal cord injury based on acute clinical factors. *Journal of Neurotrauma* 2017;**34**(12):2027-33.

Kavuri 2019 *{published data only}*10.1097/BPO.0000000000001309

Kavuri V, Pannu G, Moront M, Pizzutillo P, Herman M. "Next day" examination reduces radiation exposure in cervical spine clearance at a level 1 pediatric trauma center: preliminary findings. *Journal of Pediatric Orthopaedics* 2019;**39**(5):e339-42.

Keenan 2001 *{published data only}*

Keenan HT, Hollingshead MC, Chung CJ, Ziglar MK. Using CT of the cervical spine for early evaluation of pediatric patients with head trauma. *AJR: American Journal of Roentgenology* 2001;**177**(6):1405-9.

Kerr 2005 *{published data only}*

Kerr D, Bradshaw L, Kelly AM. Implementation of the Canadian C-Spine Rule reduces cervical spine x-ray rate for alert patients with potential neck injury. *Journal of Emergency Medicine* 2005;**28**(2):127-31.

Khetarpal 2021 *{published data only}*

Khetarpal S, Smith J, Weiss B, Bhattarai B, Sinha M. Pediatric cervical spine clearance and immobilization practice among prehospital emergency medical providers: a statewide survey. *Pediatric Emergency Care* 2021;**37**(8):e474-8.

Kokabi 2011 *{published data only}*

Kokabi N, Raper DM, Xing M, Giuffre BM. Application of imaging guidelines in patients with suspected cervical spine trauma: retrospective analysis and literature review. *Emergency Radiology* 2011;**18**(1):31-8.

Lee 2003 *{published data only}*

Lee SL, Sena M, Greenholz SK, Fledderman M. A multidisciplinary approach to the development of a cervical spine clearance protocol: process, rationale, and initial results. *Journal of Pediatric Surgery* 2003;**38**(3):358-62.

Lee 2022 *{published data only}*

Lee LK, Porter JJ, Mannix R, Rees CA, Schutzman SA, Fleegler EW, et al. Pediatric traumatic injury emergency department visits and management in US children's hospitals from 2010 to 2019. *Annals of Emergency Medicine* 2022;**79**(3):279-87.

Lemley 2015 *{published data only}*10.1055/s-0035-1554986

Lemley K, Bauer P. Pediatric spinal cord injury: recognition of injury and initial resuscitation, in hospital management, and coordination of care. *Journal of Pediatric Intensive Care* 2015;**4**(1):27-34.

Leonard 2011 *{published data only}*

Leonard JC, Kuppermann N, Olsen C, Babcock-Cimpello L, Brown K, Mahajan P, et al. Factors associated with cervical spine injury in children after blunt trauma. *Annals of Emergency Medicine* 2011;**58**(2):145-55.

Letica-Kriegel 2022 *{published data only}*

Letica-Kriegel AS, Kaplan A, Orlas C, Masiakos PT. Variability of pediatric cervical spine clearance protocols: a systematic review. *Annals of Surgery* 2022;**276**(6):989-94.

Liawrungrueang 2020 *{published data only}*10.1186/s12891-019-3019-9

Liawrungrueang W, Chamnan R, Chaiyamongkol W, Bintachitt P. Acute traumatic unilateral cervical C4–C5 facet dislocation in pediatric toddlers. *BMC Musculoskeletal Disorders* 2020;**21**(1):4.

Luehmann 2020 *{published data only}*10.1007/s00383-019-04544-8

Luehmann NC, Pastewski JM, Cirino JA, Al-Hadidi A, DeMare AM, Riggs TW, et al. Implementation of a pediatric trauma cervical spine clearance pathway. *Pediatric Surgery International* 2020;**36**(1):93-101.

Malomo 1995 *{published data only}*

Malomo AO, Shokunbi MT, Adeloye A. Evaluation of the use of plain cervical spine radiography in patients with head injury. *East African Medical Journal* 1995;**72**(3):186-8.

Mannix 2011 *{published data only}*

Mannix R, Nigrovic LE, Schutzman SA, Hennelly K, Bourgeois FT, Meehan WP, et al. Factors associated with the use of cervical spine computed tomography imaging in pediatric trauma patients. *Academic Emergency Medicine* 2011;**18**(9):905-11.

Markuske 1983 *{published data only}*

Markuske H. Roentgenologic diagnosis of the cervical spine in childhood [German]. *Psychiatrie, Neurologie und Medizinische Psychologie* 1983;**35**(5):257-66.

Markuske 1988 *{published data only}*

Markuske H. The cervical spine of children in the x-ray and clinical picture [German]. *Radiologia Diagnostica* 1988;**29**(1):137-41.

Martin 2004 *{published data only}*

Martin BW, Dykes E, Lecky FE. Patterns and risks in spinal trauma. *Archives of Disease in Childhood* 2004;**89**(9):860-5.

McLaughlin 2019 *{published data only}*

McLaughlin CM, Jensen AR, Upperman JS. Cervical spine clearance in the pediatric trauma patient. *Current Treatment Options in Pediatrics* 2019;**5**:483-93. [DOI: 10.1007/s40746-019-00180-5]

McMahon 2015 *{published data only}*

McMahon PM, Alwood SM, Zeretzke-Bien C, Chalasani S, Herskovitz S, Blanchard MC, et al. Protocol to clear cervical spine injuries in pediatric trauma patients. *Radiology Management* 2015;**37**(5):42-8.

Meek 2007 *{published data only}*

Meek R, McGannon D, Edwards L. The safety of nurse clearance of the cervical spine using the National Emergency X-radiography Utilization Study low-risk criteria. *Emergency Medicine Australasia* 2007;**19**(4):372-6.

Meldon 1998 *{published data only}*

Meldon SW, Brant TA, Cydulka RK, Collins TE, Shade BR. Out-of-hospital cervical spine clearance: agreement between emergency medical technicians and emergency physicians. *Journal of Trauma – Injury Infection & Critical Care* 1998;**45**(6):1058-61.

Mitrofan 2016 *{published data only}*

Mitrofan D. Cervical spine injuries in children – assessment algorithm for emergency services. *Clujul Medical* 2016;**89**(S2):S23.

Morrison 2012 *{published data only}*

Morrison J, Jeanmonod R. Utilization of NEXUS C-spine criteria among clinicians in a community emergency department setting. *Annals of Emergency Medicine* 2012;**Suppl**:S115.

Mower 2001 *{published data only}*

Mower WR, Hoffman JR, Pollack CV Jr, Zucker MI, Browne BJ, Wolfson AB, et al. Use of plain radiography to screen for cervical spine injuries. *Annals of Emergency Medicine* 2001;**38**(1):1-7.

NCT05605847 *{published data only}*

NCT05605847. Adherence of imaging order to the 2020 French guidelines for patients with cervical spine injury in the emergency setting. clinicaltrials.gov/show/NCT05605847 (first received 31 October 2022).

Neifeld 1988 *{published data only}*

Neifeld GL, Keene JG, Hevesy G, Leikin J, Proust A, Thisted RA. Cervical injury in head trauma. *Journal of Emergency Medicine* 1988;**6**(3):203-7.

Nguyen 2005 *{published data only}*

Nguyen GK, Clark R. Adequacy of plain radiography in the diagnosis of cervical spine injuries. *Emergency Radiology* 2005;**11**(3):158-61.

Nolte 2022 *{published data only}*10.1097/PEC.0000000000002151

Nolte PC, Liao S, Kuch M, Grützner PA, Münzberg M, Kreinest M. Development of a new emergency medicine spinal immobilization protocol for pediatric trauma patients and first

applicability test on emergency medicine personnel. *Pediatric Emergency Care* 2022;**38**(1):e75-84.

Novick 2018 *{published data only}*10.1016/j.amjsurg.2018.03.003

Novick D, Wallace R, DiGiacomo JC, Kumar A, Lev S, George Angus LD. The cervical spine can be cleared without MRI after blunt trauma: a retrospective review of a single level 1 trauma center experience over 8 years. *American Journal of Surgery* 2018;**216**(3):427-30.

Nunn 2021 *{published data only}*10.1177/1460408620939381

Nunn C, Negus S, Lawrence T, Lecky F, Roland D. Have changes in computerised tomography guidance positively impacted detection of cervical spine injury in children? A review of the trauma audit and research network data. *Trauma* 2021;**23**(2):139-44.

Omran 2001 *{published data only}*

Omran HA, Dowd MD, Knapp JF. Removing the pediatric cervical collar: current practice patterns. *Archives of Pediatrics & Adolescent Medicine* 2001;**155**(2):162-6.

Overberger 2018 *{published data only}*10.1111/acem.13424

Overberger R, Madrak J, Selman A, Althoff S, Castillo J. Vehicle damage characteristics may adequately exclude serious spinal injury after motor vehicle collision. *Academic Emergency Medicine* 2018;**25**(S1):S197.

Overmann 2020 *{published data only}*10.1016/j.ajem.2019.11.051

Overmann KM, Robinson BR, Eckman MH. Cervical spine evaluation in pediatric trauma: a cost-effectiveness analysis. *American Journal of Emergency Medicine* 2020;**38**(11):2347-55.

Özkan 2015 *{published data only}*10.1007/s00381-015-2698-2

Özkan N, Wrede K, Ardeshiri A, Sariaslan Z, Stein KP, Dammann P, et al. Management of traumatic spinal injuries in children and young adults. *Child's Nervous System* 2015;**31**(7):1139-48.

Pannu 2017 *{published data only}*10.1097/BPO.0000000000000806

Pannu GS, Shah MP, Herman MJ. Cervical spine clearance in pediatric trauma centers: the need for standardization and an evidence-based protocol. *Journal of Pediatric Orthopedics* 2017;**37**(3):e145-9.

Pennell 2020 *{published data only}*10.1097/BPO.0000000000001619

Pennell C, Gupta J, March M, Arthur LG, Lindholm E, Herman M, et al. A standardized protocol for cervical spine evaluation in children reduces imaging utilization: a pilot study of the pediatric cervical spine clearance working group protocol. *Journal of Pediatric Orthopedics* 2020;**40**(8):e780-84.

Pepin 2015 *{published data only}*

Pepin LC, Bressler S, Brenner C, Avarello JT, Johnson AA, Prince JM, et al. 398 Application of the national emergency x-radiography utilization study criteria and the Canadian C-Spine Rule among children aged 8 to 17 years in the emergency department: a retrospective review. *Annals of Emergency Medicine* 2015;**66**(4):S144.

Platzer 2006a *{published data only}*

Platzer P, Jaindl M, Thalhammer G, Dittrich S, Wieland T, Vecsei V, et al. Clearing the cervical spine in critically injured patients: a comprehensive C-spine protocol to avoid unnecessary delays in diagnosis. *European Spine Journal* 2006;**15**(12):1801-10.

Platzer 2006b *{published data only}*

Platzer P, Thalhammer G, Jaindl M, Dittrich S, Vecsei V, Gaebler C. Clearing the cervical spine in polytrauma patients: current standards in diagnostic algorithm. *European Journal of Trauma* 2006;**32**(6):570-5.

Poorman 2019 *{published data only}*10.14444/6009

Poorman GW, Segreto FA, Beaubrun BM, Jalai CM, Horn SR, Bortz CA, et al. Traumatic fracture of the pediatric cervical spine: etiology, epidemiology, concurrent injuries, and an analysis of perioperative outcomes using the kids' inpatient database. *International Journal of Spine Surgery* 2019;**13**(1):68-78.

Pulfrey 2002 *{published data only}*

Pulfrey S, Evans MF. Blunt trauma: which patients require diagnostic imaging of the cervical spine? *Canadian Family Physician* 2002;**48**:1061-2.

Quigley 2014 *{published data only}*

Quigley A, Stafrace S. Paediatric trauma: children are not just small adults-Emergency imaging by the general radiologist. *Pediatric Radiology* 2014;**44**:S326.

Raza 2013 *{published data only}*

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

Robinson 2022 *{published data only}*

Robinson BT, Kink R, Jones T, Williams R. Predicting cervical spine injury in children. *Journal of Investigative Medicine* 2022;**70**(2):537.

Rolfe 2019 *{published data only}*

Rolfe M, Guerin J, Brucker J, Kalina P. Neuroimaging of pediatric abusive head trauma. *Applied Radiology* 2019;**48**(3):22-7.

Ropele 2009 *{published data only}*

Ropele D, Blech K, Vander Laan KJ. Cervical spine clearance in the nonalert, noncommunicative, or unreliable pediatric blunt trauma patient. *Journal of Trauma Nursing* 2009;**16**(3):148-59.

Rosati 2015 *{published data only}*10.1097/TA.0000000000000643

Rosati SF, Maarouf R, Wolfe L, Parrish D, Poppe M, Manners R, et al. Implementation of pediatric cervical spine clearance guidelines at a combined trauma center: twelve-month impact. *Journal of Trauma and Acute Care Surgery* 2015;**78**(6):1117-21.

Rose 2012 *{published data only}*

Rose MK, Rosal LM, Gonzalez RP, Rostas JW, Baker JA, Simmons JD, et al. Clinical clearance of the cervical spine in patients with distracting injuries: it is time to dispel the myth? *Journal of Trauma and Acute Care Surgery* 2012;**73**(2):498-502.

Ross 1987 *{published data only}*

Ross SE, Schwab CW, David ET, DeLong WG, Born CT. Clearing the cervical spine: initial radiologic evaluation. *Journal of Trauma – Injury Infection & Critical Care* 1987;**27**(9):1055-60.

Saddison 1991 *{published data only}*

Saddison D, Vanek VW, Racanelli JL. Clinical indications for cervical spine radiographs in alert trauma patients. *American Surgeon* 1991;**57**(6):366-9.

Sanchez 2005 *{published data only}*

Sanchez B, Waxman K, Jones T, Conner S, Chung R, Becerra S. Cervical spine clearance in blunt trauma: evaluation of a computed tomography-based protocol. *Journal of Trauma – Injury Infection & Critical Care* 2005;**59**(1):179-83.

Scarrow 1999 *{published data only}*

Scarrow AM, Levy EI, Resnick DK, Adelson PD, Sclabassi RJ. Cervical spine evaluation in obtunded or comatose pediatric trauma patients: a pilot study. *Pediatric Neurosurgery* 1999;**30**(4):169-75.

Schleehauf 1989 *{published data only}*

Schleehauf K, Ross SE, Civil ID, Schwab CW. Computed tomography in the initial evaluation of the cervical spine. *Annals of Emergency Medicine* 1989;**18**(8):815-7.

Sharma 2023 *{published data only}*

Sharma B, Kolousek A, Lian B, Koganti D, Smith RN, Sola R Jr. Cervical spine computed tomography in adolescent blunt trauma patients: are they being overutilized? *Journal of Surgical Research* 2023;**282**:155-9.

Sheikh 2012 *{published data only}*

Sheikh K, Belfi LM, Sharma R, Baad M, Sanelli PC. Evaluation of acute cervical spine imaging based on ACR Appropriateness Criteria. *Emergency Radiology* 2012;**19**(1):11-7.

Shin 2016 *{published data only}*10.1097/BRS.0000000000001176

Shin JI, Lee NJ, Cho SK. Pediatric cervical spine and spinal cord injury: a national database study. *Spine* 2016;**41**(4):283-92.

