Triage tools for detecting cervical spine injury in pediatric trauma patients

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[Diagnostic Test Accuracy Review]

Triage tools for detecting cervical spine injury in pediatric trauma patients

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ABSTRACT

Background

Pediatric cervical spine injury (CSI) after blunt trauma is rare. Nonetheless, missing these injuries can have severe consequences. To prevent the overuse of radiographic imaging, two clinical decision tools have been developed: The National Emergency X-Radiography Utilization Study (NEXUS) criteria and the Canadian C-spine Rule (CCR). Both tools are proven to be accurate in deciding whether or not diagnostic imaging is needed in adults presenting for blunt trauma screening at the emergency department. However, little information is known about the accuracy of these triage tools in a pediatric population.

Objectives

To determine the diagnostic accuracy of the NEXUS criteria and the Canadian C-spine Rule in a pediatric population evaluated for CSI following blunt trauma.

Search methods

We searched the following databases to 24 February 2015: CENTRAL, MEDLINE, MEDLINE Non-Indexed and In-Process Citations, PubMed, Embase, Science Citation Index, ProQuest Dissertations & Theses Database, OpenGrey, ClinicalTrials.gov, World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP), Cochrane Database of Systematic Reviews, the Database of Abstracts of Reviews of Effects, the Health Technology Assessment, and the Aggressive Research Intelligence Facility.

Selection criteria

We included all retrospective and prospective studies involving children following blunt trauma that evaluated the accuracy of the NEXUS criteria, the Canadian C-spine Rule, or both. Plain radiography, computed tomography (CT) or magnetic resonance imaging (MRI) of the cervical spine, and follow-up were considered as adequate reference standards.

Data collection and analysis

Two review authors independently assessed the quality of included studies using the QUADAS-2 checklists. They extracted data on study design, patient characteristics, inclusion and exclusion criteria, clinical parameters, target condition, reference standard, and the

diagnostic two-by-two table. We calculated and plotted sensitivity, specificity and negative predictive value in ROC space, and constructed forest plots for visual examination of variation in test accuracy.

Main results

Three cohort studies were eligible for analysis, including 3380 patients ; 96 children were diagnosed with CSI. One study evaluated the accuracy of the Canadian C-spine Rule and the NEXUS criteria, and two studies evaluated the accuracy of the NEXUS criteria. The studies were of moderate quality. Due to the small number of included studies and the diverse outcomes of those studies, we could not describe a pooled estimate for the diagnostic test accuracy. The sensitivity of the NEXUS criteria of the individual studies was 0.57 (95% confidence interval (CI) 0.18 to 0.90), 0.98 (95% CI 0.91 to 1.00) and 1.00 (95% CI 0.88 to 1.00). The specificity of the NEXUS criteria was 0.35 (95% CI 0.25 to 0.45), 0.54 (95% CI 0.45 to 0.62) and 0.2 (95% CI 0.18 to 0.21). For the Canadian C-spine Rule the sensitivity was 0.86 (95% CI 0.42 to 1.00) and specificity was 0.15 (95% CI 0.08 to 0.23). Since the quantity of the data was small we were not able to investigate heterogeneity.

Authors' conclusions

There are currently few studies assessing the diagnostic test accuracy of the NEXUS criteria and CCR in children. At the moment, there is not enough evidence to determine the accuracy of the Canadian C-spine Rule to detect CSI in pediatric trauma patients following blunt trauma. The confidence interval of the sensitivity of the NEXUS criteria between the individual studies showed a wide range, with a lower limit varying from 0.18 to 0.91 with a total of four false negative test results, meaning that if physicians use the NEXUS criteria in children, there is a chance of missing CSI. Since missing CSI could have severe consequences with the risk of significant morbidity, we consider that the NEXUS criteria are at best a guide to clinical assessment, with current evidence not supporting strict or protocolized adoption of the tool into pediatric trauma care. Moreover, we have to keep in mind that the sensitivity differs among several studies, and individual confidence intervals of these studies show a wide range. Our main conclusion is therefore that additional well-designed studies with large sample sizes are required to better evaluate the accuracy of the NEXUS criteria or the Canadian C-spine Rule, or both, in order to determine whether they are appropriate triage tools for the clearance of the cervical spine in children following blunt trauma.

PLAIN LANGUAGE SUMMARY

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

Background and Rationale

The cervical spine is the upper part of the spine between the head and shoulders (the neck). The incidence of traumatic cervical spine injury (CSI) in children is very low. However it is very important not to miss this type of injury. To detect CSI, several types of scan imaging techniques can be used (computed tomography (CT) scan, magnetic resonance imaging (MRI) and plain radiography (x-ray)). CT scan and x-ray use radiation that can lead to an increased risk in the development of cancer, especially in children. We therefore need to use plain radiography or CT scan in children only if really necessary. To avoid unnecessary use of those radiographic imaging techniques, it is important to look for clinical tests that can detect whether children are at risk for cervical spine injury and if radiographic imaging needs to be done.

Index tests

The NEXUS criteria and Canadian C-spine Rules are tools that doctors use to decide whether adults are at risk for cervical spine injury and whether they need to use radiographic imaging. These tools are already being used in children, but little information is known about how accurate they are in children. The goal of this review was therefore to evaluate whether these tools can also be used safely and effectively in children.

Study characteristics

We searched medical literature databases to identify studies which tested how well both decision tools can establish whether children are at risk for CSI after blunt trauma. We performed the search in February 2015.

Quality of the evidence

We identified three studies of moderate to good quality. All studies tested the accuracy of the NEXUS criteria, and one of them also tested the accuracy of the Canadian C-spine Rules.

Key results:

Since only one study looked at the accuracy of the Canadian C-spine Rules, there is not enough evidence at the moment to determine whether the Canadian C-spine Rules can be used safely in children. The sensitivity and specificity of the NEXUS criteria varied among the three studies, meaning that there is a chance of false-negative test results when using the NEXUS criteria, and as a result there is a chance of missing cervical spine injury if doctors only rely on the NEXUS criteria. We therefore consider that the NEXUS criteria are at best a guide to clinical assessment, with current evidence not supporting strict or protocolized adoption of the tool into pediatric trauma care. The

conclusion of our review is that we need more research to evaluate the accuracy of the NEXUS criteria and the Canadian C-spine rules for routine use in children.

SUMMARY OF FINDINGS

Summary of findings 1. New Summary of findings table

Triage tools for detecting cervical spine injury in pediatric trauma patients				
Population	**Children evaluated for CSI following blunt trauma**			
Setting	**Emergency Departments**			
Index test	**NEXUS criteria, Canadian C-spine Rule (CCR)**			
Reference standard	**Plain radiography, CT scan, and or MRI of the cervical spine, or follow-up without imaging**			
Target Condition	Cervical Spine Injury			
Included studies	Cohort studies (3) -1 direct comparison between CCR and NEXUS. -2 indirect evaluations of the NEXUS criteria.			
Studies	**Accuracy (95%CI)**	**Number of participants**	**CSI prevalence**	**Quality (QUADAS-2)**
Jaffe 1987	**NEXUS criteria** Sensitivity: 0.98 (0.91 to 1.00) Specificity: 0.54 (0.45 to 0.62) Positive LR*: 2.13 Negative LR: 0.03	206	59 (28.6%)	High risk of bias, low concerns of applicability**
Ehrlich 2009	**NEXUS criteria** Sensitivity: 0.57 (0.18 to 0.9) Specificity: 0.35 (0.25 to 0.45) Positive LR: 0.87 Negative LR: 1.24	108	7 (6.5%)	Low risk of bias. No applicability concerns
	Canadian C-spine Rule Sensitivity: 0.86 (0.42 to 1.0) Specificity: 0.15 (0.08 to 0.23) Positive LR: 1.00 Negative LR: 0.97	109	7 (6.4%)	
Viccellio 2001	**NEXUS criteria** Sensitivity: 1.00 (0.88 to 1.0) Specificity: 0.2 (0.18 to 0.21) Positive LR: 1.25 Negative LR: 0.081	3065	30 (0.98%)	Low risk of bias. No applicability concerns

*LR=Likelihood ratio
**High risk of bias based on inclusion of not only a consecutive group of children evaluated for the presence of CSI, but also an alternative group of children already diagnosed with CSI.

BACKGROUND

Target condition being diagnosed

Pediatric cervical spine injury (CSI) after blunt trauma is rare, accounting for only 1% to 2% in children presenting at the emergency department for blunt trauma evaluation (Patel 2001; Viccellio 2001). Nonetheless, every physician should be concerned about missing these injuries because they can have severe consequences, such as death (up to 40%) or life-changing neurological damage (up to 60%) (Cirak 2004; Givens 1996; Hutchings 2009; Kokoska 2001; Parent 2011; Patel 2001; Platzer 2007). In 5% to 10% of cases where CSI is missed, patients experience worsening of neurological symptoms (Ravichandran 1982; Schuster 2005). These adverse sequelae depend primarily on the anatomical level of injury and the presence of dislocation (Partrick 2000), whereby CSI of the upper cervical spine is associated with higher morbidity and mortality than CSI of the lower cervical spine (Leonard 2014).

Children aged under eight display different patterns of injury than children aged between eight and 18 years (Viccellio 2001). This is because younger children have unique anatomic features, such as a relatively larger head, immature neck musculature, horizontally-articulating facet joints, and ligamentous laxity (Kokoska 2001). Consequently, injury at the cranio-cervical junction and upper cervical spine is seen more frequently in younger children (Cirak 2004; Orenstein 1994; Sun 2000). The same applies to ligamentous injury (Dickman 1989; Dormans 1995; Hadley 1988; Hamilton 1992; Osenbach 1992). CSI in children aged eight and older is comparable to blunt trauma patterns in adults (Hill 1984). In this age group, subaxial injuries are most common (Leonard 2014).

Several blunt trauma mechanisms can cause CSI. In children of all ages, falls and motor vehicle crashes account for a large proportion (Leonard 2011; Patel 2001). In younger children, pedestrian and inflicted injuries are seen more often. Older children sustain more injury due to sports-related and recreational activities (Brown 2001; Garton 2008; Hasler 2012; Leonard 2011).

Symptoms of CSI that have been reported are neck pain, torticollis, altered mental status, sensory loss, motor loss and respiratory arrest (Leonard 2013). In children it may be difficult to discriminate between general discomfort and actual complaints due to blunt trauma.

Multiple imaging modalities are available to the physician to diagnose or rule out CSI:

- Plain radiography is usually performed to detect pediatric CSI, since this technique is portable, readily available, and has a relatively low radiation dosage (Booth 2012). As the sensitivity for detecting bony CSI is greater than 90%, plain radiographs are considered adequate for the screening of alert patients who show no abnormalities on neurological examination (Mower 2001; Nigrovic 2012).
- Computed tomography (CT) is superior to plain radiography in detecting cervical spine fractures, with a sensitivity of nearly 100% for detecting bony CSI (Schenarts 2001). However, it is associated with a 90- to 200-fold increased radiation dose and subsequently a higher risk of developing thyroid cancer (Booth 2012; Jimenez 2008). The routine use of CT of the neck is therefore not recommended (NICE 2014). CT has a sensitivity of 23% and a specificity of 100% in detecting soft-tissue injury in children (Henry 2013), but the yield of positive, clinically-significant findings on CT of cervical spine injuries in children under five years old is low (Hernandez 2004).
- Magnetic resonance imaging (MRI) is an imaging modality that uses a magnetic field and radio waves instead of ionizing radiation. Compared to plain radiographs and CT, it detects a larger proportion of soft-tissue abnormalities when performed within 48 hours of injury (Benzel 1996; Keiper 1998). The properties of MRI might therefore suggest a larger role in blunt trauma evaluation of young children (Bagley 2006), but its role in screening after blunt trauma has not been widely explored, as it comprises multiple limitations (availability, time, costs), and the clinical significance of the injuries is sometimes unclear (Booth 2012).

If plain radiography or CT, or both, are used in every patient, the amount of unnecessary imaging and associated radiation exposure will rise to unacceptable levels. Especially in children, excessive radiation exposure can lead to an elevated lifetime risk of developing cancer, primarily thyroid cancer (Jimenez 2008; Pearce 2012; Ron 2002). Unnecessary imaging will also lead to a rise in healthcare costs. To justify the use of diagnostic imaging, it is necessary to know when - and especially when not - to obtain radiographic imaging in children after blunt trauma, without the risk of missing injuries.

The type of CSI that occurs most often in children aged under two years is atlanto-occipital dislocation. In children aged two to seven years, atlanto-axial rotatory subluxation and atlanto-occipital dislocation occur most frequently. Among children aged eight to 15, subaxial vertebral body fractures are most common (Leonard 2013; Leonard 2014). Spinal cord injury is more frequent in the younger age groups (Leonard 2014).

Spinal cord injury without radiographic abnormalities (SCIWORA) on plain radiography or CT accounts for 4% to 66% of all spinal cord injuries in children (Pang 1982; Pang 2004; Trigylidas 2010; Yucesoy 2008). In younger children, falls and pedestrian motor vehicle accidents are the most common cause of SCIWORA. In older children, sports-related injuries are more common (Mortazavi 2011).

If radiographic imaging detects CSI, the therapeutic options for children depend on the type of injury, but might include fixating the cervical spine with a rigid or soft collar, brace, halo-frame, or by internal fixation (Mortazavi 2011). Corticosteroids are sometimes given, but this practice remains controversial (Bracken 1990; Leonard 2013; Leonard 2014).

Outcomes for patients differ according to the type of injury. Children with axial injury are nearly five times more likely to die than children with injuries in the subaxial region (23% versus 4%, respectively) (Patel 2001).

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 anywhere from six to 45 years, depending on the anatomical level of injury and the degree of spinal cord involvement (NSCISC 2012).

In the long term, people who suffer CSI can develop two types of progressive spinal deformity; (1) paralytic scoliosis, which

develops in 40% to 97% of children following spinal cord injury; and (2) cervical kyphosis secondary to laminectomy (although laminectomy after trauma is seldom necessary) (Seal 2005).

Due to prolonged hospital stay, the large number of treatments and associated long-term assistance, severe pediatric CSI is associated with very high medical, psychological, and societal costs (Vogel 2002a; Vogel 2002b; Vogel 2002c).

Index test(s)

The tools under evaluation are the NEXUS criteria and the Canadian C-spine Rule (Viccellio 2001, as reported by Hoffman 2000; Stiell 2001). Both tools are designed to decide whether or not diagnostic imaging is needed to prove or rule out any type of CSI in adult trauma patients. There is notably little information about the accuracy of these two tools in children. Currently the Trauma Association of Canada (Chung 2011), the guidelines of the Congress of Neurological Surgeons (Rozzelle 2013), and the National Institute for Health and Care Excellence (NICE) criteria recommend the use of a combination of these tools for the clearance of the cervical spine in children (NICE 2014).

Both tools consist of multiple scoring items. The NEXUS criteria observe only clinical parameters, while the Canadian C-spine Rule takes the trauma mechanism into account.

Both tools divide the population into high-risk and low-risk patients, where only the high-risk patients (positive index test) need further evaluation by radiographic imaging (see Figure 1: Viccellio 2001; Stiell 2003; and Figure 2: Stiell 2003; Stiell 2001). A negative index test (low-risk patients) means that the person is at low risk for CSI and therefore subsequent radiographic imaging is not necessary, with only clinical follow-up warranted.

Figure 1. NEXUS Criteria, Viccellio 2001 (from Hoffman 2000 paper); Stiell 2003

The NEXUS Low-Risk Criteria
Cervical-spine radiography is indicated for patients with trauma unless the meet all of the following criteria:
No posterior midline cervical-spine tenderness,*
No evidence of intoxication, **
A normal level of alertness, ***
No focal neurologic deficit, **** and
No painful distracting injuries. *****

*Midline posterior bony cervical-spine tenderness is present if the patient reports pain on palpation of the posterior midline neck from the nuchal ridge to the prominence of the first thoracic vertebra, or if the patients evinces pain with direct palpation of any cervical spinous process.

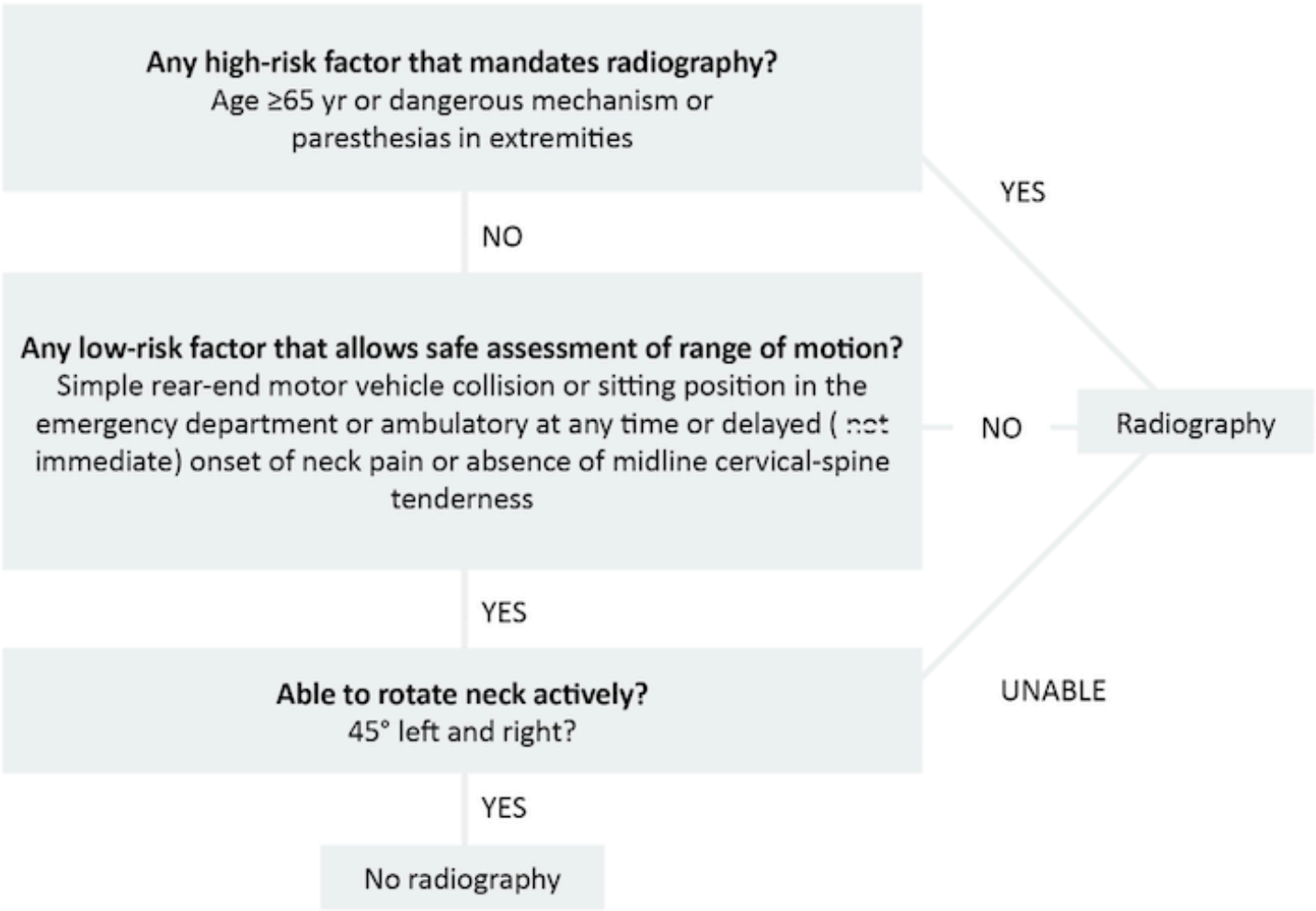
* * Patients should be considered intoxicated if they have either of the following: a recent history provided by the patient or an observer of intoxication or intoxicating ingestion, or evidence of intoxication on physical examination such as an odor of alcohol, slurred speech, ataxia, dysmetria, or other cerebellar findings, or any behavior consistent with intoxication. Patients may also be considered to be intoxicated if tests of bodily secretions are positive for alcohol or drugs that affect the level of alertness.