Singh 2018 *{published data only}*

Singh K, Du L. Retrospective audit on the appropriateness of CT cervical spine imaging and the positive diagnostic yield of paediatric cervical spine injury at Gold Coast University Hospital. *Journal of Medical Imaging and Radiation Oncology* 2018;**62**(S2):31-2.

Slaar 2016 *{published data only}*10.1016/j.ejrad.2015.11.005

Slaar A, Fockens MM, van Rijn RR, Maas M, Goslings JC, Bakx R, et al. Adherence to the guidelines of paediatric cervical spine clearance in a level I trauma centre: a single centre experience. *European Journal of Radiology* 2016;**85**(1):55-60.

Smart 2003 *{published data only}*

Smart PJ, Hardy PJ, Buckley DM, Somers JM, Broderick NJ, Halliday KE, et al. Cervical spine injuries to children under 11: should we use radiography more selectively in their initial assessment? *Emergency Medicine Journal* 2003;**20**(3):225-7.

Sokoloff 2022 *{published data only}*

Sokoloff WC, Mirisis V, Rocker J. Utility of emergent magnetic resonance imaging in children with persistent traumatic neck pain without radiographic injury. *Journal of Investigative Medicine* 2022;**70**(4):987-8.

Songür Kodik 2020 *{published data only}*10.14744/tjtes.2019.35813

Songür Kodik M, Eraslan C, Kitiş Ö, Altuncı YA, Biçeroğlu H, Akay A. Computed tomography vs. magnetic resonance imaging in unstable cervical spine injuries. *Ulus Travma Acil Cerrahi Derg* 2020;**26**(3):431-8.

Stanton 2017 *{published data only}*10.1016/j.afjem.2017.01.007

Stanton D, Hardcastle T, Muhlbauer D, van Zyl D. Cervical collars and immobilisation: A South African best practice recommendation. *African Journal of Emergency Medicine* 2017;**7**(1):4-8.

Stiell 2003 *{published data only}*

Stiell IG, Clement CM, McKnight RD, Brison R, Schull MJ, Rowe BH, et al. The Canadian C-Spine Rule versus the NEXUS low-risk criteria in patients with trauma. *New England Journal of Medicine* 2003;**349**(26):2510-8.

Stiell 2009 *{published data only}*

Stiell IG, Clement CM, Grimshaw J, Brison RJ, Rowe BH, Schull MJ, et al. Implementation of the Canadian C-Spine Rule: prospective 12-centre cluster randomised trial. *BMJ (Clinical Research Ed.)* 2009;**339**:b4146.

Stiell 2010 *{published data only}*

Stiell IG, Clement CM, O'Connor A, Davies B, Leclair C, Sheehan P, et al. Multicentre prospective validation of use of the Canadian C-Spine Rule by triage nurses in the emergency department. *CMAJ: Canadian Medical Association Journal* 2010;**182**(11):1173-9.

Stiell 2018 *{published data only}*10.1016/j.annemergmed.2018.03.033

Stiell IG, Clement CM, Lowe M, Sheehan C, Miller J, Armstrong S, et al. A multicenter program to implement the Canadian C-Spine Rule by emergency department triage nurses. *Annals of Emergency Medicine* 2018;**72**(4):333-41.

Stroh 2001 *{published data only}*

Stroh G, Braude D. Can an out-of-hospital cervical spine clearance protocol identify all patients with injuries? An argument for selective immobilization. *Annals of Emergency Medicine* 2001;**37**(6):609-15.

Sun 2013 *{published data only}*

Sun R, Skeete D, Wetjen K, Lilienthal M, Liao J, Madsen M, et al. A pediatric cervical spine clearance protocol to reduce

radiation exposure in children. *Journal of Surgical Research* 2013;**183**(1):341-6.

Syrmos 2015 *{published data only}*10.1007/s00381-015-2811-6

Syrmos N, Mylonas A, Iliadis C, Gavridakis G, Valadakis V, Grigoriou K, et al. Management of combined brain and spine sport injuries. *Child's Nervous System* 2015;**31**(10):1983.

Tahvonen 2013 *{published data only}*

Tahvonen P, Oikarinen H, Pääkkö E, Karttunen A, Blanco Sequeiros R, Tervonen O. Justification of CT examinations in young adults and children can be improved by education, guideline implementation and increased MRI capacity. *British Journal of Radiology* 2013;**86**(1029):20130337.

Ten Brinke 2021 *{published data only}*

Ten Brinke JG, Slinger G, Slaar A, Saltzherr TP, Hogervorst M, Goslings JC. Increased and unjustified CT usage in paediatric C-spine clearance in a level 2 trauma centre. *European Journal of Trauma and Emergency Surgery* 2021;**47**(3):781-9.

Tricks 2019 *{published data only}*10.1136/archdischild-2019-rcpch.315

Tricks R, Saunders E, Davies P. Paediatric trauma imaging: are the guidelines working? *Archives of Disease in Childhood* 2019;**104**(S2):A132-A3.

Vaillancourt 2017 *{published data only}*10.1017/cem.2017.61

Vaillancourt C, Charette M, Sinclair JE, Maloney J, Dionne R, Kelly P, et al. Implementation of the Canadian C-Spine Rule by paramedics: a safety evaluation. *Canadian Journal of Emergency Medicine* 2017;**19**(S1):S26-7.

Vaillancourt 2020 *{published data only}*10.2196/16966

Vaillancourt C, Charette M, Taljaard M, Thavorn K, Hall E, McLeod B. Pragmatic strategy empowering paramedics to assess low-risk trauma patients with the Canadian C-Spine Rule and selectively transport them without immobilization: protocol for a stepped-wedge cluster randomized trial. *JMIR Research Protocols* 2020;**9**(6):e16966.

Valusek 2010 *{published data only}*

Valusek PA, Langworthy J, Laituri CA, Garey CL, Ostlie DJ, St Peter SD. Detection of cervical spine injury in pediatric trauma patients. *Journal of Surgical Research* 2010;**-**:420.

Velmahos 1996 *{published data only}*

Velmahos GC, Theodorou D, Tatevossian R, Belzberg H, Cornwell EE 3rd, Berne TV, et al. Radiographic cervical spine evaluation in the alert asymptomatic blunt trauma victim: much ado about nothing. *Journal of Trauma – Injury Infection & Critical Care* 1996;**40**(5):768-74.

Vittetoe 2022 *{published data only}*

Vittetoe K, Sborov KD, Benvenuti TA, Benvenuti MA, Ross K, Schoenecker JG, et al. A spine score for children: utility of SLIC in traumatic pediatric cervical spine fractures. *Pediatrics* 2022;**149**:769.

Waddell 2018 *{published data only}*10.1097/JTN.0000000000000340

Waddell VA, Connelly S. Decreasing radiation exposure in pediatric trauma related to cervical spine clearance: a quality improvement project. *Journal of Trauma Nursing* 2018;**25**(1):38-44.

Zebracki 2022 *{published data only}*

Zebracki K, Hwang M, Vogel LC, Mulcahey MJ, Varni JW. PedsQL™ spinal cord injury module: reliability and validity. *Topics in Spinal Cord Injury Rehabilitation* 2022;**28**(1):64-77.

References to studies awaiting assessment

Arbuthnot 2017 *{published data only}*10.1016/j.jpedsurg.2016.10.031

Arbuthnot M, Mooney DP. The sensitivity and negative predictive value of a pediatric cervical spine clearance algorithm that minimizes computerized tomography. *Journal of Pediatric Surgery* 2017;**52**(1):130-135.

Vargas 2022 *{published data only}*

Vargas J, Babbitt C, Suh P, Estevez D, Johnson J, Putnam B, Benjamin E, Mink R. A clinical decision tool to predict the need for cervical imaging in children less than 8 years. *Critical Care Medicine* 2022;**50**(1 Suppl):794.

References to ongoing studies

ACTRN12621001050842 *{published and unpublished data}*

ACTRN12621001050842. Study Of Neck Injuries In Children (SONIC): a prospective observational study to validate existing international clinical decision rules for children presenting to the emergency department with suspected cervical spine injuries. www.anzctr.org.au/Trial/Registration/TrialReview.aspx?id=381928 (first received 11 May 2021). [ACTRN12621001050842]

NCT05049330 *{published and unpublished data}*

NCT05049330. Development and testing of a pediatric cervical spine injury risk assessment tool (C-Spine). clinicaltrials.gov/study/NCT05049330 (first received 9 September 2021).

Additional references

Babl 2017

Babl FE, Borland ML, Phillips N, Kochar A, Dalton S, McCaskill M, et al, Paediatric Research in Emergency Departments International Collaborative (PREDICT). Accuracy of PECARN, CATCH, and CHALICE head injury decision rules in children: a prospective cohort study. *Lancet* 2017;**389**(10087):2393-402. [DOI: 10.1016/S0140-6736(17)30555-X]

Booth 2012

Booth TN. Cervical spine evaluation in pediatric trauma. *American Journal of Roentgenology* 2012;**198**(5):W417-25. [DOI: 10.2214/AJR.11.8150]

Bosch 2002

Bosch PP, Vogt MT, Ward WT. Pediatric spinal cord injury without radiographic abnormality (SCIWORA): the absence of occult instability and lack of indication for bracing. *Spine (Phila Pa 1976)* 2002;**27**(24):2788-800. [DOI: 10.1097/00007632-200212150-00009]

Brenner 2007

Brenner DJ, Hall EJ. Computed tomography – an increasing source of radiation exposure. *New England Journal of Medicine* 2007;**357**(22):2277-84. [DOI: 10.1056/NEJMra072149]

Chan 1994

Chan D, Goldberg R, Tascone A, Harmon S, Chan L. The effect of spinal immobilization on healthy volunteers. *Annals of Emergency Medicine* 1994;**23**(1):48-51. [DOI: 10.1016/s0196-0644(94)70007-9]

Chen 2014

Chen JX, Kachniarz B, Gilani S, Shin JJ. Risk of malignancy associated with head and neck CT in children: a systematic review. *Otolaryngology–Head and Neck Surgery* 2014;**151**(4):554-66. [DOI: 10.1177/0194599814542588]

Chung 2011

Chung S, Mikrogianakis A, Wales PW, Dirks P, Shroff M, Singhal A, et al. Trauma association of Canada Pediatric Subcommittee National Pediatric Cervical Spine Evaluation Pathway: consensus guidelines. *Journal of Trauma* 2011;**70**(4):873-84.

Cirak 2004

Cirak B, Ziegfeld S, Knight VM, Chang D, Avellino AM, Paidas CN. Spinal injuries in children. *Journal of Pediatric Surgery* 2004;**39**(4):607-12. [DOI: 10.1016/j.jpedsurg.2003.12.011]

Covidence [Computer program]

Covidence. Version accessed prior to 6 March 2024. Melbourne, Australia: Veritas Health Innovation. Available at covidence.org.

Cutler 2007

Cutler KO, Bush AJ, Godambe SA, Gilmore B. The use of a pediatric emergency medicine-staffed sedation service during imaging: a retrospective analysis. *American Journal of Emergency Medicine* 2007;**25**(6):654-61. [DOI: 10.1016/j.ajem.2006.11.043]

Easter 2011

Easter JS, Barkin R, Rosen CL, Ban K. Cervical spine injuries in children, part I: mechanism of injury, clinical presentation, and imaging. *Journal of Emergency Medicine* 2011;**41**(2):142-50. [DOI: 10.1016/j.jemermed.2009.11.034]

Farrell 2017

Farrell CA, Hannon M, Lee LK. Pediatric spinal cord injury without radiographic abnormality in the era of advanced imaging. *Current Opinion in Pediatrics* 2017;**29**(3):286-90. [DOI: 10.1097/MOP.0000000000000481]

Gargas 2013

Gargas J, Yaszay B, Kruk P, Bastrom T, Shellington D, Khanna S. An analysis of cervical spine magnetic resonance imaging findings after normal computed tomographic imaging findings in pediatric trauma patients: ten-year experience of a level I pediatric trauma center. *Journal of Trauma and Acute Care Surgery* 2013;**74**(4):1102-7. [DOI: 10.1097/TA.0b013e3182827139]

Garton 2008

Garton HJ, Hammer MR. Detection of pediatric cervical spine injury. *Neurosurgery* 2008;**62**(3):700-8. [DOI: 10.1227/01.NEU.0000311348.43207.B7]

Goldwasser 2015

Goldwasser T, Bressan S, Oakley E, Arpone M, Babl FE. Use of sedation in children receiving computed tomography after head injuries. *European Journal of Emergency Medicine* 2015;**22**(6):413-8. [DOI: 10.1097/MEJ.0000000000000201]

Gore 2009

Gore PA, Chang S, Theodore N. Cervical spine injuries in children: attention to radiographic differences and stability compared to those in the adult patient. *Seminars in Pediatric Neurology* 2009;**16**(1):42-58. [DOI: 10.1016/j.spen.2009.03.003]

Henry 2013

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

Hoffman 2000

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. *New England Journal of Medicine* 2000;**343**(2):94-9.

Hoyle 2014

Hoyle JD Jr, Callahan JM, Badawy M, Powell E, Jacobs E, Gerardi M, et al. Pharmacological sedation for cranial computed tomography in children after minor blunt head trauma. *Pediatric Emergency Care* 2014;**30**(1):1-7. [DOI: 10.1097/PEC.0000000000000059]

Jimenez 2008

Jimenez RR, Deguzman MA, Shiran S, Karrellas A, Lorenzo RL. CT versus plain radiographs for evaluation of c-spine injury in young children: do benefits outweigh risks? *Pediatric Radiology* 2008;**38**(6):635-44.

Junewick 2010

Junewick JJ. Cervical spine injuries in pediatrics: are children small adults or not? *Pediatric Radiology* 2010;**40**(4):493-8. [DOI: 10.1007/s00247-009-1527-8]

Kokoska 2001

Kokoska ER, Keller MS, Rallo MC, Weber TR. Characteristics of pediatric cervical spine injuries. *Journal of Pediatric Surgery* 2001;**36**(1):100-5.

Kreykes 2010

Kreykes NS, Letton RW Jr. Current issues in the diagnosis of pediatric cervical spine injury. *Seminars in Pediatric Surgery* 2010;**19**(4):257-64. [DOI: 10.1053/j.sempedsurg.2010.06.002]

Laupacis 1997

Laupacis A, Sekar N, Stiell IG. Clinical prediction rules. A review and suggested modifications of methodological standards. *JAMA* 1997;**277**(6):488-94.