* * * An altered level of alertness can include any of the following: a Glascow Coma Scale score of 14 or less; disorientation to person, place, time, or event; an inability to remember three objects at five minutes; a delayed or inappropriate response to external stimuli; or other findings.

* * * * A focal neurological deficit is any focal neurologic finding on motor or sensory examination.

* * * * * No precise definition of a painful distracting injury is possible. This category includes any condition thought by the clinician to be producing pain sufficient to distract the patient from a second (neck) injury. Such injuries may include, but are not limited to, any long-bone fracture; a visceral injury requiring surgical consultation; a large laceration, degloving injury, or crush injury; large burns; or any other injury causing acute functional impairment. Physicians may also classify any injury as distracting if it is thought to have the potential to impair the patient's ability to appreciated their injuries.

Figure 2. Canadian C-Spine Rules Stiell 2003; Stiell 2001



For patients with trauma who are alert (as indicated by a score of 15 on the Glascow Coma Scale) and in stable condition and in whom cervical-spine injury is a concern, the determination of risk factors guides the use of cervical spine radiography. A dangerous trauma mechanism is considered to be a fall from an elevation > 3ft or 5 stairs; an axial load to the head (e.g., diving); a motor vehicle collision at high speed (>100km/hr) or with rollover or ejection; a collision involving a motorized recreational vehicle; or a bicycle collision. A simple rear-end motor vehicle collision excludes being pushed into oncoming traffic, being hit by a bus or a large truck, a rollover, and being hit by a high-speeds vehicle.

The low-risk criteria of the NEXUS tool are:

- no posterior midline cervical tenderness

- no evidence of intoxication
- the patient is alert and oriented to person, place, time, and event
- no focal neurological deficit
- no painful distracting injuries (e.g. long-bone fracture)

The high-risk criteria of the Canadian C-spine Rule are:

- age > 65 years
- dangerous trauma mechanism
- paraesthesia in extremities

The low-risk criteria of the Canadian C-spine Rule are:

- simple rear-end motor vehicle crash
- sitting in emergency department
- ambulatory at any time
- delayed onset of neck pain
- absent midline C-spine tenderness
- able to actively rotate neck 45° left and right

The NEXUS criteria were developed in an almost entirely adult population. The study group consisted of 34,069 participants, of which 2.5% were eight years old or younger. In the participants with CSI, 1.3% were eight years old or younger (Ehrlich 2009; Viccellio 2001). The Canadian C-spine Rule included no pediatric patients (Ehrlich 2009; Stiell 2001).

For the development of both decision tools, plain radiography was used as the reference standard, unless a CT scan or MRI of the neck was performed because plain radiography was impractical or impossible (Viccellio 2001; Stiell 2001).

The role of the index test is to estimate whether a child is at high risk for CSI in order to determine whether or not further imaging is necessary. Application of the index test should prevent unnecessary radiographic imaging, thus limiting the amount of radiation exposure and healthcare costs. But most importantly, the main goal of the index tests is not to miss CSI.

Clinical pathway

In general, when children present at the emergency department following blunt trauma, they undergo trauma work-up according to Advanced Trauma Life Support (ATLS 2013) or the Advanced Pediatric Life Support (APLS). One of the goals of the trauma work-up is to identify possible CSI. Clinicians therefore perform a series of anamnestic and physical tests to decide whether or not radiographic imaging of the cervical spine is necessary to rule out or define CSI. In most cases a trauma surgeon, a pediatric surgeon, or an emergency physician makes this decision.

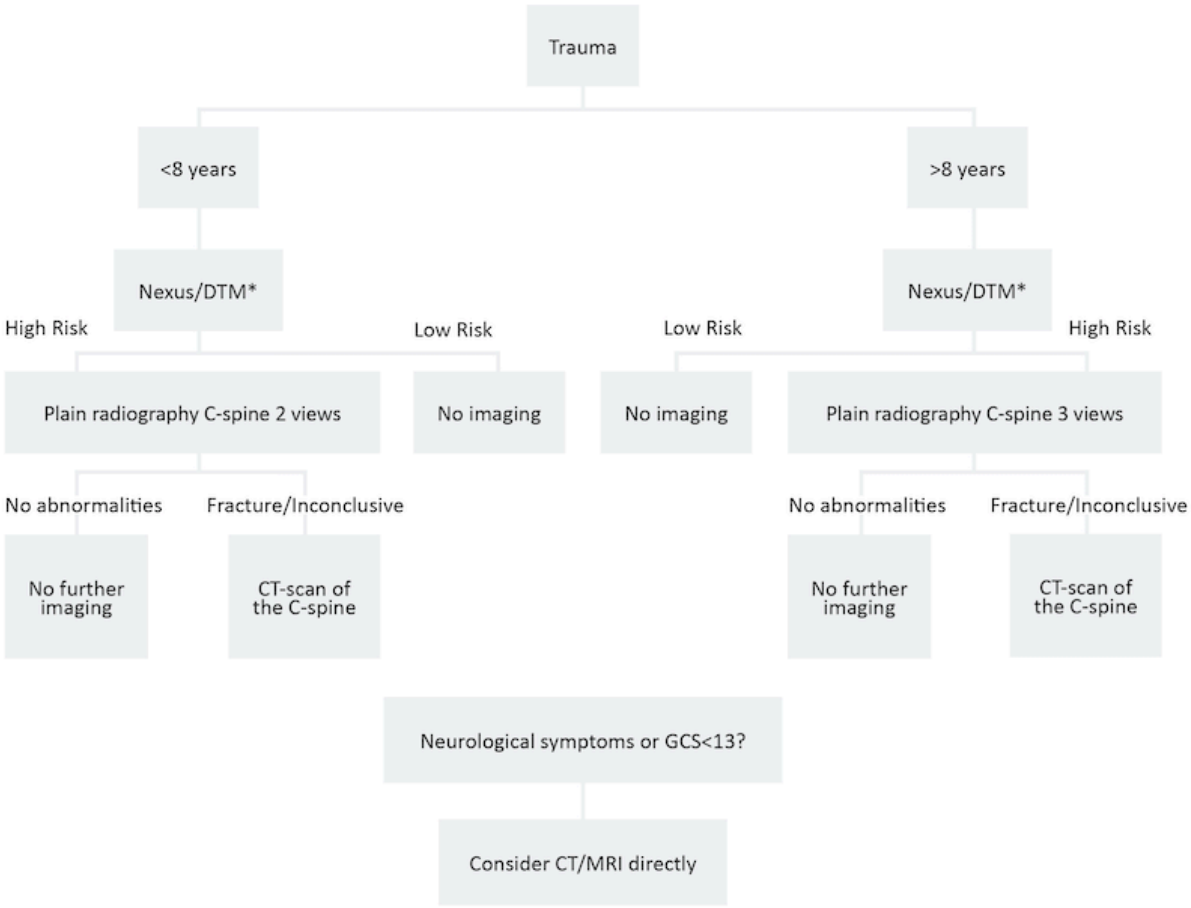
The most commonly-used tools for identifying patients eligible for imaging are the NEXUS criteria and the Canadian C-spine Rule. Both tools divide the population into high-risk and low-risk patients, where only the high-risk patients need further evaluation by radiographic imaging.

If no cervical spine injury is suspected based on clinical findings using one of these decision tools, the neck collar (if worn) can be removed and after clinical follow-up the cervical spine is cleared. However, if cervical spine injury is suspected, radiographic imaging is needed to rule out or define CSI.

The first-choice imaging modality in children is plain radiography of the cervical spine. A lateral view and an anteroposterior view are performed in all age groups; from nine years old an odontoid radiograph (open-mouth view) is also obtained. Under the age of nine, the open-mouth view provides no additional information beyond that found on anteroposterior and lateral views (Buhs 2000).

Several guidelines advise performing a CT scan of the cervical spine if the patient has neurological symptoms, the patient is intubated, or the Glasgow Coma Scale is less than 13 at initial assessment (Chung 2011; NICE 2014; Rozzelle 2013). They also advise a CT scan if plain radiography is technically difficult or inadequate, if bony injury is seen at plain radiography, or if there is a strong clinical suspicion of injury despite normal radiographs. MRI of the cervical spine is recommended in patients in whom plain radiography or CT scans are equivocal, or when neurological or ligamentous injury is suspected (NICE 2014). For a flowchart of the clinical pathway, see Figure 3.

Figure 3. Flow chart clinical practice



Role of index test(s)

So far, little information is known about the applicability of the NEXUS criteria and the Canadian C-spine Rule in children. However, using one or both tools is already the standard of care in many centres for trauma evaluation in children (Chung 2011; NICE 2014; Rozzelle 2013). If the NEXUS criteria and the Canadian C-spine Rule are accurate in defining the need for radiographic imaging in children after blunt trauma, unnecessary imaging can be prevented and radiation exposure and healthcare costs can be reduced.

Rationale

Since CSI has severe consequences such as spinal cord injury or death (Cirak 2004; Givens 1996; Hutchings 2009; Kokoska 2001; Parent 2011; Patel 2001; Platzer 2007), identifying these injuries during trauma work-up is of great importance.The main purpose the NEXUS criteria and Canadian C-spine Rule is to help the physician decide whether or not a patient needs radiographic imaging.

Evaluation of the cervical spine in a young patient is challenging. Firstly, young children may not be able to communicate crucial symptoms. The physical examination can be compromised in an anxious, crying, or uncooperative child (Ehrlich 2009). Furthermore, pediatric cervical anatomy differs from that of adults (Cattell 1965; Ehrlich 2009; Fesmire 1989; Kriss 1997; Swischuk 1977; Swischuk 1984).

In conclusion, pediatric cervical spine assessment is different when compared to adults. It is therefore questionable whether these clinical decision tools developed for clearing the cervical spine in an adult population can be applied directly to a pediatric population.

OBJECTIVES

To determine the diagnostic accuracy of the NEXUS criteria and the Canadian C-spine Rule in a pediatric population evaluated for CSI following blunt trauma.

Secondary objectives

We expected to observe heterogeneity in the estimates of diagnostic accuracy. Factors that may contribute to heterogeneous results include:

1. Differences in the healthcare setting and study design; previous studies state that CSI is seen less often in general emergency departments than in pediatric trauma hospitals, and that a CT

of the neck is more common in general emergency departments (Adelgais 2014).

2. Study quality, as assessed by the QUADAS-2 checklist (Whiting 2011).
3. Age-related differences; we expect that both the applicability of the NEXUS criteria and the Canadian C-spine Rule and the type of injury will differ according to age in children younger and older than eight (Leonard 2013; Leonard 2014).

METHODS

Criteria for considering studies for this review

Types of studies

We included studies that compared the accuracy of the NEXUS criteria or the Canadian C-spine Rule, or both, with the reference standard.

We considered diagnostic studies with cross-sectional or cohort designs (retrospective or prospective), and randomized controlled trials. We only included results from full reports.

We preferred to include studies in which plain radiography, CT and MRI of the cervical spine was performed, since the sensitivity and specificity for the detection of ligamentous and skeletal injury differ between those imaging modalities. However, we expected this triple combination to be very rare, due to multiple limitations (radiation consequences, availability, time and costs). We therefore also included studies in which only one of the reference standards was applied. For the same reason we also included studies in which no radiographic imaging was obtained but only clinical follow-up (in case of a negative index test).

We expected that there would be studies in which all patients had undergone the reference standard without the index test being scored positive. We therefore also included studies in which those participants who had a negative result of the index test (no high-risk factors) still underwent one of the reference standards (for example, plain radiography).

We excluded case-control studies because of the bias they might introduce.

We preferred studies that evaluated the accuracy of the NEXUS criteria and the Canadian C-spine Rule in direct comparisons to each other, but we did not exclude studies with indirect comparisons, because we expected the number of studies with direct comparisons to be limited.

Participants

We Included children between the age of 0 and 18 who underwent blunt trauma evaluation in the emergency department. We excluded patients with a history of previous surgery of the cervical spine or congenital cervical spine anomalies, or both.

In case of studies with mixed populations, e.g. that included some participants in the groups and that could not be separated from the eligible participants, we tried to contact the study author to provide the data for the group of interest.

Index tests

The tests under evaluation are the NEXUS criteria and the Canadian C-spine Rule, or tools in which the clinical variables contained four or more elements that are also part of the NEXUS criteria or the Canadian C-spine Rule.

Target conditions

The target condition was clinically-important CSI, defined as any fracture, dislocation, or ligamentous instability detectable by diagnostic imaging.

Reference standards

Radiographic imaging (plain radiography, CT or MRI or both) or clinical follow-up (if the index test was scored negative) were the reference standards. Follow-up was defined as clinical evaluation of the neck after removal of the neck collar (if worn) in the case of low-risk patients. The first clinical follow-up is performed in the emergency room during trauma evaluation. If cervical spine injury is suspected based on the index test, or after the first clinical follow-up, radiographic imaging is needed to rule out or define CSI.

We included patients who underwent an eligible reference standard within 72 hours of presentation at the emergency department following blunt trauma. We also included patients who did not undergo radiographic imaging, but who obtained clinical follow-up directly during trauma evaluation during the first 72 hours.

Search methods for identification of studies

Electronic searches

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.

The Information Specialist of the Cochrane Back and Neck Review Group (CBN) developed the search strategies. Chapter 7 'Searching for Studies' of the *Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy* (De Vet 2008), as well as feedback and guidance from Information Specialists of the Cochrane DTA Working Group and Cochrane Netherlands, were used to guide strategy development and the selection of databases to be searched.

We searched the following databases from inception to 24 February 2015:

- Cochrane Central Register of Controlled Trials (CENTRAL, the Cochrane Library, Issue 1)
- MEDLINE (OvidSP, 1946 to February Week 3 2015)
- MEDLINE Non-Indexed and In-Process Citations (OvidSP, 23 February 2015)
- Embase (OvidSP, 1980 to 2015 Week 08)
- Science Citation Index (Web of Science, Core Collection)
- ProQuest Dissertations & Theses Database for relevant conference proceedings, dissertations, and theses
- PubMed
- OpenGrey for 'grey literature'

We searched PubMed to identify studies not in MEDLINE, using the strategy recommended by Duffy 2014. We also searched ClinicalTrials.gov and the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) for ongoing trials. An Information Specialist from the Cochrane Renal Group searched the Diagnostic Test Accuracy (DTA) Studies Register on 10 March 2015.

We also searched the Cochrane Database of Systematic Reviews (CDSR, Issue 2), the Database of Abstracts of Reviews of Effects (DARE, Issue 1), and the Health Technology Assessment (HTA, Issue 1) databases (through the Cochrane Library); and the Aggressive Research Intelligence Facility (ARIF) database for relevant systematic reviews and health technology assessments on 25 February 2015. We searched The Medion Database October 2013. It was not accessible in February 2015.

The search strategies can be found in Appendix 1. The citations per search engine are shown in Table 1.

Searching other resources

We searched the reference lists of all primary studies and relevant systematic reviews to identify additional studies. There were no language restrictions. Non-English articles were translated.

Data collection and analysis

Selection of studies

Two review authors (AS and MMF) assessed titles and abstracts of the search results provided by the Information Specialist. Two review authors (AS and MMF) independently retrieved all potentially relevant articles in full text and examined them, using an assessment form, and resolving discrepancies by discussion. If there was a difference in coding, we approached a third review author (NWLS) to reach consensus.

Data extraction and management

Two review authors (AS and JW) extracted data separately to a data extraction form, resolving disagreements by consultation with a third review author (NWLS, MM, or RRvR) if necessary. We contacted study authors to provide additional information.

Data collected included:

1. Study ID: year of publication, author
2. Participants: number of children, age, sex, country
3. Inclusion and exclusion criteria
4. Study design: consecutive/random, retrospectively/prospectively
5. Clinical parameters: trauma mechanism, clinical pathway
6. Target condition: cervical spine injury
7. Reference standard: clinical follow-up, plain radiography, CT scan, MRI
8. Results: numerical data from a two-by-two table. If no two-by-two tables were available, we extracted data from the text. If there was a difference between the sensitivity or specificity, or both, between table and text, we used the numbers provided in the text.

Assessment of methodological quality

Two review authors (AS and MMF) independently assessed methodological quality in duplicate, using QUADAS-2 (Whiting 2003; Whiting 2011; Table 2; Table 3) . We resolved any disagreements in a consensus meeting, involving a third review author when necessary.

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, 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 to clarify.

We planned to perform meta-analyses of sensitivity and specificity employing a bivariate logistic normal model using a hierarchical approach (Reitsma 2005). This approach enabled 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 plotted sensitivities and specificities in forest plots and in ROC space.

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

We planned to do test comparison by adding covariates for different types of index tests into the bivariate model and testing the significance (significance level = 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 evaluate 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 use all the evidence available. We planned to compare them qualitatively if data were insufficient for comparison by statistical test. Verification bias is to be expected, since we enable the use of different types of reference standards in test-positive (plain radiography, CT scan, or MRI) and test-negative (clinical follow-up). All the statistical analyses were performed with Review Manager 5 (Review Manager 2014)

Investigations of heterogeneity

We were unable to formally explore heterogeneity, due to a lack of studies. Should there be sufficient data available we used forest plots and sensitivities and specificities plotted in ROC space for visual examination of heterogeneity between studies. We also added covariates, for example age groups (less than eight years old versus eight and older) and QUADAS-2 items to bivariate model to investigate the heterogeneity between studies in the meta-analysis (Whiting 2011). We could investigate heterogeneity only if there were a sufficient number of studies providing adequate information on the factor of interest.

Sensitivity analyses

Verification bias is the most important form of bias that we expected to encounter, because we evaluated four different types

of reference standards. We could not conduct sensitivity analyses because we retrieved too few studies.