Leonard 2012

Leonard JC, Mao J, Jaffe DM. Potential adverse effects of spinal immobilization in children. *Prehospital Emergency Care* 2012;**16**(4):513-8. [DOI: 10.3109/10903127.2012.689925]

Leonard 2014

Leonard JR, Jaffe DM, Kuppermann N, Olsen CS, Leonard JC. Cervical spine injury patterns in children. *Pediatrics* 2014;**133**(5):e1179-88. [DOI: 10.1542/peds.2013-3505]

Leonard 2015

Leonard JC, Jaffe DM, Olsen CS, Kuppermann N. Age-related differences in factors associated with cervical spine injuries in children. *Academic Emergency Medicine* 2015;**22**(4):441-6. [DOI: 10.1111/acem.12637]

Mahajan 2013

Mahajan P, Jaffe DM, Olsen CS, Leonard JR, Nigrovic LE, Rogers AJ, et al. Spinal cord injury without radiologic abnormality in children imaged with magnetic resonance imaging. *Journal of Trauma and Acute Care Surgery* 2013;**75**(5):843-7. [DOI: 10.1097/TA.0b013e3182a74abd]

March 2002

March JA, Ausband SC, Brown LH. Changes in physical examination caused by use of spinal immobilization. *Prehospital Emergency Care* 2002;**6**(4):421-4. [DOI: 10.1080/10903120290938067]

Mathews 2013

Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *BMJ* 2013;**346**:f2360. [DOI: 10.1136/bmj.f2360]

McGinn 2000

McGinn TG, Guyatt GH, Wyer PC, Naylor CD, Stiell IG, Richardson WS. Users' guides to the medical literature: XXII: how to use articles about clinical decision rules. Evidence-Based Medicine Working Group. *JAMA* 2000;**284**(1):79-84. [DOI: 10.1001/jama.284.1.79]

Miglioretti 2013

Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. *Journal of the American Medical Association Pediatrics* 2013;**167**(8):700-7. [DOI: 10.1001/jamapediatrics.2013.311]

Mohseni 2011

Mohseni S, Talving P, Branco BC, Chan LS, Lustenberger T, Inaba K, et al. Effect of age on cervical spine injury in pediatric population: a National Trauma Data Bank review. *Journal of Pediatric Surgery* 2011;**46**(9):1771-6. [DOI: 10.1016/j.jpedsurg.2011.03.007]

Mortazavi 2011

Mortazavi M, Gore PA, Chang S, Tubbs RS, Theodore N. Pediatric cervical spine injuries: a comprehensive review. *Child's Nervous System* 2011;**27**(5):705-17.

National Clinical Guideline Centre 2014

National Clinical Guideline Centre (UK). Head injury: triage, assessment, investigation and early management of head injury in children, young people and adults. National Institute for Health and Care Excellence (UK) 2014.

Nigrovic 2012

Nigrovic LE, Rogers AJ, Adelgais KM, Olsen CS, Leonard JR, Jaffe DM, et al. Utility of plain radiographs in detecting traumatic injuries of the cervical spine in children. *Pediatric Emergency Care* 2012;**28**(5):426-32.

NSCISC 2019

National Spinal Cord Injury Statistical Center. 2019 Annual Statistical Report – Complete Public Version. National Spinal Cord Injury Statistical Center, University of Alabama 2019.

Nyaga 2018

Nyaga VN, Aerts M, Arbyn M. ANOVA model for network meta-analysis of diagnostic test accuracy data. *Statistical Methods in Medical Research* 2018;**27**(6):1766-1784. [DOI: 10.1177/0962280216669182]

Pang 1982

Pang D, Wilberger JE. Spinal cord injury without radiographic abnormalities in children. *Journal of Neurosurgery* 1982;**57**(1):114-29.

Pang 2004

Pang D. Spinal cord injury without radiographic abnormality in children, 2 decades later. *Neurosurgery* 2004;**55**(6):1325-42; discussion 1342-3.

Parent 2011

Parent S, Mac-Thiong JM, Roy-Beaudry M, Sosa JF, Labelle H. Spinal cord injury in the pediatric population: a systematic review of the literature. *Journal of Neurotrauma* 2011;**28**(8):1515-24. [DOI: 10.1089/neu.2009.1153]

Parizel 2010

Parizel PM, van der Zijden T, Gaudino S, Spaepen M, Voormolen MH, Venstermans C, et al. Trauma of the spine and spinal cord: imaging strategies. *European Spine Journal* 2010;**19**(Suppl 1):S8-17. [DOI: 10.1007/s00586-009-1123-5]

Patel 2001

Patel JC, Tepas JJ, Mollitt DL, Pieper P. Pediatric cervical spine injuries: defining the disease. *Journal of Pediatric Surgery* 2001;**36**(2):373-6.

Pearce 2012

Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet* 2012;**380**(9840):499-505.

Platzer 2007

Platzer P, Jaindl M, Thalhammer G, Dittrich S, Kutscha-Lissberg Fl, Vecsei V, et al. Cervical spine injuries in pediatric patients. *Journal of Trauma* 2007;**62**(2):389-96.

Polk-Williams 2008

Polk-Williams A, Carr BG, Blinman TA, Masiakos PT, Wiebe DJ, Nance ML. Cervical spine injury in young children: a National Trauma Data Bank review. *Journal of Pediatric Surgery* 2008;**43**(9):1718-21. [DOI: 10.1016/j.jpedsurg.2008.06.002]

Rana 2009

Rana AR, Drongowski R, Breckner G, Ehrlich PF. Traumatic cervical spine injuries: characteristics of missed injuries. *Journal of Pediatric Surgery* 2009;**44**(1):151-5; discussion 155. [DOI: 10.1016/j.jpedsurg.2008.10.024]

Ravichandran 1982

Ravichandran G, Silver JR. Missed injuries of the spinal cord. *BMJ (Clinical Research Ed.)* 1982;**284**(6320):953-6.

Reitsma 2005

Reitsma JB, Glas AS, Rutjes AW, Scholten RJ, Bossuyt PM, Zwinderman AH. Bivariate analysis of sensitivity and specificity produces informative summary measures in diagnostic reviews. *Journal of Clinical Epidemiology* 2005;**58**(10):982-90.

Review Manager 2014 [Computer program]

Review Manager 5 (RevMan 5). Version 5.3. Copenhagen: Nordic Cochrane Centre, The Cochrane Collaboration, 2014.

Rozzelle 2013

Rozzelle CJ, Aarabi B, Dhall SS, Gelb DE, Hurlbert RJ, Ryken TC, et al. Management of pediatric cervical spine and spinal cord injuries. *Neurosurgery* 2013;**72**(Suppl 2):205-26.

Ryken 2013

Ryken TC, Hadley MN, Walters BC, Aarabi B, Dhall SS, Gelb DE, et al. Radiographic assessment. *Neurosurgery* 2013;**72**(Suppl 2):54-72. [DOI: 10.1227/NEU.0b013e318276edee]

Schuster 2005

Schuster R, Waxman K, Sanchez B, Becerra S, Chung R, Conner S, et al. Magnetic resonance imaging is not needed to clear cervical spines in blunt trauma patients with normal computed tomographic results and no motor deficits. *Archives of Surgery* 2005;**140**(8):762-6. [DOI: 10.1001/archsurg.140.8.762]

Schünemann 2020

Schünemann HJ, Mustafa RA, Brozek J, Steingart KR, Leeflang M, Murad MH, et al. GRADE guidelines: 21 part 2. Test accuracy: inconsistency, imprecision, publication bias, and other domains for rating the certainty of evidence and presenting it in evidence profiles and summary of findings tables. *Journal of Clinical Epidemiology* 2020;**122**:142-52.

Shavelle 2007

Shavelle RM, Devivo MJ, Paculdo DR, Vogel LC, Strauss DJ. Long-term survival after childhood spinal cord injury. *Journal of Spinal Cord Medicine* 2007;**30**(Suppl 1):S48-54. [DOI: 10.1080/10790268.2007.11753969]

Stiell 1999

Steill IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. *Annals of Emergency Medicine* 1999;**33**(4):437-47. [DOI: 10.1016/s0196-0644(99)70309-4]

Stiell 2001

Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ, et al. The Canadian C-Spine Rule for radiography in alert and stable trauma patients. *JAMA* 2001;**286**(15):1841-8.

Sundstrom 2014

Sundstrøm T, Asbjørnsen H, Habiba S, Sunde GA, Wester K. Prehospital use of cervical collars in trauma patients: a critical review. *Journal of Neurotrauma* 2014;**31**(6):531-40. [DOI: 10.1089/neu.2013.3094]

Vogel 2002a

Vogel LC, Krajci KA, Anderson CJ. Adults with pediatric-onset spinal cord injury: part 1: prevalence of medical complications. *Journal of Spinal Cord Medicine* 2002;**25**(2):106-16.

Vogel 2002b

Vogel LC, Krajci KA, Anderson CJ. Adults with pediatric-onset spinal cord injury: part 2: musculoskeletal and neurological complications. *Journal of Spinal Cord Medicine* 2002;**25**(2):117-23.

Vogel 2002c

Vogel LC, Krajci KA, Anderson CJ. Adults with pediatric-onset spinal cord injuries: part 3: impact of medical complications. *Journal of Spinal Cord Medicine* 2002;**25**(4):297-305.

Weber 2019

Weber EJ, Carlton EW. Side effects of decision rules, or the law of unintended consequences. *Emergency Medicine Journal* 2019;**36**(1):2-3.

Whiting 2011

Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al, QUADAS-2 Group. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Annals of Internal Medicine* 2011;**155**(8):529-36.

Yucesoy 2008

Yucesoy K, Yuksel KZ. SCIWORA in MRI era. *Clinical Neurology and Neurosurgery* 2008;**110**(5):429-33.

References to other published versions of this review

Slaar 2015

Slaar A, Fockens MM, Wang J, Maas M, Wilson DJ, Goslings JC, et al. Triage tools for detecting cervical spine injury in pediatric trauma patients. *Cochrane Database of*

Systematic Reviews 2015, Issue 5. Art. No: CD011686. [DOI: 10.1002/14651858.CD011686]

Slaar 2017

Slaar A, Fockens MM, Wang J, Maas M, Wilson DJ, Goslings JC, et al. Triage tools for detecting cervical spine injury in pediatric trauma patients. *Cochrane Database of Systematic Reviews* 2017, Issue 12. Art. No: CD011686. [DOI: 10.1002/14651858.CD011686.pub2]

* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Davies 2016

Study characteristics	
Patient Sampling	Level 1 trauma centre, Royal London Hospital, UK **Study dates:** 1 October 2008 to 1 October 2013 **Sampling:** retrospective cohort (medical record review) – children aged < 10 years who underwent cervical spine imaging following blunt trauma
Patient characteristics and setting	**Inclusion criteria:** children aged < 10 years presenting following blunt trauma and who had any imaging of the cervical spine (X-ray, CT, MRI, or a combination of these) within 24 hours of admission to exclude CSI. Children with incomplete data were excluded (8/278) **Participant characteristics** Children enrolled: 278 Children included in analysis: 270 (8 excluded due to incomplete data) Mean age: 5.2 years (range 0.2–9.9 years) Sex: 180 boys, 90 girls Children with CSI: 5 (1.85%) **Setting:** level 1 trauma centre, London UK
Index tests	**Index tests:** NICE guideline 56 (CG56) and NICE guideline 176 (CG176) – see Table 3 for details **Test administrator/training:** not stated **Blinding of examiners:** not stated
Target condition and reference standard(s)	**Target condition:** CSI (no definition provided) **Reference standard:** X-ray, MRI, CT, or a combination of these within 24 hours of admission
Flow and timing	Time between presentation to ED with blunt trauma and imaging was assumed to be < 1 day. 8 children were excluded due to incomplete data. A total of 68 children had a cervical spine X-ray of which 44 (64%) were reported as technically inadequate; of these 5 had a subsequent CT. 6 cases with adequate X-rays underwent subsequent CT and 1 had a subsequent MRI
Comparative	

Davies 2016 *(Continued)*

Notes	**Funding:** not stated		
Methodological quality			
Item	**Authors' judgement**	**Risk of bias**	**Applicability concerns**
DOMAIN 1: Patient selection			
Was a consecutive or random sample of patients enrolled?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
Prospective design	No		
Could the selection of patients have introduced bias?		High risk	
Are there concerns that the included patients and setting do not match the review question?			High
DOMAIN 2: Index test (All tests)			
Were the index test results interpreted without knowledge of the results of the reference standard?	No		
If a threshold was used, was it pre-specified?	Yes		
Could the conduct or interpretation of the index test have introduced bias?		High risk	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?			Unclear
DOMAIN 3: Reference standard			
Is the reference standard likely to correctly classify the target condition?	Unclear		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Yes		
Could the reference standard, its conduct, or its interpretation have introduced bias?		Unclear risk	
Are there concerns that the target condition as defined by the reference standard does not match the question?			Unclear
DOMAIN 4: Flow and timing			
Did all patients receive the same reference standard?	Yes		
Were all patients included in the analysis?	Yes		
Was there an appropriate interval between presentation to ED with blunt trauma and conduct of the index test and reference standard?	Yes		

Davies 2016 *(Continued)*

Could the patient flow have introduced bias?	Low risk

Leonard 2019

Study characteristics	
Patient Sampling	4 tertiary care children's hospitals in the USA **Study dates:** March 2014 to November 2016 **Sampling:** prospective, consecutive sampling
Patient characteristics and setting	**Inclusion criteria:** children aged < 18 years who presented to the ED for blunt trauma and were transported from the scene of injury by emergency medical services in spinal motion restriction devices (cervical collars and rigid longboards), underwent trauma team evaluation, had cervical spine imaging ordered in the ED or a combination of these **Exclusion criteria:** children whose injury mechanism was solely penetrating trauma, whose legal guardian had a substantial language barrier, who were in state's custody, or who were transferred from the study site for definitive care **Participant characteristics** Children enrolled: 4144 Children included in analysis: 4091 (legal guardians withdrew 53 children) Mean age of cohort: 9.4 years Mean age of those with CSI: 10.7 years Sex: 2373 boys, 1718 girls Children with CSI: 74 (1.8%) Children aged < 8 years: 1609 (39.3%); 23 (1.4%) had CSI **Setting:** tertiary care children's hospitals, USA
Index tests	**Index tests:** Pediatric Emergency Care Applied Research Network (PECARN) retrospective criteria and Leonard de novo model – see Table 3 for details **Test administrator/training:** trained research personnel administered electronic branch-logic questionnaires to treating ED providers **Blinding of examiners:** observations were gained regarding CSI risk factors before knowledge of cervical spine imaging results, if ordered or if obtained at a transferring hospital, before knowledge of their institutional radiologist's interpretation
Target condition and reference standard(s)	**Target condition:** CSI defined as vertebral fractures, ligamentous injury, intraspinal haemorrhage, or spinal cord injury (either on MRI or spinal cord injury without radiographic association) involving the cervical region (occiput to seventh cervical vertebra, including ligamentous structures attaching the seventh cervical vertebra to first thoracic vertebra) **Reference standard:** cervical spine imaging reports and if applicable, spine surgeon consultation notes. If the imaging report conflicted with the spine surgeon consultation, clarification was sought. For children who did not undergo imaging, the medical record was reviewed 21 days later for subsequent imaging and if no imaging was noted, a follow-up

Leonard 2019 *(Continued)*

	call with a legal guardian was conducted 21–28 days after the ED visit to verify the absence of CSI
Flow and timing	Time between presentation with blunt trauma to ED and imaging was assumed to be < 1 day
Comparative	
Notes	**Funding:** Dr JC Leonard was supported by Eunice Kennedy Shriver National Institute of Child Health and Human Development grant R21HDO76108-02. Funded by the National Institutes of Health (NIH), USA

Methodological quality

Item	Authors' judgement	Risk of bias	Applicability concerns
DOMAIN 1: Patient selection			
Was a consecutive or random sample of patients enrolled?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
Prospective design	Yes		
Could the selection of patients have introduced bias?		Low risk	
Are there concerns that the included patients and setting do not match the review question?			Low concern
DOMAIN 2: Index test (All tests)			
Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear		
If a threshold was used, was it pre-specified?	Yes		
Could the conduct or interpretation of the index test have introduced bias?		Unclear risk	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?			High
DOMAIN 3: Reference standard			
Is the reference standard likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear		