Assessment of reporting bias

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

RESULTS

Results of the search

We identified 14,730 citations. The number of citations by search engine is shown in Table 1. We checked the references of relevant reviews and primary diagnostic studies. After initial title and abstract screening, we retrieved 98 full-text papers, of which we considered five to be eligible for the review. Two papers reported on the same cohort with pediatric data only extractable from one of the papers, which we used as the primary data source (Viccellio 2001). We excluded Hoffman 1992, an unrelated study, as only a small number of children were included and the authors did not separate out the data for the pediatric population. We therefore include three studies (five papers) in the meta-analysis: one was a cohort study with a prospective design (Viccellio 2001) and two were cohort studies with retrospective designs (Ehrlich 2009; Jaffe 1987). There were no disagreements between the review authors on studies eligible for the review. There were no ongoing studies identified and no studies are awaiting classification.

Figure 4 shows the summary of the search, including the reason for excluding papers. Exclusion mainly concerned studies with a different index test (n = 45) and studies with a different study population (n = 26). The latter was explained by the fact that most of these studies were conducted in adults (n = 18).

Figure 4. Study flow diagram.

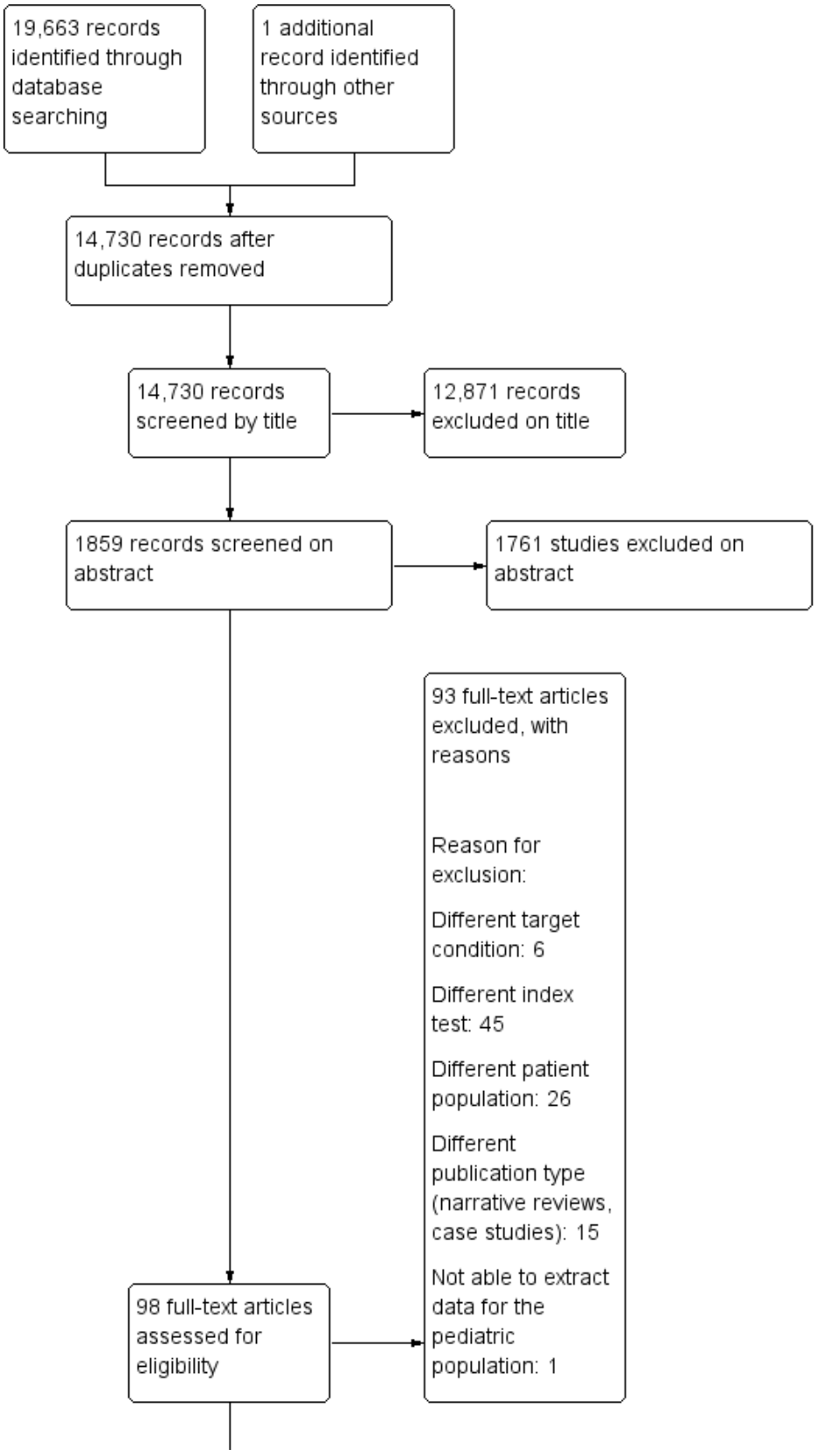
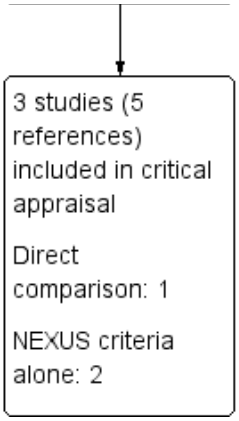


Figure 4. (Continued)

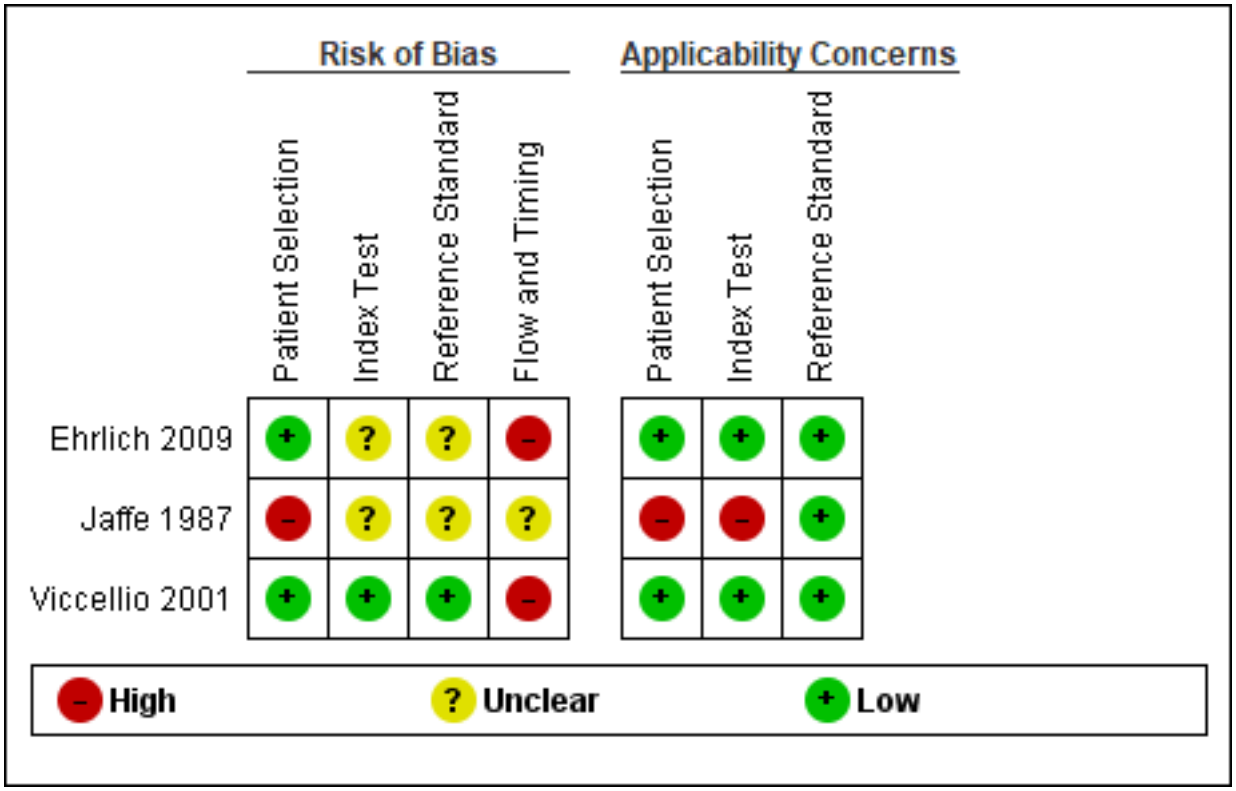


We provide details on the design, setting, population, reference standard and definition of the target condition in the Characteristics of included studies table. Details of the excluded studies are shown in the Characteristics of excluded studies table.

Methodological quality of included studies

The results of the quality assessment for three included studies are presented in Figure 5.

Figure 5. Risk of bias and applicability concerns summary: review authors' judgements about each domain for each included study



We rated two studies as being at low risk of concern for applicability in all domains (Ehrlich 2009; Viccellio 2001). We judged one study to be at high risk of bias and high concern for applicability in the domain of the index test (Jaffe 1987). This was because this study was a derivation study and did not evaluate the NEXUS criteria or the Canadian C-spine Rule; however, the index test of this study contained many items that are also part of the NEXUS criteria. We also rated Jaffe 1987 at high risk of bias in the domains of 'patient selection' and 'flow and timing'. This was based on them not including a consecutive group of patients, but using a second cohort to increase the number of patients with CSI. We judged the study as being at unclear risk of bias in the domain 'index test and reference standard', because it was not clear whether the reference standard results were interpreted without knowledge of the results of the index test and vice versa. We also judged it as being at

unclear risk of bias, since it was a derivation study and therefore no threshold was described for the index test.