Leonard 2019 *(Continued)*

Could the reference standard, its conduct, or its interpretation have introduced bias?		Unclear risk
Are there concerns that the target condition as defined by the reference standard does not match the question?		Low concern
DOMAIN 4: Flow and timing		
Did all patients receive the same reference standard?	Yes	
Were all patients included in the analysis?	Yes	
Was there an appropriate interval between presentation to ED with blunt trauma and conduct of the index test and reference standard?	Yes	
Could the patient flow have introduced bias?		Low risk

Phillips 2021

Study characteristics	
Patient Sampling	Single-centre tertiary paediatric ED in Brisbane, Australia **Study dates:** September 2015 to September 2016 **Sampling:** prospective, consecutive sampling
Patient characteristics and setting	**Inclusion criteria:** aged < 16 years and met ≥ 1 of the following: immobilisation prearrival for possible CSI; presentation with neck pain in the context of trauma; otherwise considered at risk of neck injury by the ED team (e.g. multitrauma patient or trauma patient with abnormal neurology, posturing or altered consciousness level) **Exclusion criteria:** declined to participate, did not wait to be seen or a successful follow-up telephone call was viewed unlikely (e.g. overseas resident, no easily identifiable guardian, transient living situation, insufficient English language). Children assessed by ED clinicians as having had their cervical spines fully assessed and cleared at another hospital prior to transfer for the definitive management of other injuries were excluded **Participant characteristics** Children enrolled: 1010 (37 excluded as had initial imaging prior to arrival of which 9 had confirmed CSI) Children included in analysis: 973 Median age: 10.9 years (IQR 7.1–13.6 years) Sex: 643 boys, 330 girls Children with CSI: 5 (0.5%)

Phillips 2021 *(Continued)*

	Children aged < 8 years: 295 (30.3%) Children aged < 2 years: 46 (4.7%) **Setting:** tertiary paediatric ED, Australia
Index tests	**Index tests:** NEXUS criteria, Canadian C-Spine Rule and PECARN rule – see Table 3 for details **Test administrator/training:** criteria were collected prospectively by clinicians using "clinician interpreted criteria" – no training reported. Variables were collected at 2 time points: prospectively by clinicians based on information available during initial assessment in ED and retrospectively by researchers when complete clinical notes were available to assess for variation **Blinding of examiners:** radiologists at each site interpreted all radiographic images and formal radiology reports were used for assessing index test criteria
Target condition and reference standard(s)	**Target condition:** CSI defined as any radiological CSI on X-ray, CT or MRI as reported by specialist paediatric radiologists **Reference standard:** X-ray, CT or MRI or clinical clearance if no imaging sought. Telephone follow-up occurred for all children to ensure no CSIs were missed
Flow and timing	Time between presentation to ED with blunt trauma and imaging was assumed to be < 1 day. 396 (40.7%) children had their cervical spine imaged after ED arrival; 315 (32.4%) received X-ray, 130 (13.5%) CT and 29 (3%) MRI. 577 (59.3%) children did not receive imaging; of these, 6.8% were lost to telephone follow-up and were included in the analysis. There were no known missed injuries X-ray and sometimes a CT scan were obtained as the primary imaging modality
Comparative	
Notes	**Funding:** grant from the Emergency Medicine Foundation (Australasia) Queensland Program – EMSS-404R21-2014. NP, JA, RB, GA and MW obtained grant funding

Methodological quality

Item	**Authors' judgement**	**Risk of bias**	**Applicability concerns**
DOMAIN 1: Patient selection			
Was a consecutive or random sample of patients enrolled?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
Prospective design	Yes		
Could the selection of patients have introduced bias?		Low risk	
Are there concerns that the included patients and setting do not match the review question?			Low concern
DOMAIN 2: Index test (All tests)			

Phillips 2021 *(Continued)*

Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear		
If a threshold was used, was it prespecified?	Yes		
Could the conduct or interpretation of the index test have introduced bias?		Unclear risk	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?			Low concern
DOMAIN 3: Reference standard			
Is the reference standard likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear		
Could the reference standard, its conduct, or its interpretation have introduced bias?		Unclear risk	
Are there concerns that the target condition as defined by the reference standard does not match the question?			Low concern
DOMAIN 4: Flow and timing			
Did all patients receive the same reference standard?	Yes		
Were all patients included in the analysis?	Yes		
Was there an appropriate interval between presentation to ED with blunt trauma and conduct of the index test and reference standard?	Yes		
Could the patient flow have introduced bias?		Low risk	

Pieretti-Vanmarcke 2009

Study characteristics	
Patient Sampling	Trauma registries of 22 institutions in the USA, Canada and Brazil. There were 15 paediatric level I, 6 adult level I, and 1 adult level II trauma centres

Pieretti-Vanmarcke 2009 *(Continued)*

	Study dates: 1 January 1995 to 1 January 2005 **Sampling:** retrospective sampling of children aged ≤ 3 years after blunt trauma identified in the paediatric trauma registries. Sample randomly split into 2 data sets: 2/3 of the sample was used to identify clinical predictors of CSI to develop a scoring algorithm (evaluation set) and 1/3 to validate the algorithm (validation set)
Patient characteristics and setting	**Inclusion criteria:** children aged < 3 years who sustained blunt trauma **Participant characteristics** Total children enrolled: 12,882 Total children included in analysis: 12,537 (345 children were excluded as they died immediately upon presentation to the ED) Mean age: 1.4 (SD 0.8) years Sex: 7463 boys, 5074 girls Children with CSI: 83 (0.66%) **Validation set** Total children in analysis: 4179 Children with CSI: 30 (0.72%) **Setting:** paediatric and adult, level I and level II hospitals in the USA, Canada and Brazil
Index tests	**Index tests:** PEDSPINE – see Table 3 for details **Test administrator/training:** not stated **Blinding of examiners**: not stated
Target condition and reference standard(s)	**Target condition:** CSI defined by any osseous or ligamentous injury to the cervical spine seen on CT, X-ray or MRI **Reference standard:** X-ray, CT or MRI or clinical clearance
Flow and timing	Time between presentation to ED with blunt trauma and imaging was assumed to be < 1 day. X-rays (2 or 3 views) were obtained in 4046 children (32.3%), CT in 3358 (30.6%) and MRI in 478 (3.8%)
Comparative	
Notes	**Funding:** grants from the American Association for the Surgery of Trauma Foundation and Anthem Blue Cross/Blue Shield of Connecticut We contacted the authors to request additional data on participant characteristics

Methodological quality

Item	Authors' judgement	Risk of bias	Applicability concerns
DOMAIN 1: Patient selection			

Pieretti-Vanmarcke 2009 *(Continued)*

Was a consecutive or random sample of patients enrolled?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
Prospective design	No		
Could the selection of patients have introduced bias?		High risk	
Are there concerns that the included patients and setting do not match the review question?			Low concern
DOMAIN 2: Index test (All tests)			
Were the index test results interpreted without knowledge of the results of the reference standard?	No		
If a threshold was used, was it pre-specified?	Yes		
Could the conduct or interpretation of the index test have introduced bias?		High risk	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?			High
DOMAIN 3: Reference standard			
Is the reference standard likely to correctly classify the target condition?	No		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Yes		
Could the reference standard, its conduct, or its interpretation have introduced bias?		High risk	
Are there concerns that the target condition as defined by the reference standard does not match the question?			Low concern
DOMAIN 4: Flow and timing			
Did all patients receive the same reference standard?	No		
Were all patients included in the analysis?	Yes		
Was there an appropriate interval between presentation to ED with blunt trauma and conduct of the index test and reference standard?	Yes		
Could the patient flow have introduced bias?		High risk	

Viccellio 2001

Study characteristics	
Patient Sampling	UCLA Emergency Medicine Center (USA) and 20 participating centres. Study sites comprise a range of acute care facilities, including academic trauma centres, community trauma centres, and community EDs **Study dates:** 1990–2000 (estimated) **Sampling:** prospective multicentre cohort study
Patient characteristics and setting	**Inclusion criteria:** children aged < 18 years with blunt trauma injuries who received cervical spine imaging **Participant characteristics** Total adults and children enrolled: 34,069 Children aged < 18 years: 3065 (all included in analysis) Age: 0–2 years (88 children, 2.9%), 2–8 years (817 children, 26.7%), 9–17 years (2160 children, 70.5%) Sex: not stated Children with CSI: 30 (0.98%) Children aged < 8 years with CSI: 4 **Setting:** acute care facilities in the USA
Index tests	**Index tests:** NEXUS criteria – see Table 3 for details **Test administrator/training:** physicians at participating centres undertook brief training programmes **Blinding of examiners:** study radiologists at each site interpreted all radiographic studies. Neither the official radiology interpretation nor the coding of injuries was performed with knowledge of the findings on the NEXUS data form
Target condition and reference standard(s)	**Target condition:** CSI defined as cervical spine fracture or dislocation **Reference standard:** X-ray, CT, MRI, or a combination of these
Flow and timing	Time between presentation to ED with blunt trauma and imaging was assumed to be < 1 day. Only those children who were selected for radiographic imaging were included. X-rays and CT scan were the primary imaging modalities
Comparative	
Notes	Analysis of the paediatric population included in the original Hoffman 2000, the seminal publication of the NEXUS tool **Funding:** Grant R01 HS08239 from the Agency for Healthcare Research and Quality

Methodological quality

Item	Authors' judgement	Risk of bias	Applicability concerns

Viccellio 2001 *(Continued)*

DOMAIN 1: Patient selection			
Was a consecutive or random sample of patients enrolled?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
Prospective design	Yes		
Could the selection of patients have introduced bias?		Low risk	
Are there concerns that the included patients and setting do not match the review question?			Low concern
DOMAIN 2: Index test (All tests)			
Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear		
If a threshold was used, was it pre-specified?	Yes		
Could the conduct or interpretation of the index test have introduced bias?		Unclear risk	
Are there concerns that the index test, its conduct, or interpretation differ from the review question?			Low concern
DOMAIN 3: Reference standard			
Is the reference standard likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Yes		
Could the reference standard, its conduct, or its interpretation have introduced bias?		Low risk	
Are there concerns that the target condition as defined by the reference standard does not match the question?			Low concern
DOMAIN 4: Flow and timing			
Did all patients receive the same reference standard?	Yes		
Were all patients included in the analysis?	Yes		
Was there an appropriate interval between presentation to ED with blunt trauma and conduct of the index test and reference standard?	Yes		
Could the patient flow have introduced bias?		Low risk	

CSI: cervical spine injury; CT: computed tomography; ED: emergency department; IQR: interquartile range; MRI: magnetic resonance imaging; NEXUS: National Emergency X-Radiography Utilization Study; NICE: National Institute for Health and Care Excellence; PECARN: Pediatric Emergency Care Applied Research Network; SD: standard deviation; UCLA: University of California, Los Angeles.

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Adelgais 2014	Index test not relevant
Ahmad 2017	Index test not relevant
Al-Sarheed 2020	Index test not relevant
Alas 2021	Index test not relevant
Anderson 2006	Target condition not relevant
Anderson 2010	Index test not relevant
Atesok 2018	Ineligible study design (review)
Babcock 2018	Index test not relevant
Babu 2016	Different study population (only people with CSI)
Bailey 2022	Ineligible study design (insufficient evidence to present a 2 × 2 table on the accuracy of the CDR)
Baker 1999	Index test not relevant
Bandiera 2003	Different study population (adults)
Banit 2000	Index test not relevant
Bayless 1989	Index test not relevant
Benayoun 2016	Different study population (mostly adults; data on children not reported separately)
Bennett 2015	Index test not relevant
Blacksin 1995	Index test not relevant
Boese 2015	Index test not relevant
Borock 1991	Different study population (only people with CSI)
Boustani 2015	Different study population (adults)
Brockmeyer 2012	Different study population (suspected or confirmed CSI)
Brooks 2001	Index test not relevant
Brown 2001	Index test not relevant
Browne 2003	Target condition not relevant
Browne 2017	Index test not relevant

Study	Reason for exclusion
Browne 2021	Different study population (prehospital)
Burns 2011	Different target condition
Caltili 2017	Different study population (mostly adults). Contacted authors for data on children but they did not respond.
Carter 2017	Different study population (suspected or confirmed CSI)
Chaudhry 2016	Index test not relevant
Clayton 2012	Index test not relevant
Coffey 2011	Different study population (adults)
Como 2011	Index test not relevant
Cui 2016	Index test not relevant
Dahlquist 2013	Index test not relevant
Dalle 2022	Index test not relevant
Dickinson 2004	Different study population (adults)
DiGiacomo 2002	Index test not relevant
Douglas 2022	Ineligible study design (study did not compare the accuracy of the cervical spine clearance guideline to the reference standard)
Dranoff 2019	Different study population (adults)
Dwyer 2019	Different study population (suspected or confirmed CSI)
Edwards 2001	Index test not relevant
Ehrlich 2009	Ineligible study design; retrospective case-matched design
Ekhator 2022	Ineligible study design
Eren 2020	Index test not relevant
Ersoy 1995	Index test not relevant
Fischer 1984	Index test not relevant
Flynn-O'Brien 2016	Index test not relevant
Gajera 2017	Ineligible study design (review)
Garton 2008	Different study population (only people with CSI)
Gbaanador 1986	Index test not relevant
Ghelichkhani 2021	Different study population (adults)

Study	Reason for exclusion
Gonzalez 1999	Index test not relevant
Gonzalez 2009	Index test not relevant
Gonzalez 2013	Different study population (prehospital evaluation)
Griffen 2003	Index test not relevant
Griffith 2011	Different study population (adults)
Griffith 2013	Different study population (adults)
Griffith 2014	Different study population (adults)
Hale 2015	Index test not relevant
Handler 2018	Index test not relevant
Hannon 2015	Index test not relevant
Hanson 2000a	Different study population (adults)
Hanson 2000b	Different study population (adults)
Hasan 2022	Index test not relevant
Hasler 2011	Different study population (adults)
Hazboun 2021	Index test not relevant
Heffernan 2005	Different study population (adults)
Henry 2016	Index test not relevant
Henry 2021	Index test not relevant
Herman 2019	Ineligible study design (review)
Hoffman 1992	Authors did not separate data for children from adults (only a few children were included)
Hollingshead 2000	Index test not relevant
Hood 2015	Ineligible study design (review)
Hopper 2020	Index test not relevant
Hutchings 2009	Index test not relevant
Ihalainen 2017	Index test not relevant
Inaba 2015	Different study population (adults)
Inaba 2016	Target condition not relevant
Jacob 2016	Index test not relevant

Study	Reason for exclusion
Jaffe 1987	Ineligible study design; recruited a second non-consecutive cohort of CSI cases
Jakes 2015	Ineligible study design (review)
Jarvers 2020	Index test not relevant
Kadom 2019	Ineligible study design (review)
Kaminski 2017	Index test not relevant
Kavuri 2019	Index test not relevant
Keenan 2001	Index test not relevant
Kerr 2005	Different study population (adults)
Khetarpal 2021	Ineligible participant population (prehospital)
Kokabi 2011	Different study population (adults)
Lee 2003	Index test not relevant
Lee 2022	Index test not relevant
Lemley 2015	Ineligible study design (review)
Leonard 2011	Ineligible study design (case control study)
Letica-Kriegel 2022	Ineligible study design (review)
Liawrungrueang 2020	Ineligible study design (case study)
Luehmann 2020	Index test not relevant
Malomo 1995	Index test not relevant
Mannix 2011	Index test not relevant
Markuske 1983	Target condition not relevant
Markuske 1988	Target condition not relevant
Martin 2004	Index test not relevant
McLaughlin 2019	Ineligible study design (review)
McMahon 2015	Index test not relevant
Meek 2007	Index test not relevant
Meldon 1998	Different study population (out-of-hospital participants)
Mitrofan 2016	Ineligible study design (review)
Morrison 2012	Index test not relevant

Study	Reason for exclusion
Mower 2001	Index test not relevant
NCT05605847	Different study population (adults)
Neifeld 1988	Different study population (adults)
Nguyen 2005	Index test not relevant
Nolte 2022	Different study population (prehospital)
Novick 2018	Index test not relevant
Nunn 2021	Index test not relevant
Omran 2001	Index test not relevant
Overberger 2018	Different study population (adults)
Overmann 2020	Index test not relevant
Pannu 2017	Index test not relevant
Pennell 2020	Index test not relevant
Pepin 2015	Ineligible study design (full text unavailable). Contacted authors but they did not reply.
Platzer 2006a	Index test not relevant
Platzer 2006b	Index test not relevant
Poorman 2019	Index test not relevant
Pulfrey 2002	Different study population (adults)
Quigley 2014	Index test not relevant
Raza 2013	Different study population (adults)
Robinson 2022	Index test not relevant
Rolfe 2019	Target condition not relevant
Ropele 2009	Index test not relevant
Rosati 2015	Index test not relevant
Rose 2012	Index test not relevant
Ross 1987	Index test not relevant
Saddison 1991	Different study population (only people with CSI)
Sanchez 2005	Index test not relevant
Scarrow 1999	Different study population (only people with CSI)

Study	Reason for exclusion
Schleehauf 1989	Index test not relevant
Sharma 2023	Ineligible study design (study did not compare the accuracy of a CDR to the reference standard)
Sheikh 2012	Different study population (adults)
Shin 2016	Index test not relevant
Singh 2018	Index test not relevant
Slaar 2016	Index test not relevant
Smart 2003	Index test not relevant
Sokoloff 2022	Different study population
Songür Kodik 2020	Different study population (mostly adults; data on children not extractable)
Stanton 2017	Ineligible study design (review)
Stiell 2003	Different study population (adults)
Stiell 2009	Different study population (adults)
Stiell 2010	Different study population (adults)
Stiell 2018	Different study population (mostly adults; data on children not extractable)
Stroh 2001	Index test not relevant
Sun 2013	Target condition not relevant
Syrmos 2015	Ineligible study design (case study)
Tahvonen 2013	Index test not relevant
Ten Brinke 2021	Index test not relevant.
Tricks 2019	Full text unavailable. Contacted the authors who explained that no full-text studies had been published
Vaillancourt 2017	Different study population (prehospital)
Vaillancourt 2020	Different study population (prehospital)
Valusek 2010	Index test not relevant
Velmahos 1996	Index test not relevant
Vittetoe 2022	Index test not relevant
Waddell 2018	Target condition not relevant
Zebracki 2022	Index test not relevant.

Study	Reason for exclusion
Özkan 2015	Different study population (suspected or confirmed CSI)

CDR: clinical decision rule; CSI: cervical spine injury.

Characteristics of studies awaiting classification *[ordered by study ID]*

Arbuthnot 2017

Patient Sampling	Level 1 paediatric trauma centre (Boston Children's Hospital), USA Retrospective review
Patient characteristics and setting	Inclusion criteria: people aged ≤ 21 years with blunt trauma injury who underwent cervical spine evaluation
Index tests	Boston Children's Hospital paediatric cervical spine clearance algorithm
Target condition and reference standard(s)	Target condition: cervical spine injury (no definition provided) Reference standard: X-ray, MRI, CT, or a combination of these within 24 hours of admission
Flow and timing	Time between presentation to ED with blunt trauma and imaging was assumed to be < 1 day. 1 missed injury
Comparative	
Notes	Authors contacted for data for children aged 0 to < 18 years (inclusion criteria for the review)

Vargas 2022

Patient Sampling	3 level 1 paediatric trauma centres, USA
Patient characteristics and setting	Children aged < 8 years with traumatic injury admitted to 1 of 3 level 1 paediatric trauma centres between August 2007 and August 2017
Index tests	Previously identified 6 risk factors that increased the odds of having a CSI in children aged < 8 years
Target condition and reference standard(s)	Target condition: CSI defined as • radiographic evidence of CSI or • radiographic evidence of CSI or treatment due to clinical concern, or both Reference standard: radiography
Flow and timing	Time between presentation to ED with blunt trauma and imaging: not reported (abstract)
Comparative	
Notes	Authors contacted requesting full-text article to assess study for eligibility.

CT: computed tomography; ED: emergency department; MRI: magnetic resonance imaging.

Characteristics of ongoing studies *[ordered by study ID]*

ACTRN12621001050842

Study name	Study Of Neck Injuries In Children (SONIC)
Target condition and reference standard(s)	Target condition: cervical spine injury Reference standard: imaging or follow-up (or both)
Index and comparator tests	NEXUS, Canadian C-Spine Rule and PECARN
Starting date	Ethics: 9 April 2021
Contact information	Dr Natalie Phillips Email: natalie.phillips@health.qld.gov.au
Notes	11 sites and estimated completion date: 30 December 2025 Australia and New Zealand Clinical Registry: ACTRN12621001050842

NCT05049330

Study name	Development and testing of a pediatric cervical spine injury risk assessment tool (C-Spine)
Target condition and reference standard(s)	Target condition: cervical spine injury Reference standard: imaging and follow-up
Index and comparator tests	Pediatric CSI Risk Assessment Tool
Starting date	12 December 2018
Contact information	Email: Julie.Leonard@Nationwidechildrens.org
Notes	18 centres Estimated completion date: 1 September 2023 ClinicalTrials.gov Identifier: NCT05049330

NEXUS: National Emergency X-Radiography Utilization Study; PECARN: Pediatric Emergency Care Applied Research Network.

D A T A

Presented below are all the data for all of the tests entered into the review.

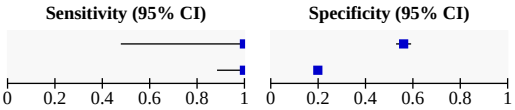
Table Tests. Data tables by test

Test	No. of studies	No. of participants
1 NEXUS	2	4038

Test	No. of studies	No. of participants
2 Canadian C-Spine Rule	1	973
3 PECARN Retrospective	2	5064
4 Leonard de novo	1	4091
5 PEDSPINE	1	4179
6 NICE guideline (CG56)	1	270
7 NICE guideline (CG176)	1	270

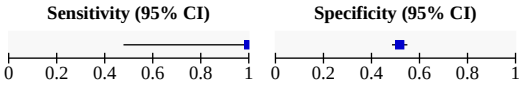
Test 1. NEXUS

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Phillips 2021	5	425	0	543	1.00 [0.48, 1.00]	0.56 [0.53, 0.59]
Viccellio 2001	30	2432	0	603	1.00 [0.88, 1.00]	0.20 [0.18, 0.21]



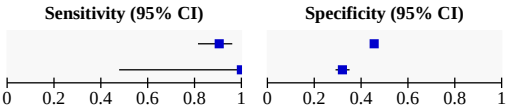
Test 2. Canadian C-Spine Rule

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Phillips 2021	5	467	0	501	1.00 [0.48, 1.00]	0.52 [0.49, 0.55]



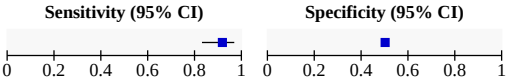
Test 3. PECARN Retrospective

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Leonard 2019	67	2186	7	1831	0.91 [0.81, 0.96]	0.46 [0.44, 0.47]
Phillips 2021	5	658	0	310	1.00 [0.48, 1.00]	0.32 [0.29, 0.35]



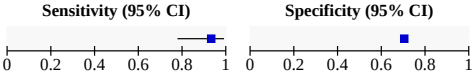
Test 4. Leonard de novo

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Leonard 2019	68	1998	6	2019	0.92 [0.83, 0.97]	0.50 [0.49, 0.52]



Test 5. PEDSPINE

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)
Pieretti-Vanmarcke 2009	28	1224	2	2925	0.93 [0.78, 0.99]	0.70 [0.69, 0.72]



Test 6. NICE guideline (CG56)

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
Davies 2016	5	144	0	121	1.00 [0.48, 1.00]	0.46 [0.40, 0.52]	0 0.2 0.4 0.6 0.8 1	0 0.2 0.4 0.6 0.8 1

Test 7. NICE guideline (CG176)

Study	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
Davies 2016	5	246	0	19	1.00 [0.48, 1.00]	0.07 [0.04, 0.11]	0 0.2 0.4 0.6 0.8 1	0 0.2 0.4 0.6 0.8 1

ADDITIONAL TABLES

Table 1. Assessment of methodological quality: QUADAS-2 and additional items

Quality item	Risk of bias		Applicability	
	Quality indicator	Notes	Quality indicator	Notes
Domain 1 **Patient selection**	**Could the selection of participants have introduced bias?** **(high/low/unclear)**		**Are there concerns that the included patients and settings do not match the review question? (high/low/unclear)**	
	1. Was a consecutive or random sample of patients enrolled?	**Yes:** if a consecutive or random sample of patients was enrolled **No:** if non-consecutive patients or a non-random sample was enrolled **Unclear:** if there is insufficient information on enrolled patients		
	2. Did the study avoid inappropriate exclusions?	This needs to be addressed on a case-to-case basis. **Yes:** if all children who presented with blunt trauma were included or if there were appropriate reasons provided for all excluded participants **No:** if eligible patients were excluded without providing a reason or if exclusions might affect test accuracy (e.g. excluding on the basis of certain clinical features or comorbidities) **Unclear:** if there is insufficient information on exclusions		
	3. Was the study of prospective study design?	**Yes:** if study was of prospective study design **No:** if the study was of retrospective or cross-sectional study design **Unclear:** if there is insufficient information on study design		

Table 1. Assessment of methodological quality: QUADAS-2 and additional items *(Continued)*

Domain 2 **Index test**	**Could the interpretation of the index test have introduced bias? (high/low/unclear)**		**Are there concerns that the index test, its conduct, or the interpretation differ from the review question? (high/low/unclear)**	
	1. Were the index test results interpreted without knowledge of the results of the reference standard?	**Yes:** if the index test results were always interpreted without knowledge of the reference standard **No:** if the index test results were interpreted with knowledge of the results of the reference standard **Unclear:** if there is insufficient information provided on whether the results of the index test were interpreted without knowledge of the reference standard		
	2. Was the threshold used prespecified?	**Yes:** if the threshold was prespecified **No:** if the threshold was not prespecified **Unclear:** if it is unclear whether the threshold was prespecified		
Domain 3 **Reference standard**	**Could the interpretation of the reference standard have introduced bias? (high/low/unclear)**		**Are there concerns that the target condition as defined by the reference standard does not match the review question? (high/low/unclear)**	
	1. Is the reference standard likely to correctly classify the target condition?	**Yes:** if the target condition was defined and all patients received either imaging (CT, MRI or X-ray) or clinical evaluation to clear the cervical spine and an additional follow-up after discharge **No:** if any participant did not receive either imaging or clinical evaluation to clear the cervical spine **Unclear:** if the target condition definition was unclear or if information on the interpretation or execution of the reference standard was unclear	1. Did the study provide a clear definition of what was considered to be a "positive" result for the reference standard?	**Yes:** if the target condition was clearly defined **No:** if the target condition was not defined **Unclear:** if the definition of the target condition was not clearly reported
	2. Were the reference standard results interpreted without knowledge of the results of the index test?	**Yes:** if the interpreter of the reference standard was clearly not aware of the results of the index text **No:** if the interpreter of the reference standard was aware of the results of the index text **Unclear:** if insufficient information was provided on independent or blind assessment of the reference test		
Domain 4 **Flow & timing**	**Could the patient flow have introduced bias? (low/high/unclear)**			
	1. Is the time period between presentation to ED	**Yes:** if the delay between presentation to ED with blunt trauma, execution of the index test(s) and reference standard was acceptable in most partic-		

Table 1. Assessment of methodological quality: QUADAS-2 and additional items *(Continued)*

with blunt trauma and execution of the reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	ipants. If imaging was conducted in the ED it was acceptable **No:** if the delay between presentation to ED with blunt trauma, execution of the index test(s) and reference standard was unacceptable in most participants **Unclear:** if the time between presentation to ED with blunt trauma, execution of the index test(s) and reference standard was unclear
2. Did all patients receive the same reference standard?	**Yes:** all patients underwent the same type of imaging or all patients underwent follow-up after discharge **No:** patients received different reference standards without follow-up after discharge **Unclear:** if information provided was unclear
3. Were all patients included in the analysis?	**Yes:** if all participants were included in the analysis or if not all participants were included in the analysis but: • the withdrawals did not meet inclusion criteria prior to execution of index test • the withdrawals were explained and were appropriate **No:** if any participant was excluded from the analysis for inappropriate reasons or exclusions were not explained **Unclear:** if information provided was unclear

ED: emergency department.

Table 2. Number of citations by search engine

Search engine	Number of citations
CENTRAL	154
MEDLINE	3109
Embase	7001
Proquest Dissertation and Theses	35
PubMed	2810
OpenGrey	6
ClinicalTrials.gov	57
WHO ICTRP	3

Table 2. Number of citations by search engine *(Continued)*

Web of Science	1260
Subtotal	14,435
Minus duplicates	4415
TOTAL	10,020

Table 3. Index tests for CSI identification

Test	Clinical predictors	Classification of result
NEXUS	• Focal neurological deficit present • Midline spinal tenderness present • Altered level of consciousness present • Intoxication present • Distracting injury present	A negative test occurs when all predictors are absent and suggests imaging can be avoided.
Canadian C-Spine Rule	High-risk predictors • Age ≥ 65 years • Dangerous mechanism (fall from ≥ 0.9 m (3 feet), axial load to the head, high-speed motor vehicle collision (e.g. > 100 km/hour, rollover, ejection), motorised recreational vehicles, bicycle collision) • Paraesthesias in extremities Low-risk predictors • Simple rear-end motor vehicle collision (exclude hit by bus/large truck, rollover, hit by high-speed vehicle, pushed into traffic) • Sitting position in emergency department • Ambulatory at any time since the injury • Delayed onset of neck pain • Absence of midline cervical spine tenderness If patient has any low-risk predictor then a physical examination is needed to ascertain if the patient can rotate their neck 45° left and right.	A positive test occurs if any high-risk predictor is present or if low-risk predictors are absent and suggests imaging is warranted. A positive test also occurs if any low-risk predictor is present but a patient is unable to actively rotate their neck 45° left and right.
NICE clinical guideline 56	• Severe head injury (GCS ≤ 8) • Strong clinical suspicion despite normal plain films • Plain films are technically difficult or inadequate	A positive index test occurs if any predictors are present and are considered appropriate indications for CT imaging.
NICE clinical guideline 176	• GCS < 13 on initial assessment • Strong clinical suspicion despite normal plain films • Plain films are technically difficult or inadequate • Patient is intubated • Focal peripheral neurological signs • Paraesthesia in upper and lower limbs • A definitive diagnosis is required (such as before surgery) • The patient is having other areas scanned for multiregion trauma	A positive index test occurs if any predictors are present and are considered appropriate indications for CT imaging.