Ehrlich 2009 poorly described whether the index test results were interpreted without knowledge of the results of the reference standard, and we therefore rated the domain of the reference standard and index test as being at unclear risk of bias. Ehrlich 2009 also used different types of reference standards, with patients excluded for no clear reason; we therefore rated the domain 'flow and timing' as being at high risk of bias. However, for this review we have only focused on the cohort that was used for analysing the accuracy of the NEXUS and Canadian C-spine Rule, and this cohort only used one type of reference standard.

In Viccellio 2001 plain radiography and sometimes a CT scan were obtained as the primary imaging modality, so we judged this study to be at high risk of bias in the domain 'flow and timing'.

None of the studies thoroughly explained the interval between the index test and reference standard, but all three studies took place in the emergency department and confirmed that radiographic imaging was conducted there. The interval was therefore less than one day in all studies.

The review authors (AS and MMF) disagreed on only two items of the QUADAS-2 criteria in three studies (Whiting 2011). All disagreements were resolved during consensus meetings.

Findings

We evaluated three studies (Ehrlich 2009; Jaffe 1987; Viccellio 2001) which included 3380 children, for the presence of CSI by using the NEXUS criteria or the Canadian C-spine Rule. The overall incidence of CSI in these three studies was 2.8%.

The three studies described four patient cohorts. In total 3379 children were evaluated for CSI by applying the NEXUS criteria, and 109 children were evaluated for CSI by applying the Canadian C-spine Rule. Around one-third of the patients included in the studies were younger than eight years old. Ninety-six children were diagnosed with CSI, with 10% to 20% of them aged less than eight.

In Ehrlich 2009, all included children where younger than 10 years old, but a further division by age was not provided. Jaffe 1987 made a distinction between children aged up to three and those aged four to 12 years, so we do not know the exact number of children aged under eight.

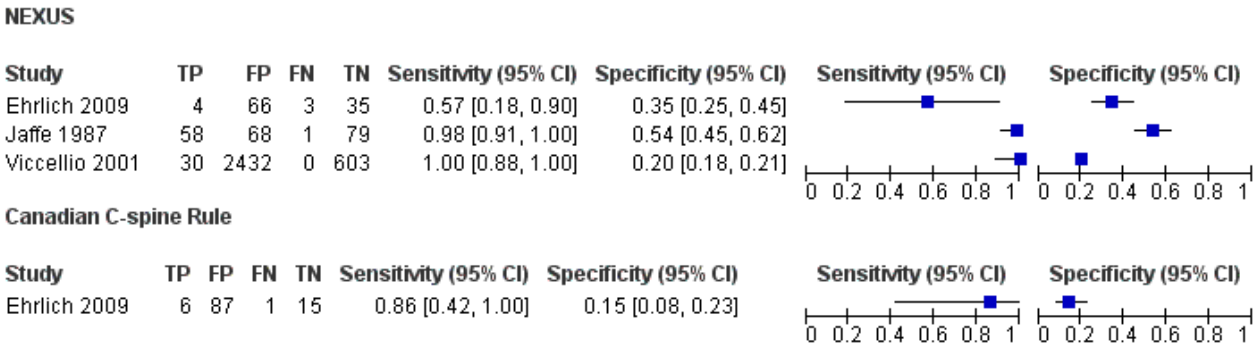
Jaffe 1987 was a derivation study to develop a clinical decision tool for the clearance of the cervical spine. They included an extra set of patients to increase the amount of those with CSI. The index test criteria differed from the NEXUS criteria, but the items that were analysed were almost the same as the NEXUS criteria, and we therefore included this study in the analysis. Plain radiography was obtained for all children as the primary imaging modality.

Viccellio 2001 evaluated the NEXUS criteria in 3065 children. As well as plain radiography, a CT was also obtained as the primary imaging modality in some of these children. The number of children for whom a CT was obtained was not clear.

Ehrlich 2009 was the only study that tested the accuracy of the Canadian C-spine Rule in a direct comparison to the NEXUS criteria. The other two studies did not test the accuracy of the Canadian C-spine Rule (Jaffe 1987; Viccellio 2001). The sensitivity and specificity presented by Ehrlich 2009 were not the same when we did our own calculations with the numbers provided in the text. We contacted the authors to invite them to explain the differences between the numbers provided in the text and the sensitivity and specificity that they had calculated, but did not receive a response. We therefore produced our own two-by-two table using the numbers provided in the text.

Since the number of eligible studies was fewer than four, and since the outcomes of those studies were too diverse, we did not conduct a meta-analysis and therefore present no summary estimates in this review. Instead, we interpret sensitivity and specificity from each primary study separately. Since there were few data, we were unable to investigate heterogeneity. We summarize the extracted data in the forest plots presented in Figure 6 and in Summary of findings 1.

Figure 6. Forest plot of the NEXUS criteria and Canadian C-spine Rule.

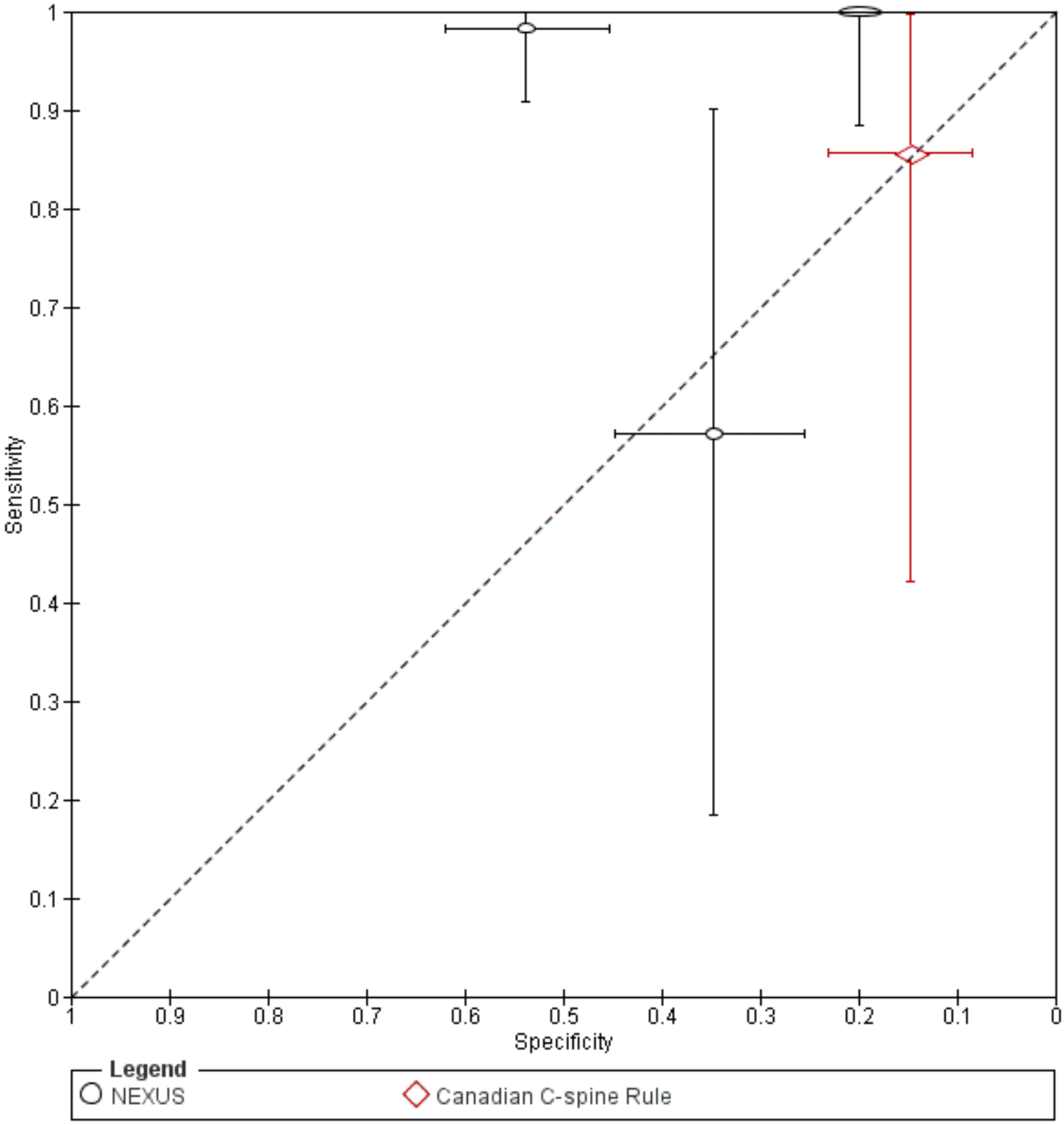


The sensitivity of the NEXUS criteria in the studies was 0.57 (95% CI 0.18 to 0.90) (Ehrlich 2009), 0.98 (95% CI 0.91 to 1.00) (Jaffe 1987) and 1.00 (95% CI 0.88 to 1.00) (Viccellio 2001). The specificity of the NEXUS criteria varied in the studies and was 0.35 (95% CI 0.25 to 0.45) (Ehrlich 2009), 0.54 (95% CI 0.45 to 0.62) (Jaffe 1987) and 0.2 (95% CI 0.18 to 0.21) (Viccellio 2001). For the Canadian C-spine Rule,

the sensitivity was 0.86 (95% CI 0.42 to 1.00) and specificity was 0.15 (95% CI 0.08 to 0.23) (Ehrlich 2009).

The positive and negative predictive values and the positive and negative likelihood ratios for the individual studies are summarized in Figure 6; and Summary of findings 1. The test accuracy of both tests in individual studies is shown in Figure 7.