Table 3. Index tests for CSI identification *(Continued)*

	• Plain films demonstrate a significant bony injury	
Pierretti de novo (PEDSPINE)	• GCS ≥ 14 • Motor vehicle crash • GCS_{EYE} = 1 • Age > 2 years (24–36 months)	Each of the predictors were assigned points as part of an overall weighted score (3 points to GCS < 14, 2 points to GCS_{EYE} = 1 and motor vehicle crash and 1 point to age > 2 years). A negative index test occurs if the weighted score is 0 or 1 and suggests imaging can be avoided.
PECARN retrospective criteria	• High-risk motor vehicle crash • Diving • Conditions predisposing to CSI • Substantial torso injury • Torticollis (decreased neck mobility by report or examination) • Neck pain (child complaint if > 2 years) • Focal neurological findings • Altered mental status	Identified an 8 variable model of predictive factors for CSI after blunt trauma. These factors are considered in the development of the Leonard de novo model. A negative test occurs when all predictors are absent and suggests imaging can be avoided.
Leonard de novo	• Altered mental status • Focal neurological findings • Substantial torso injury • Neck pain • Torticollis • Conditions predisposing to cervical injury • Diving • High-risk motor vehicle crash	A negative test occurs when all predictors are absent and suggests imaging can be avoided.

CSI: cervical spine injury; CT: computed tomography; GCS: Glasgow Coma Scale; NEXUS: National Emergency X-Radiography Utilization Study; NICE: National Institute for Health and Care Excellence; PECARN: Pediatric Emergency Care Applied Research Network.

APPENDICES

Appendix 1. Search strategies – update

MEDLINE

Search 13 December 2022

1. (NEXUS or CCR).mp.

2. National-Emergency-X-Radiography.mp.

3. (Canadian-C-Spine or Canadian-cervical-spine).mp.

4. ((clinical or critical or treatment) adj3 (pathway* or protocol*)).mp.

5. (algorithm* or guideline*).mp.

6. (decision adj3 (tree* or rule* or tool*)).mp.

7. (triage or protocol*).mp.

8. exp guideline/

9. Guideline Adherence/

10. exp Guidelines as Topic/

11. exp algorithms/

12. exp Clinical Protocols/

13. Decision Trees/

14. exp decision support techniques/

15. Critical Pathways/

16. Triage/

17. ((neurolog* or physical* or clinical*) adj3 (exam* or assess* or sign*)).mp.

18. (MRI* or CT* or Computed-tomograph* or CAT-scan*).mp.

19. (x-ray* or xray* or radiograph* or roentgenogra* or imaging).mp.

20. exp Physical Examination/

21. exp trauma severity indices/

22. "Severity of Illness Index"/

23. X-Rays/

24. tomography/ or exp tomography, emission-computed/ or exp tomography, x-ray/

25. exp Magnetic Resonance Imaging/

26. Radiography/

27. or/1-26

28. ((cervical-spine or c-spine) adj5 clear*).mp.

29. (cervical adj5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)).mp.

30. (spinal-cord-injury-without-radiographic-abnormalit* or SCIWORA).mp.

31. exp Cervical Vertebrae/

32. exp Neck Injuries/

33. exp Spinal Injuries/

34. exp Spinal Cord Injuries/

35. or/28-34

36. (perinatal or perinatology or newborn* or new-born* or baby or babies or neonat* or neo-nat* or infan* or toddler* or pre-schooler* or preschooler* or kinder or kinders or kindergarten* or kinder-aged or boy or boys or girl or girls or child or children or childhood or pediatric* or paediatric* or adolescen* or youth or youths or teen or teens or teenage* or school-age* or schoolage* or school-child* or schoolchild* or school-girl* or schoolgirl* or school-boy* or schoolboy* or juvenile* or preteen* or pre-teen*).af.

37. 27 and 35 and 36

38. limit 37 to yr="2015 -Current"

39. limit 38 to english language

Embase

Search 13 December 2022

1. (NEXUS or CCR).mp.

2. National-Emergency-X-Radiography.mp.

3. (Canadian-C-Spine or Canadian-cervical-spine).mp.

4. ((clinical or critical or treatment) adj3 (pathway* or protocol*)).mp.

5. (algorithm* or guideline*).mp.

6. (decision adj3 (tree* or rule* or tool*)).mp.

7. (triage or protocol*).mp.

8. practice guideline/ or clinical pathway/ or exp clinical protocol/

9. exp algorithm/

10. "decision tree"/

11. exp decision support system/

12. emergency health service/

13. ((neurolog* or physical* or clinical*) adj3 (exam* or assess* or sign*)).mp.

14. (MRI* or CT* or Computed-tomograph* or CAT-scan*).mp.

15. (x-ray* or xray* or radiograph* or roentgenogra* or imaging).mp.

16. exp physical examination/

17. exp neurologic examination/

18. exp injury scale/

19. X ray/

20. exp tomography/

21. exp radiography/

22. or/1-21

23. ((cervical-spine or c-spine) adj5 clear*).mp.

24. (cervical adj5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)).mp.

25. (spinal-cord-injury-without-radiographic-abnormalit* or SCIWORA).mp.

26. exp cervical spine/

27. exp neck injury/

28. exp spine injury/

29. exp spinal cord injury/

30. or/23-29

31. (perinatal or perinatology or newborn* or new-born* or baby or babies or neonat* or neo-nat* or infan* or toddler* or pre-schooler* or preschooler* or kinder or kinders or kindergarten* or kinder-aged or boy or boys or girl or girls or child or children or childhood or pediatric* or paediatric* or adolescen* or youth or youths or teen or teens or teenage* or school-age* or schoolage* or school-child* or schoolchild* or school-girl* or schoolgirl* or school-boy* or schoolboy* or juvenile* or preteen* or pre-teen*).af.

32. 22 and 30 and 31

33. limit 32 to (english language and yr="2015 -Current")

CENTRAL (the Cochrane Library)

Search 13 December 2022

1. (NEXUS or CCR) (Word variations have been searched)

2. (National-Emergency-X-Radiography) (Word variations have been searched)

3. (Canadian-C-Spine or Canadian-cervical-spine) (Word variations have been searched)

4. ((clinical or critical or treatment) NEAR/3 (pathway* or protocol*)) (Word variations have been searched)

5. ((clinical or critical or treatment) NEAR/3 (pathway* or protocol*)) (Word variations have been searched)

6. (decision NEAR/3 (tree* or rule* or tool*)) (Word variations have been searched)

7. (triage or protocol*) (Word variations have been searched)

8. MeSH descriptor: [Guideline] explode all trees

9. MeSH descriptor: [Guideline Adherence] this term only

10. MeSH descriptor: [Guidelines as Topic] explode all trees

11. MeSH descriptor: [Algorithms] explode all trees

12. MeSH descriptor: [Clinical Protocols] explode all trees

13. MeSH descriptor: [Decision Trees] this term only

14. MeSH descriptor: [Decision Support Techniques] explode all trees

15. MeSH descriptor: [Critical Pathways] this term only

16. MeSH descriptor: [Triage] this term only

17. ((neurolog* or physical* or clinical*) NEAR/3 (exam* or assess* or sign*)) (Word variations have been searched)

18. (MRI* or CT* or Computed-tomograph* or CAT-scan*) (Word variations have been searched)

19. (x-ray* or xray* or radiograph* or roentgenogra* or imaging) (Word variations have been searched)

20. MeSH descriptor: [Physical Examination] explode all trees

21. MeSH descriptor: [Trauma Severity Indices] explode all trees

22. MeSH descriptor: [Severity of Illness Index] this term only

23. MeSH descriptor: [X-Rays] this term only

24. MeSH descriptor: [Tomography] this term only

25. MeSH descriptor: [Tomography, Emission-Computed] explode all trees

26. MeSH descriptor: [Tomography, X-Ray] explode all trees

27. MeSH descriptor: [Magnetic Resonance Imaging] explode all trees

28. MeSH descriptor: [Radiography] this term only

29. #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24 or #25 or #26 or #27 or #28

30. ((cervical-spine or c-spine) NEAR/5 clear*) (Word variations have been searched)

31. (cervical NEAR/5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)) (Word variations have been searched)

32. (spinal-cord-injury-without-radiographic-abnormalit* or SCIWORA)

33. MeSH descriptor: [Cervical Vertebrae] explode all trees

34. MeSH descriptor: [Neck Injuries] explode all trees

35. MeSH descriptor: [Spinal Injuries] explode all trees

36. MeSH descriptor: [Spinal Cord Injuries] explode all trees

37. #30 or #31 or #32 or #33 or #34 or #35 or #36

38. (perinatal or perinatology or newborn* or new-born* or baby or babies or neonat* or neo-nat* or infan* or toddler* or pre-schooler* or preschooler* or kinder or kinders or kindergarten* or kinder-aged or boy or boys or girl or girls or child or children or childhood or pediatric* or paediatric* or adolescen* or youth or youths or teen or teens or teenage* or school-age* or schoolage* or school-child* or schoolchild* or school-girl* or schoolgirl* or school-boy* or schoolboy* or juvenile* or preteen* or pre-teen*)

39. #29 and #37 and #38

Proquest Dissertations & Theses database

Search 13 December 2022

1. Anywhere except full text

"NEXUS" OR "CCR" OR "National Emergency X Radiography" OR "Canadian c spine" OR "Canadian cervical spine" OR "Clinical pathway*" OR "critical pathway*" OR "treatment pathway*" OR "clinical protocol*" OR "critical protocol*" OR "treatment protocol*" OR "algorithm*" OR "guideline*" OR "decision tree*" OR "decision tool*" OR "decision rule*" OR "decision support" OR "triage" OR "protocol*" OR (("neurolog*" OR "physical*" OR "clinical*") AND ("exam*" OR "assess*" OR "sign" OR "signs")) OR "MRI" OR "MRIs" OR "CT" OR "CTs" OR "Tomograph*" OR "CAT scan*" OR "x-ray*" OR "xray*" OR "radiogra*" OR "roentgenogra*" OR "imaging" OR "trauma severity" OR "severity of illness" OR "Glasgow-coma-scale" OR "injury-severity-score*" OR "injury scale"

AND

2. Anywhere except full text

(("cervical-spine" OR "c-spine") AND "clear") OR "cervical trauma*" OR "cervical injur*" OR "cervical fracture*" OR "cervical sublux*" OR "cervical disloc*" OR "cervical avuls*" OR "cervical instab*" OR "Spinal cord injury without radiographic abnormalit*" OR "SCIWORA" OR "cervical-vertebra*" OR "neck-injur*" OR "spinal-injur*" OR "spinal-trauma" OR "spine-injur*" OR "spine-trauma" OR "spinal-cord-injur*" OR "spinal-cord-trauma" OR "spinal-cord-compression" OR "spinal-fracture*" OR "spine fracture*" OR "whiplash-injur*" OR "whip-lash-injur*"

AND

3. Anywhere except full text

"perinatal" OR "perinatology" OR "newborn*" OR "new-born*" OR "baby" OR "babies" OR "neonat*" OR "neo-nat*" OR "infan*" OR "toddler*" OR "pre-schooler*" OR "preschooler*" OR "kinder" OR "kinders" OR "kindergarten*" OR "kinder-aged" OR "boy" OR "boys" OR "girl" OR "girls" OR "child" OR "children" OR "childhood" OR "pediatric*" OR "paediatric*" OR "adolescen*" OR "youth" OR "youths" OR "teen" OR "teens" OR "teenage*" OR "school-age*" OR "schoolage*" OR "school-child*" OR "schoolchild*" OR "school-girl*" OR "schoolgirl*" OR "school-boy*" OR "schoolboy*" OR "juvenile*" OR "preteen*" OR "pre-teen*"

Limit from 2015

PubMed

Search 13 December 2022

("NEXUS" OR "CCR" OR "National Emergency X Radiography" OR "Canadian c spine" OR "Canadian cervical spine" OR "Clinical pathway*" OR "critical pathway*" OR "treatment pathway*" OR "clinical protocol*" OR "critical protocol*" OR "treatment protocol*" OR "algorithm*" OR "guideline*" OR "decision tree*" OR "decision tool*" OR "decision rule*" OR "decision support" OR "triage" OR "protocol*" OR (("neurolog*" OR "physical*" OR "clinical*") AND ("exam*" OR "assess*" OR "sign" OR "signs")) OR "MRI" OR "MRIs" OR "CT" OR "CTs" OR "Tomograph*" OR "CAT scan*" OR "x-ray*" OR "xray*" OR "radiogra*" OR "roentgenogra*" OR "imaging" OR "trauma severity" OR "severity of illness" OR "Glasgow-coma-scale" OR "injury-severity-score*" OR "injury scale") AND(((("cervical-spine" OR "c-spine") AND "clear") OR "cervical trauma*" OR "cervical injur*" OR "cervical fracture*" OR "cervical sublux*" OR "cervical disloc*" OR "cervical avuls*" OR "cervical instab*" OR "Spinal cord injury without radiographic abnormalit*" OR "SCIWORA" OR "cervical-vertebra*" OR "neck-injur*" OR "spinal-injur*" OR "spinal-trauma" OR "spine-injur*" OR "spine-trauma" OR "spinal-cord-injur*" OR "spinal-cord-trauma" OR "spinal-cord-compression" OR "spinal-fracture*" OR "spine-fracture*" OR "whiplash-injur*" OR "whip-lash-injur*") AND ("perinatal" OR

"perinatology" OR "newborn*" OR "new-born*" OR "baby" OR "babies" OR "neonat*" OR "neo-nat*" OR "infan*" OR "toddler*" OR "pre-schooler*" OR "preschooler*" OR "kinder" OR "kinders" OR "kindergarten*" OR "kinder-aged" OR "boy" OR "boys" OR "girl" OR "girls" OR "child" OR "children" OR "childhood" OR "pediatric*" OR "paediatric*" OR "adolescen*" OR "youth" OR "youths" OR "teen" OR "teens" OR "teenage*" OR "school-age*" OR "schoolage*" OR "school-child*" OR "schoolchild*" OR "school-girl*" OR "schoolgirl*" OR "school-boy*" OR "schoolboy*" OR "juvenile*" OR "preteen*" OR "pre-teen*") AND (NOTNLM OR publisher[sb] OR inprocess[sb] OR pubmednotmedline[sb] OR indatareview[sb] OR pubstatusaheadofprint)