Figure 7. Summary ROC Plot of tests: 1 NEXUS, 2 Canadian C-spine Rule.



Verification bias was to be expected, since plain radiography and a CT scan were used as reference standards in Viccellio 2001. We could not perform sensitivity analyses because there were too few studies.

DISCUSSION

Summary of main results

This review evaluates the accuracy of the NEXUS criteria and Canadian C-spine Rule in children following blunt trauma.

Although the quality of the included studies that assessed the accuracy of the NEXUS criteria or the Canadian C-spine Rule or both was moderate, results are only based on three studies. Due to the limited number of studies and the fact that the heterogeneity between the three studies was significant (as seen in Figure 6 and Figure 7), we could not conduct a meta-analysis.

The incidence of CSI in the included studies was 2.8%. A possible explanation is the non-consecutive group of patients included in Jaffe 1987. Although the incidence of CSI is higher than in previous literature (Patel 2001), it is still very low, meaning that to properly evaluate the accuracy of the NEXUS criteria and the Canadian C-spine Rule we need a large sample size. The total sample size of the included studies in this review was 3380, of which 3065 patients were from Viccellio 2001.

Ehrlich 2009 was the only study that evaluated the accuracy of the Canadian C-spine Rule in a pediatric population. When we recalculated the sensitivity and specificity reported in the text with the numbers provided, we did not obtain the same results; this undermines the reliability of the sensitivity of the Canadian C-spine Rule reported in this study. Since this study was the only one evaluating the Canadian C-spine Rule, we cannot verify the diagnostic accuracy of the Canadian C-spine Rule in a pediatric population. There is therefore too little information to say that the Canadian C-spine Rule can be used safely for the clearance of cervical spine injury in children following blunt trauma.

The sensitivity of the NEXUS criteria was relatively high in two of the studies (Jaffe 1987; Viccellio 2001). Jaffe 1987 was a derivation study to develop a clinical decision tool, which might have led to a higher sensitivity in this study. They also enriched their cohort with children with CSI, which may have led to a sensitivity that is not representative of the population. The other study was a validation study of the NEXUS criteria (Viccellio 2001). This study included the highest number of children and showed a sensitivity of 1.00 (95% CI 0.88 to 1.00). The third study showed a lower sensitivity of 0.57 (95% CI 0.18 to 0.9) (Ehrlich 2009). In this study patients were referred for radiographic imaging if they met one of the high-risk criteria included in the NEXUS tool. By applying these criteria, seven patients were diagnosed with CSI using plain radiography. However, after re-evaluation using the NEXUS criteria on the same cohort, the authors stated that three fractures would have been missed. This is likely to lead to an underestimation of the accuracy of the NEXUS criteria in this study.

The confidence intervals of the sensitivity in the studies showed a wide range, with a lower limit varying from 0.18 to 0.91. This implies that if physicians use the NEXUS criteria in children, there is a chance of missing CSI. Moreover, they have to keep in mind that the sensitivity differs amongst several studies. Since missing CSI could have severe consequences with the risk of significant morbidity, we consider that the NEXUS criteria are at best a guide to clinical assessment as current evidence does not support strict or protocolized adoption of the tool into pediatric trauma care (Cirak 2004; Givens 1996; Hutchings 2009; Kokoska 2001; Parent 2011; Patel 2001; Platzer 2007).

The confidence interval of the specificity of the studies of both the NEXUS criteria and the Canadian C-spine Rule did not show as wide a range as the confidence interval for sensitivity. The confidence interval of the specificity had a lower limit varying from 0.08 to 0.45. The specificity of all studies varied from 0.2 to 0.54. This means that when the NEXUS criteria or the Canadian C-spine Rule are applied in pediatric trauma patients, one of the effects will be that, in several children, radiographic imaging will be obtained without showing CSI. However the aim of these triage tools is to reduce the chance of missing CSI, so the sensitivity needs to be high, which indirectly leads to a low specificity.

Strengths and weaknesses of the review

This is the first systematic review on the accuracy of the NEXUS criteria and the Canadian C-spine Rule in children.

One of the strengths of this review is that we performed an extensive search in a large number of databases. We selected articles by using clear inclusion and exclusion criteria. Another strength of this review is 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 small number of studies were eligible for inclusion. We therefore could not conduct sensitivity analyses or formally investigate potential sources of heterogeneity. We excluded Hoffman 1992 after we contacted the authors of the study for pediatric data. They explained that they did not complete a detailed examination of the pediatric population in that cohort, because the derivation study had only a small number of children. For this reason, we do not think that excluding this study has a significant effect on the results of this review.

Only one study tested the accuracy of the Canadian C-spine Rule by direct comparison to the NEXUS criteria (Ehrlich 2009); the other two studies did not evaluate the accuracy of the Canadian C-spine Rule. We therefore cannot state whether the NEXUS or the Canadian C-spine Rule is a better tool to decide if imaging is indicated to detect CSI in children following blunt trauma. Also, the numbers provided in this study for the sensitivity and the specificity of the tools were not correct (Ehrlich 2009), and since this was the only study that evaluated the accuracy of the Canadian C-spine Rule there is not enough evidence to determine its accuracy in children. Another limitation is that one study developed an algorithm with items that are also included in the NEXUS criteria. However, this algorithm did not contain all items of the NEXUS criteria.

Another weakness of this review is that the results are based on only a few children diagnosed with CSI, although the incidence was higher than in previous literature (Patel 2001). A larger sample size would be desirable to better evaluate the accuracy of the two triage tools, which should indirectly lead to a higher number of events (patients with CSI).

In this review we have only focused on two decision tools that determine whether children following blunt trauma need to be referred for radiography. In the last two decades, several institutional decision tools have been developed to evaluate the need for referral for radiography in children after blunt trauma, to rule out or diagnose CSI (Anderson 2006; Anderson 2010; Edwards 2001; Hutchings 2009; Pieretti-Vanmarcke 2011). However, these newly-developed decision tools are mostly used in single institutions and none of them is validated in another cohort, let alone evaluated in an implementation study.

Applicability of findings to the review question

The aim of this review was to evaluate if the NEXUS criteria and the Canadian C-spine Rule are accurate decision tools for detecting CSI in pediatric trauma patients following blunt trauma. Only one study examined the accuracy of the Canadian C-spine Rule (Ehrlich 2009). The NEXUS criteria were assessed in a pediatric population in three studies, but only one study (Viccellio 2001) evaluated the accuracy of the NEXUS criteria in a manner that corresponded to the research question of this review. Only one-third of the patients included in all three studies were younger than eight years old, and only an estimated 10% to 20% of the children with CSI were younger than eight.

AUTHORS' CONCLUSIONS

Implications for practice

At the moment, there is not enough evidence to determine if the Canadian C-spine Rule is accurate in detecting CSI in pediatric patients following blunt trauma. Therefore the evidence does not support the use of the Canadian C-spine Rule can to detect or rule out CSI in pediatric trauma patients.

The information available on the accuracy of the NEXUS criteria in a pediatric population is sparse and based on a small number of CSI events. Clinicians must keep in mind that the sensitivity of the NEXUS criteria differs among the three studies, with a wide range of individual confidence intervals for their sensitivity. This means that there is a chance of missing CSI when only relying on the NEXUS criteria to evaluate the need for imaging in children following blunt trauma. We therefore consider that the NEXUS criteria are at best a guide to clinical assessment as the evidence does not support strict or protocolized adoption of the tool into pediatric trauma care.

The specificity of the triage tools was low. However, in triage tools the main goal is to reduce the chance of missing CSI, so the sensitivity needs to be high, which indirectly leads to a low specificity. If the specificity were higher, fewer radiographic images would be obtained, but this would lead to a decrease in sensitivity and thus an increase in the chance of missing CSI. Moreover, even a small reduction in the amount of radiographic imaging is better than obtaining radiographic imaging of the cervical spine on a routine basis.

Data on children under the age of eight is especially sparse; there is therefore currently is no evidence to support the use of these clinical decision tools in this age group.

Implications for research

Since the incidence of CSI in children is low, a large number of patients are needed to test the accuracy of a clinical decision tool. Hence, future research should focus on large adequately powered multicenter prospective trials to assess the accuracy of the NEXUS criteria and Canadian C-spine Rule in children. Only then can we determine whether the NEXUS criteria or Canadian C-spine Rule are sensitive and specific enough to be applied as a decision tool following blunt trauma. It would be important to include enough patients younger than eight years old to ensure the decision tools could be used in children of all ages. Also, the number of CSI events should be high enough. A study should optimally evaluate both the NEXUS criteria and Canadian C-spine rule in all pediatric trauma patients. The first step would be plain radiographic imaging in pediatric trauma patients after clinical evaluation, according to all the items of the NEXUS criteria and Canadian C-spine Rule, so all items of both triage tools would be taken into consideration to evaluate whether or not further radiographic imaging should be obtained. In this way we can evaluate the sensitivity and specificity of both triage tools for predicting the need for radiographic imaging of the cervical spine after blunt trauma in children. As in other studies, clinical follow-up of patients in whom no radiographic imaging is necessary should be considered according to the NEXUS criteria and the Canadian C-spine Rule, thereby reducing the likelihood of missing CSI. In planning the study, trialists should conduct a power analysis to determine how many children younger and older than eight should be included, and how many events (patients with CSI) would be required.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