Limited to English; 2015-

OpenGrey

Search 15 December 2022

(NEXUS OR CCR OR "National Emergency X Radiography" OR "Canadian c spine" OR "Canadian cervical spine" OR Clinical-pathway* OR critical-pathway* OR treatment-pathway* OR clinical-protocol* OR critical-protocol* OR treatment-protocol* OR algorithm* OR guideline* OR decision-tree* OR decision-tool* OR decision-rule* OR decision-support OR triage OR protocol* OR ((neurolog* OR physical* OR clinical*) AND (exam* OR assess* OR sign OR signs)) OR MRI OR MRIs OR CT OR CTs OR Tomograph* OR CAT-scan* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging OR trauma-severity OR severity-of-illness OR Glasgow-coma-scale OR injury-severity-score* OR injury-scale) AND(((cervical-spine OR c-spine) AND clear) OR cervical-trauma* OR cervical-injur* OR cervical-fracture* OR cervical-sublux* OR cervical-disloc* OR cervical-avuls* OR cervical-instab* OR Spinal-cord-injury-without-radiographic-abnormalit* OR SCIWORA OR cervical-vertebra* OR neck-injur* OR spinal-injur* OR spinal-trauma OR spine-injur* OR spine-trauma OR spinal-cord-injur* OR spinal-cord-trauma OR spinal-cord-compression OR spinal-fracture* OR spine-fracture* OR whiplash-injur* OR whip-lash-injur*)

Limit to English

Limit from 2015

ClinicalTrials.gov

Search 14 December 2022

Condition or disease

SCIWORA OR ((Cervical OR c-spine OR spinal OR neck OR spine OR whiplash OR whip-lash) AND (trauma OR sublux OR dislocat* OR avuls* OR instab* OR injur* OR abnormalit* OR compression OR fracture*))

AND

Other terms

NEXUS OR CCR OR "National Emergency X Radiography" OR "Canadian c spine" OR "Canadian cervical spine" OR pathway* OR protocol* OR algorithm* OR guideline* OR decision OR triage

Science Citation Index (Web of Science, Core Collection)

Search 15 December 2022

#1 TS=(NEXUS OR CCR OR National-Emergency-X-Radiography OR Canadian-c-spine OR Canadian-cervical-spine OR Clinical-pathway* OR critical-pathway* OR treatment-pathway* OR clinical-protocol* OR critical-protocol* OR treatment-protocol* OR algorithm* OR guideline* OR decision-tree* OR decision-tool* OR decision-rule* OR decision-support OR triage OR protocol* OR MRI OR MRIs OR CT OR CTs OR Tomograph* OR CAT-scan* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging OR trauma-severity OR severity-of-illness OR Glasgow-coma-scale OR injury-severity-score* OR injury-scale)

#2 TS=((neurolog* OR physical* OR clinical*) AND (exam* OR assess* OR sign OR signs))

#3 #1 OR #2

#4 TS=((cervical-spine OR c-spine) AND clear*)

#5 TS=(cervical-trauma* OR cervical-injur* OR cervical-fracture* OR cervical-sublux* OR cervical-disloc* OR cervical-avuls* OR cervical-instab* OR Spinal-cord-injury-without-radiographic-abnormalit* OR SCIWORA OR cervical-vertebra* OR neck-injur* OR spinal-injur* OR spinal-trauma OR spine-injur* OR spine-trauma OR spinal-cord-injur* OR spinal-cord-trauma OR spinal-cord-compression OR spinal-fracture* OR spine-fracture* OR whiplash-injur* OR whip-lash-injur*)

#6 #4 OR #5

#7 TS=(perinatal OR perinatology OR newborn* OR new-born* OR baby OR babies OR neonat* OR neo-nat* OR infan* OR toddler* OR pre-schooler* OR preschooler* OR kinder OR kinders OR kindergarten* OR kinder-aged OR boy OR boys OR girl OR girls OR child OR children OR childhood OR pediatric* OR paediatric* OR adolescen* OR youth OR youths OR teen OR teens OR teenage* OR school-age* OR schoolage* OR school-child* OR schoolchild* OR school-girl* OR schoolgirl* OR school-boy* OR schoolboy* OR juvenile* OR preteen* OR pre-teen*)

#8 #3 AND #6 AND #7

Limited to English; 2015-

WHO International Clinical Trials Registry Platform (ICTRP)

Search 15 December 2022

(NEXUS OR National Emergency X-Radiography OR Canadian c-spine OR Canadian Cervical Spine) AND (cervical fracture OR cervical injury OR cervical trauma ORR cervical dislocation OR cervical instability OR cervical avulsion)

Appendix 2. Search strategies – original review

MEDLINE

Search 24 February 2015

1 (NEXUS or CCR).mp. (5678)

2 National Emergency X-Radiography.mp. (48)

3 (Canadian c-spine or Canadian cervical spine).mp. (40)

4 ((Clinical or critical or treatment) adj3 (pathway* or protocol*)).mp. (52575)

5 (algorithm* or guideline*).mp. (488839)

6 (decision adj3 (tree* or rule* or tool*)).mp. (15657)

7 (triage or protocol*).mp. (366206)

8 or/1-7 [Triage tool keywords] (856300)

9 exp Guideline/ (25808)

10 Guideline Adherence/ (21997)

11 exp guidelines as topic/ (117788)

12 exp algorithms/ (181301)

13 exp Clinical Protocols/ [includes antineoplastic protocols] (127941)

14 Decision Trees/ (8964)

15 exp decision support techniques/ [includes data interpretation, statistical] (61776)

16 Critical Pathways/ (4775)

17 triage/ (8242)

18 or/9-17 [Triage tool MeSH terms] (522506)

19 8 or 18 [Triage tools] (907178)

20 ((neurolog* or physical* or clinical*) adj3 (exam* or assess* or sign*)).mp. (384485)

21 MRI*.mp. (359278)

22 (CT* or Computed Tomography or CAT scan*).mp. (384167)

23 (X ray* or x-ray* or xray* or radiogra* or roentgenogra*).mp. (734670)

24 Imaging.mp. (660363)

25 or/20-24 [Reference standard keywords] (1748610)

26 exp physical examination/ or exp neurologic examination/ (1075565)

27 exp trauma severity indices/ [includes Glasgow Coma Scale, Injury Severity Score, others] (24531)

28 "Severity of Illness Index"/ [not exploded - leave out Karnofsky Performance Status - cancer ADL measure] (173516)

29 X-Rays/ (16413)

30 Tomography/ or exp Tomography, Emission-Computed/ or exp Tomography, X-Ray/ [includes tomography, x-ray computed] (386295)

31 exp Magnetic Resonance Imaging/ (317050)

32 Radiography/ (24883)

33 or/26-32 [Reference standard MeSH terms] (1874249)

34 25 or 33 [Reference standard] (2858529)

35 19 or 34 [Triage tools or reference standard] (3572718)

36 ((Cervical spine or c-spine) adj5 clear*).mp. (241)

37 (cervical adj5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)).mp. [cervical spine injury, cervical spine trauma] (10352)

38 (Spinal cord injury without radiographic abnormality or SCIWORA).mp. (113)

39 or/36-38 [cervical trauma keywords] (10494)

40 exp Cervical Vertebrae/ [includes axis and atlas] (30752)

41 exp Neck Injuries/ [includes whiplash injuries] (6628)

42 exp Spinal Injuries/ [includes spinal fractures] (17863)

43 exp Spinal Cord Injuries/ [includes spinal cord compression, others] (38273)

44 spinal fractures/ (10537)

45 or/40-44 [cervical trauma MeSH terms] (81875)

46 39 or 45 [cervical trauma terms] (84419)

47 (Pediatric* or paediatric* or peadiatric*).mp. (239652)

48 (Child*).mp. (1864223)

49 (neonate* or newborn* or new-born*).mp. (639758)

50 (infant* or baby or babies or toddler*).mp. (1042256)

51 (adolescen* or juvenile* or youth* or teen* or preteen*).mp. (1709977)

52 or/47-51 [pediatric keywords] (3315420)

53 exp Pediatrics/ [includes perinataology, neonatology] (44737)

54 exp Child/ [includes child, preschool] (1562070)

55 exp Infant/ [includes infant, newborn] (946461)

56 Adolescent/ (1632349)

57 or/53-56 [pediatric MeSH terms] (2910260)

58 52 or 57 [Pediatric terms] (3316163)

59 35 and 46 and 58 (7985)

*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier]

MEDLINE In-Process & Other Non-Indexed Citations

Search 24 February 2015

1 (NEXUS or CCR).mp. (492)

2 National Emergency X-Radiography.mp. (3)

3 (Canadian c-spine or Canadian cervical spine).mp. (13)

4 ((Clinical or critical or treatment) adj3 (pathway* or protocol*)).mp. (3193)

5 (algorithm* or guideline*).mp. (49484)

6 (decision adj3 (tree* or rule* or tool*)).mp. (1156)

7 (triage or protocol*).mp. (29444)

8 or/1-7 [Triage tool keywords] (79262)

9 exp Guideline/ or / (62)

10 Guideline Adherence/ (0)

11 exp guidelines as topic/ / (0)

12 exp algorithms/ (0)

13 exp Clinical Protocols/ [includes antineoplastic protocols] (0)

14 Decision Trees/ (0)

15 exp decision support techniques/ [includes data interpretation, statistical] (0)

16 Critical Pathways/ (0)

17 triage/ (0)

18 or/9-17 [Triage tool MeSH terms] (62)

19 8 or 18 [Triage tools] (79262)

20 ((neurolog* or physical* or clinical*) adj3 (exam* or assess* or sign*)).mp. (30580)

21 MRI*.mp. (24133)

22 (CT* or Computed Tomography or CAT scan*).mp. (39230)

23 (X ray* or x-ray* or xray* or radiogra* or roentgenogra*).mp. (62975)

24 Imaging.mp. (61152)

25 or/20-24 [Reference standard keywords] (175595)

26 exp physical examination/ or exp neurologic examination/ (0)

27 exp trauma severity indices/ [includes Glasgow Coma Scale, Injury Severity Score, others] (0)

28 "Severity of Illness Index"/ [not exploded - leave out Karnofsky Performance Status - cancer ADL measure] (0)

29 X-Rays/ (0)

30 Tomography/ or exp Tomography, Emission-Computed/ or exp Tomography, X-Ray/ [includes tomography, x-ray computed] (0)

31 exp Magnetic Resonance Imaging/ (0)

32 Radiography/ (0)

33 or/26-32 [Reference standard MeSH terms] (0)

34 25 or 33 [Reference standard] (175595)

35 19 or 34 [Triage tools or reference standard] (244188)

36 ((Cervical spine or c-spine) adj5 clear*).mp. (20)

37 (cervical adj5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)).mp. [cervical spine injury, cervical spine trauma] (833)

38 (Spinal cord injury without radiographic abnormality or SCIWORA).mp. (10)

39 or/36-38 [cervical trauma keywords] (848)

40 exp Cervical Vertebrae/ [includes axis and atlas] (0)

41 exp Neck Injuries/ [includes whiplash injuries] (0)

42 exp Spinal Injuries/ [includes spinal fractures] (0)

43 exp Spinal Cord Injuries/ [includes spinal cord compression, others] (0)

44 spinal fractures/ (0)

45 or/40-44 [cervial trauma MeSH terms] (0)

46 39 or 45 [cervical trauma terms] (848)

47 (Pediatric* or paediatric* or peadiatric*).mp. (20264)

48 (Child*).mp. (67273)

49 (neonate* or newborn* or new-born*).mp. (9578)

50 (infant* or baby or babies or toddler*).mp. (19120)

51 (adolescen* or juvenile* or youth* or teen* or preteen*).mp. (24018)

52 or/47-51 [pediatric keywords] (106495)

53 exp Pediatrics/ [includes perinataology, neonatology] (0)

54 exp Child/ [includes child, preschool] (0)

55 exp Infant/ [includes infant, newborn] (0)

56 Adolescent/ (0)

57 or/53-56 [pediatric MeSH terms] (0)

58 52 or 57 [Pediatric terms] (106495)

59 35 and 46 and 58 (39)

Embase

Search 24 February 2015

1 (NEXUS or CCR).mp. (7884)

2 National Emergency X-Radiography.mp. (59)

3 (Canadian c-spine or Canadian cervical spine).mp. (74)

4 ((Clinical or critical or treatment) adj3 (pathway* or protocol*)).mp. (116085)

5 (algorithm* or guideline*).mp. (665390)

6 (decision adj3 (tree* or rule* or tool*)).mp. (16747)

7 (triage or protocol*).mp. (426356)

8 or/1-7 (1087993)

9 practice guideline/ or clinical pathway/ or clinical protocol/ (315692)

10 exp algorithm/ (188334)

11 "decision tree"/ (6358)

12 exp decision support system/ (14055)

13 emergency health service/ [used for triage] (69092)

14 or/9-13 (575274)

15 8 or 14 (1149485)

16 ((neurolog* or physical* or clinical*) adj3 (exam* or assess* or sign*)).mp. (779457)

17 MRI*.mp. (587063)

18 (CT* or Computed Tomography or CAT scan*).mp. (600538)

19 (X ray* or x-ray* or xray* or radiogra* or roentgenogra*).mp. (876246)

20 Imaging.mp. (1064732)

21 or/16-20 (2762608)

22 exp physical examination/ (160790)

23 exp neurologic examination/ (350398)

24 exp injury scale/ [used for trauma severity indices] (29378)

25 X ray/ (41737)

26 exp tomography/ (728786)

27 exp computer assisted tomography/ (636166)

28 exp nuclear magnetic resonance imaging/ (576997)

29 exp radiography/ (897201)

30 or/22-29 (2073134)

31 21 or 30 (3328617)

32 15 or 31 (4251928)

33 ((Cervical spine or c-spine) adj5 clear*).mp. (344)

34 (cervical adj5 (trauma* or injur* or fracture* or sublux* or dislocat* or avuls* or instab*)).mp. (17235)

35 (Spinal cord injury without radiographic abnormality or SCIWORA).mp. (181)

36 or/33-35 (17402)

37 exp cervical spine/ (27701)

38 exp neck injury/ (10805)

39 exp spine injury/ (30879)

40 exp spinal cord injury/ (54289)

41 exp spine fracture/ (15827)

42 or/37-41 (112517)

43 36 or 42 (115463)

44 (Pediatric* or paediatric* or peadiatric*).mp. (389216)

45 (Child or children or childhood).mp. (2006835)

46 (neonate* or newborn* or new-born*).mp. (567587)

47 (infant* or baby or babies or toddler*).mp. (778286)

48 (adolescen* or juvenile* or youth* or teen* or preteen*).mp. (1399956)

49 or/44-48 (3309713)

50 exp pediatrics/ (77383)

51 exp child/ (2059816)

52 exp infant/ (857030)

53 exp adolescent/ (1253833)

54 exp juvenile/ (2715056)

55 exp adolescence/ (66747)

56 exp childhood/ (50991)

57 exp childhood injury/ (7203)

58 or/50-57 (2785218)

59 49 or 58 (3349155)

60 32 and 43 and 59 (9187)

CENTRAL

Search 24 February 2015

#1 NEXUS or CCR 783

#2 National Emergency X-Radiography 2

#3 Canadian c-spine or Canadian cervical spine 59

#4 ((Clinical or critical or treatment) near/3 (pathway* or protocol*)) 8326

#5 algorithm* or guideline* 24279

#6 (decision near/3 (tree* or rule* or tool*)) 2370

#7 triage or protocol* 56538

#8 #1 or #2 or #3 or #4 or #5 or #6 or #7 76450

#9 MeSH descriptor: [Guideline] explode all trees 19

#10 MeSH descriptor: [Practice Guideline] 15

#11 MeSH descriptor: [Guideline Adherence] 739

#12 MeSH descriptor: [Guidelines as Topic] explode all trees 2078

#13 MeSH descriptor: [Practice Guidelines as Topic] 1770

#14 MeSH descriptor: [Algorithms] explode all trees 3040

#15 MeSH descriptor: [Clinical Protocols] explode all trees 13095

#16 MeSH descriptor: [Decision Trees] 895

#17 MeSH descriptor: [Decision Support Techniques] explode all trees 3202

#18 MeSH descriptor: [Critical Pathways] 262

#19 MeSH descriptor: [Triage] 258

#20 #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 22374

#21 #8 or #20 78691

#22 ((neurolog* or physical* or clinical*) near/3 (exam* or assess* or sign*)) 45542

#23 MRI* 11288

#24 CT* or Computed Tomography or CAT scan 56407

#25 X ray* or x-ray* or xray* or radiogra* or roentgenogra* 23437

#26 Imaging 21622

#27 #22 or #23 or #24 or #25 or #26 123319

#28 MeSH descriptor: [Physical Examination] explode all trees 72073

#29 MeSH descriptor: [Neurologic Examination] explode all trees 16982

#30 MeSH descriptor: [Trauma Severity Indices] explode all trees 993

#31 MeSH descriptor: [Severity of Illness Index] this term only 14375

#32 MeSH descriptor: [X-Rays] 44

#33 MeSH descriptor: [Tomography] explode all trees 11885

#34 MeSH descriptor: [Tomography, Emission-Computed] explode all trees 2630

#35 MeSH descriptor: [Tomography, X-Ray] explode all trees 4107

#36 MeSH descriptor: [Magnetic Resonance Imaging] explode all trees 5716

#37 MeSH descriptor: [Radiography] explode all trees 13863

#38 #28 or #29 or #30 or #31 or #32 or #33 or #34 or #35 or #36 or #37 103001

#39 #27 or #38 199647

#40 #21 or #39 253140

#41 ((Cervical spine or c-spine) near/5 clear*) 10

#42 (cervical near/5 (trauma* or injur* or fracture* or sublux* or dislocat*or avuls* or instab*)) 472

#43 Spinal cord injury without radiographic abnormality or SCIWORA 2

#44 #41 or #42 or #43 474

#45 MeSH descriptor: [Cervical Vertebrae] explode all trees 776

#46 MeSH descriptor: [Neck Injuries] explode all trees 205

#47 MeSH descriptor: [Spinal Injuries] explode all trees 720

#48 MeSH descriptor: [Spinal Cord Injuries] explode all trees 906

#49 MeSH descriptor: [Spinal Fractures] explode all trees 636

#50 #45 or #46 or #47 or #48 or #49 2442

#51 #44 or #50 2730

#52 Pediatric* or paediatric* or peadiatric* 41377

#53 Child or children or childhood 94858

#54 neonate* or newborn* or new-born* 19365

#55 infant* or baby or babies or toddler* 41412

#56 adolescen* or juvenile* or youth* or teen* or preteen* 98728

#57 #52 or #53 or #54 or #55 or #56 176411

#58 MeSH descriptor: [Pediatrics] explode all trees 546

#59 MeSH descriptor: [Child] explode all trees 135

#60 MeSH descriptor: [Infant] explode all trees 13304

#61 MeSH descriptor: [Adolescent] 76925

#62 #58 or #59 or #60 or #61 89391

#63 #57 or #62 176421

#64 40 and 51 and 63 4201

#65 #64 in Trials 651

Science Citation Index

Search 24 February 2015

4 1,220 #3 AND #2 AND #1

Indexes=SCI-EXPANDED Timespan=All years

3 1,508,937

TOPIC: (Pediatric* OR paediatric* OR peadiatric* OR Child OR children OR childhood OR neonate* OR newborn* OR new-born* OR infant* OR baby OR babies OR toddler* OR adolescen* OR juvenile* OR youth* OR teen* OR preteen*)

Indexes=SCI-EXPANDED Timespan=All years

2 19,789

TS=(cervical spine clear* OR c-spine clear* OR clearing the c-spine OR clearing the cervical spine OR cervical trauma* OR cervical injur* OR cervical fracture* OR cervical sublux* OR cervical disloc* OR cervical avuls* OR cervical instab* OR Spinal cord injury without radiographic abnormality OR SCIWORA)

Indexes=SCI-EXPANDED Timespan=All years

1 4,736,061

TS=(NEXUS OR CCR OR National Emergency X-Radiography OR Canadian c-spine OR Canadian cervical spine OR Clinical pathway* OR critical pathway* OR treatment pathway* OR clinical protocol* OR treatment protocol* OR algorithm* OR guideline* OR decision tree* OR decision tool* OR decision rule* OR triage OR protocol* OR neurolog* assess* OR neurolog* exam* OR neurolog* sign* OR physical* exam* OR physical* assess* OR physical* sign* OR clinical* exam* OR clinical* assess* OR clinical* sign* OR MRI* OR CT OR Computed Tomography OR CAT scan* OR X ray* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging)

Indexes=SCI-EXPANDED Timespan=All years

Proquest Dissertations & Theses database

Search 24 February 2015

Advanced search :

all(((NEXUS OR CCR OR National Emergency X-Radiography OR Canadian c-spine OR Canadian cervical spine OR Clinical pathway* OR critical pathway* OR treatment pathway* OR clinical protocol* OR treatment protocol* OR algorithm* OR guideline* OR decision tree* OR decision tool* OR decision rule* OR triage OR protocol* OR neurolog* assess* OR neurolog* exam* OR neurolog* sign* OR physical* exam* OR physical* assess* OR physical* sign* OR clinical* exam* OR clinical* assess* OR clinical* sign* OR MRI* OR CT* OR Computed Tomography OR CAT scan*OR X ray* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging) AND (cervical spine clear* OR c-spine clear* OR clearing the c-spine OR clearing the cervical spine OR cervical trauma* OR cervical injur* OR cervical fracture* OR cervical sublux* OR cervical disloc* OR cervical avuls* OR cervical instab* OR Spinal cord injury without radiographic abnormality OR SCIWORA) AND (Pediatric* OR paediatric* OR peadiatric* OR Child OR children OR childhood OR neonate* OR newborn* OR new-born* OR infant* OR baby OR babies OR toddler* OR adolescen* OR juvenile* OR youth* OR teen* OR preteen*)))

Additional limits - Source type: Conference Papers & Proceedings, Dissertations & Theses

PubMed

Search 24 February 2015. This search contained population terms.

((NEXUS OR CCR OR National Emergency X-Radiography OR Canadian c-spine OR Canadian cervical spine OR Clinical pathway* OR critical pathway* OR treatment pathway* OR clinical protocol* OR treatment protocol* OR algorithm* OR guideline* OR decision tree* OR decision tool* OR decision rule* OR triage OR protocol* OR neurolog* assess* OR neurolog* exam* OR neurolog* sign* OR physical* exam* OR physical* assess* OR physical* sign* OR clinical* exam* OR clinical* assess* OR clinical* sign* OR MRI* OR CT* OR Computed Tomography OR CAT scan*OR X ray* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging) **AND** (cervical spine clear* OR c-spine clear* OR clearing the c-spine OR clearing the cervical spine OR cervical trauma* OR cervical injur* OR cervical fracture* OR cervical sublux* OR cervical disloc* OR cervical avuls* OR cervical instab* OR Spinal cord injury without radiographic abnormality or SCIWORA) **AND** (Pediatric* OR paediatric* OR peadiatric* OR Child OR children OR childhood OR neonate* OR newborn* OR new-born* OR infant* OR baby OR babies OR toddler* OR adolescen* OR juvenile* OR youth* OR teen* OR preteen*) **AND** (pubstatusaheadofprint OR publisher[sb] or pubmednotmedline[sb]))

Searched 5 March 2015. This search did not contain population terms.

((NEXUS OR CCR OR National Emergency X-Radiography OR Canadian c-spine OR Canadian cervical spine OR Clinical pathway* OR critical pathway* OR treatment pathway* OR clinical protocol* OR treatment protocol* OR algorithm* OR guideline* OR decision tree* OR decision tool* OR decision rule* OR triage OR protocol* OR neurolog* assess* OR neurolog* exam* OR neurolog* sign* OR physical* exam* OR physical* assess* OR physical* sign* OR clinical* exam* OR clinical* assess* OR clinical* sign* OR MRI* OR CT* OR Computed Tomography OR CAT scan*OR X ray* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging) AND (cervical spine clear* OR c-spine clear* OR clearing the c-spine OR clearing the cervical spine OR cervical trauma* OR cervical injur* OR cervical fracture* OR cervical sublux* OR cervical disloc* OR cervical avuls* OR cervical instab* OR Spinal cord injury without radiographic abnormality or SCIWORA) AND (pubstatusaheadofprint OR publisher[sb] or pubmednotmedline[sb]))

OpenGrey

Search 24 February 2015

((NEXUS OR CCR OR National Emergency X-Radiography OR Canadian c-spine OR Canadian cervical spine OR Clinical pathway* OR critical pathway* OR treatment pathway* OR clinical protocol* OR treatment protocol* OR algorithm* OR guideline* OR decision tree* OR decision tool* OR decision rule* OR triage OR protocol* OR neurolog* assess* OR neurolog* exam* OR neurolog* sign* OR physical* exam* OR physical* assess* OR physical* sign* OR clinical* exam* OR clinical* assess* OR clinical* sign* OR MRI* OR CT* OR Computed Tomography OR CAT scan*OR X ray* OR x-ray* OR xray* OR radiogra* OR roentgenogra* OR imaging) AND (cervical spine clear* OR c-spine clear* OR clearing the c-spine OR clearing the cervical spine OR cervical trauma* OR cervical injur* OR cervical fracture* OR cervical sublux* OR cervical disloc* OR cervical avuls* OR cervical instab* OR Spinal cord injury without radiographic abnormality OR SCIWORA))

ClinicalTrials.gov

Search 24 February 2015

((cervical spine OR c-spine) AND (fracture OR injury OR trauma OR avulsion OR dislocation OR instability) AND (NEXUS OR "National Emergency X-Radiography" OR "Canadian c-spine" OR clearing OR clearance OR decision OR algorithm OR pathway OR triage))

ICTRP

Search 24 February 2015

(NEXUS OR National Emergency X-Radiography OR Canadian c-spine OR Canadian Cervical Spine) AND (cervical fracture OR cervical injury OR cervical trauma OR cervical dislocation OR cervical instability OR cervical avulsion)

CDSR, DARE, HTA

Searched 25 February 2015

clearance:ti,ab,kw or cervical spine

ARIF

Search 24 February 2015

Advanced search, all indexed fields: Clearance or cervical spine

DTA Trials Register

Searched 10 March 2015

We received the following report from the information specialist of the Renal group:

"There are no studies relating to your review in the DTAS Register. I used keywords from your review title plus other broader target condition words e.g. spinal injur* spinal trauma, head injur* etc. I found only 3 studies, all of which were in adults only, and which were using radiological modalities to screen for blunt trauma injuries, including cervical arteries. I also used the test names you mentioned, but did not retrieve anything."

Medion

Searched October 2013

ICPC code = Musculoskeletal OR Neurological

And

Abstract = clearance or “cervical spine”

WHAT'S NEW

Date	Event	Description
22 March 2024	New search has been performed	We performed a search update on 13 December 2022 to identify new studies. Inclusion criteria have been expanded to include studies that evaluate the diagnostic accuracy of any clinical decision rule or clinical criteria for the evaluation of cervical spine injury in children; previously only studies that evaluated the diagnostic accuracy of NEXUS and Canadian C-spine rule were included. The previous version of the review had reference standards of radiographic imaging or clinical follow-up if the index test score was negative or if children did not undergo radiographic imaging. Clinical follow-up was considered to be part of the initial trauma evaluation in the emergency department during the first 72 hours. In this updated review, we also included studies where the cervical spine was clinically cleared in the emergency department by the treating clinician. For children who did not undergo imaging, we preferred to include studies where children were followed up some time after discharge to ensure no cervical spine injuries were missed. We added to the patient selection domain an additional signalling question to check if the data were collected prospectively as retrospective data are prone to selective and incomplete recording.

Date	Event	Description
22 March 2024	New citation required and conclusions have changed	Review update includes five studies: one study included in the previous review; one study excluded from the previous review and now included due to expanded eligibility criteria; and three new studies identified in the updated search. Two studies are awaiting classification, with authors contacted for further eligibility information, and we identified two ongoing studies.

HISTORY

Protocol first published: Issue 5, 2015
Review first published: Issue 12, 2017

CONTRIBUTIONS OF AUTHORS

- Designing the review update: ET, NE, NP, FB
- Co-ordinating the review: ET, NE
- Updating search strategies and undertaking search: Medical Librarian, RCH, Melbourne
- Screening updated search results: ET, VR, NE, JW
- Screening retrieved papers against inclusion criteria: ET, VR, JW, NE
- Appraising quality of papers: ET, NE
- Extracting data from papers: ET, NE
- Writing to authors of papers for additional information: NE
- Obtaining and screening data on unpublished studies: ET, NE
- Data management for the review: ET, NE
- Entering data into Review Manager 5: ET, NE
- Analysis of data: JW, ET, NE
- Interpretation of data: ET, JW, NE
- Providing a methodological perspective: ET, JW, NE
- Providing a clinical perspective: FB, NP
- Writing the review: ET, NE, NP, FB

DECLARATIONS OF INTEREST

ET: none.

NE: none.

NP: is an author on one of the included studies but was not involved in the screening of papers and data extraction (Phillips 2021).

JW: none.

VR: none.

FB: is an author on one of the included studies but was not involved in the screening of papers and data extraction (Phillips 2021).

SOURCES OF SUPPORT

Internal sources

- Murdoch Children's Research Institute, Australia

  Infrastructure support
- Royal Children's Hospital Foundation, Australia

  Review author support (FB)

External sources

- National Health and Medical Research Council, Australia

  Centre of Research Excellence grant for Paediatric Emergency Medicine (GNT1058560)

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

We made the following changes from the protocol (Slaar 2015).

We planned to meta-analyse the sensitivity and specificity of the tools with a bivariate model. However, we identified only five studies that met the inclusion criteria, and the outcomes of the studies were too diverse for us to perform meta-analyses in this review. For the same reason, an analysis of heterogeneity could not be completed.

We did not anticipate in the protocol that we would encounter studies with mixed populations (adults and children) in which we could not extract the data for both groups ourselves. When this occurred during the review process, we attempted to contact the authors to obtain these data.

For this update, the inclusion criteria for studies was expanded to include all clinical decision rules rather than just NEXUS and the Canadian C-Spine Rule and weaker study designs (case-control studies) were excluded.

INDEX TERMS

Medical Subject Headings (MeSH)

Cervical Vertebrae [diagnostic imaging] [*injuries]; Checklist; Cohort Studies; *Decision Support Techniques; Magnetic Resonance Imaging; Radiography; Reference Standards; Spinal Injuries [*diagnosis] [diagnostic imaging] [etiology]; Tomography, X-Ray Computed; Triage [*methods]; Wounds, Nonpenetrating [*complications] [diagnostic imaging]

MeSH check words

Child; Humans