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

Ehrlich 2009

Study characteristics	
Patient sampling	Retrospective cohort
Patient characteristics and setting	Study location: University of Michigan CS Mott Children's Hospital Study period: 2005 - 2007 Patients enrolled: 150 patients younger than 10 years of age with plain radiography Patients included in analysis: 108 NEXUS criteria, 109 Canadian C-spine Rule Mean age: 4.3 years (SD 3.1) Sex: 72 boys, 53 girls Patients with CSI: 7
Index tests	NEXUS criteria and Canadian C-spine Rule
Target condition and reference standard(s)	Target condition: clinically-important missed CSI Reference standard: Plain radiography, CT or both
Flow and timing	Time between reference standard and index test: 0 days
Comparative	
Notes	No definition given of clinically-important CSI Referral for radiography depended on the following items: - awake or not - presence of motor/sensory deficits - presence of neck pain - presence of distracting injuries - presence of intoxicating agents 275 patients were included, 150 with the same reference standard (plain radiography), and 125 without radiographic imaging. Only 109 patients were included in their analysis

Methodological quality			
Item	**Authors' judgement**	**Risk of bias**	**Applicability concerns**
DOMAIN 1: Patient Selection			
Was a consecutive or random sample of patients enrolled?	Yes		

Ehrlich 2009 *(Continued)*

Was a case-control design avoided?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
		Low	**Low**
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		
		Unclear	**Low**
DOMAIN 3: Reference Standard			
Is the reference standards likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear		
		Unclear	**Low**
DOMAIN 4: Flow and Timing			
Was there an appropriate interval between index test and reference standard?	Yes		
Did all patients receive the same reference standard?	No		
Were all patients included in the analysis?	No		
		High	

Jaffe 1987

Study characteristics	
Patient sampling	Retrospective cohort
Patient characteristics and setting	Study location: Children's Memorial Hospital, Chicago. Study period: 139 consecutive trauma patients, younger than 16 years old, from 1983 - 1984 (1 with CSI) and all children younger than 16 years old, with CSI from 1974 to 1984 Patients enrolled: 232 patients younger than 16 years of age Patients included in analysis: 206 Age: 0 - 3 years 28%, 4 - 12 years 42%, 13 - 16 years 30% Sex: 143 boys, 63 girls

Jaffe 1987 *(Continued)*

	Patients with CSI: 59 (28.6%)
Index tests	Derivative of the NEXUS criteria with the following items: -neck pain/tenderness -abnormalities of reflexes, strength or sensation -limitation of neck mobility -abnormal mental status
Target condition and reference standard(s)	Target condition: predicting the presence of CSI in children Reference standard: plain radiography
Flow and timing	Time between reference standard and index test: 0 days
Comparative	
Notes	The items of the index test are not exactly the same as the items in the NEXUS criteria. The item missing is: the presence of distracting injury

Methodological quality

Item	**Authors' judgement**	**Risk of bias**	**Applicability concerns**
DOMAIN 1: Patient Selection			
Was a consecutive or random sample of patients enrolled?	No		
Was a case-control design avoided?	No		
Did the study avoid inappropriate exclusions?	Yes		
		High	**High**
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?	No		
		Unclear	**High**
DOMAIN 3: Reference Standard			
Is the reference standards likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear		
		Unclear	**Low**

Jaffe 1987 *(Continued)*

DOMAIN 4: Flow and Timing		
Was there an appropriate interval between index test and reference standard?	Yes	
Did all patients receive the same reference standard?	Yes	
Were all patients included in the analysis?	Yes	
		Unclear

Viccellio 2001

Study characteristics	
Patient sampling	Prospective multicenter cohort study
Patient characteristics and setting	Study location: UCLA Emergency Medicine Center (USA) and 20 participating centers. Study sites comprise a range of acute care facilities, including academic trauma centers, community trauma centers, and community EDs Study period: 1990 - 2000 (estimated) Patients enrolled: 34,069 patients, adults and children Patients included in analysis: 3065 Age: 0 - 2 years 2.9%, 2 - 8 years 26.7%, 9 - 17 years 70.5% Sex: unknown Patients with CSI: 30 (0.98%)
Index tests	NEXUS criteria
Target condition and reference standard(s)	Target condition: evaluating the performance of the NEXUS criteria for the detection of CSI in children Reference standard: Plain radiography, CT or both
Flow and timing	Time between reference standard and index test: 0 days
Comparative	
Notes	Analysis of the pediatric population included in the original Hoffman 2000, the seminal publication of the NEXUS tool Only 4 children with CSI younger than 8 years old

Methodological quality			
Item	**Authors' judgement**	**Risk of bias**	**Applicability concerns**
DOMAIN 1: Patient Selection			

Viccellio 2001 *(Continued)*

Was a consecutive or random sample of patients enrolled?	Yes		
Was a case-control design avoided?	Yes		
Did the study avoid inappropriate exclusions?	Yes		
		Low	**Low**
DOMAIN 2: Index Test All tests			
Were the index test results interpreted without knowledge of the results of the reference standard?	Yes		
If a threshold was used, was it pre-specified?	Yes		
		Low	**Low**
DOMAIN 3: Reference Standard			
Is the reference standards likely to correctly classify the target condition?	Yes		
Were the reference standard results interpreted without knowledge of the results of the index tests?	Yes		
		Low	**Low**
DOMAIN 4: Flow and Timing			
Was there an appropriate interval between index test and reference standard?	Yes		
Did all patients receive the same reference standard?	No		
Were all patients included in the analysis?	Yes		
		High	

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

Study	Reason for exclusion
Adelgais 2014	Index test not relevant
Anderson 2006	Target condition not relevant
Anderson 2010	Index test not relevant
Baker 1999	Index test not relevant
Bandiera 2003	Different study population (adults)
Banit 2000	Index test not relevant

Study	Reason for exclusion
Bayless 1989	I ndex test not relevant
Blacksin 1995	Index test not relevant
Borock 1991	Different study population (only patients with CSI)
Brockmeyer 2012	Different study population (suspected or proven CSI)
Brooks 2001	Index test not relevant
Brown 2001	Index test not relevant
Browne 2003	T arget condition not relevant
Burns 2011	Different target condition
Clayton 2012	Index test not relevant
Coffey 2011	Different study population (adults)
Como 2011	Index test not relevant
Dahlquist 2013	Index test not relevant
Dickinson 2004	Different study population (adults)
DiGiacomo 2002	Index test not relevant
Edwards 2001	Index test not relevant
Ersoy 1995	Index test not relevant
Fischer 1984	Index test not relevant
Garton 2008	Different study population (only patients with CSI)
Gbaanador 1986	Index test not relevant
Gonzalez 1999	Index test not relevant
Gonzalez 2009	Index test not relevant
Gonzalez 2013	Different study population (pre- hospital 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)
Hanson 2000	Different study population (adults)
Hanson 2000a	Different study population (adults)

Study	Reason for exclusion
Hasler 2011	Different study population (adults)
Heffernan 2005	Different study population (adults)
Hoffman 1992	Authors did not separate data for the pediatric population (only a small number of children were included)
Hollingshead 2000	Index test not relevant
Hutchings 2009	Index test not relevant
Keenan 2001	Index test not relevant
Kerr 2005	Different study population (adults)
Kokabi 2011	Different study population (adults)
Lee 2003	I ndex test not relevant
Malomo 1995	I ndex 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
Meek 2007	Index test not relevant
Meldon 1998	Different study population (out- of- hospital patients)
Morrison 2012	Index test not relevant
Mower 2001	Index test not relevant
Neifeld 1988	Different study population (adults)
Nguyen 2005	Index test not relevant
Omran 2001	Index test not relevant
Pieretti-Vanmarcke 2011	Index test not relevant
Platzer 2006a	Index test not relevant
Platzer 2006b	Index test not relevant
Pulfrey 2002	Different study population (adults)
Quigley 2014	Index test not relevant
Raza 2013	Different study population (adults)

Study	Reason for exclusion
Ropele 2009	Index test not relevant
Rose 2012	Index test not relevant
Ross 1987	Index test not relevant
Saddison 1991	Different study population (only patients with CSI)
Sanchez 2005	Index test not relevant
Scarrow 1999	Different study population (only patients with CSI)
Schleehauf 1989	Index test not relevant
Sheikh 2012	Different study population (adults)
Smart 2003	Index test not relevant
Stiell 2003	Different study population (adults)
Stiell 2009	Different study population (adults)
Stiell 2010	Different study population (adults)
Stroh 2001	Index test not relevant
Sun 2013	Target condition not relevant
Tahvonen 2013	Index test not relevant
Valusek 2010	Index test not relevant
Velmahos 1996	Index test not relevant

DATA

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	3	3379
2 Canadian C-spine Rule	1	109

Test 1. NEXUS.

Test 2. Canadian C-spine Rule.

ADDITIONAL TABLES

Table 1. Citations per search engine

Search Engine	Number of citations
MEDLINE	7985
MEDLINE In-Process	39
PubMed (search limited to studies not in MEDLINE)	86
Embase	9187
CENTRAL	651
Science Citation Index	1220
Proquest Dissertation and Theses	20
Cochrane Database of Systematic Reviews	250
DARE	105
HTA	30
Medion results	16
ClinicalTrials.gov	19
WHO ICTRP	19
OpenGrey	33
DTA Trials Register	3
Results found through other sources	1
-Duplicates	-4934
TOTAL	**14,730**

Table 2. QUADAS review question and inclusion criteria

Category	Review Question	Inclusion Criteria
Patients	All children aged 0 to 18 years who underwent trauma evaluation at the emergency room	Children following blunt trauma

Table 2. QUADAS review question and inclusion criteria *(Continued)*

Index test	NEXUS criteria, Canadian C-spine Rule	NEXUS criteria, Canadian C-spine Rule
Target condition	Cervical spine injury defined as any fracture or (sub)luxation of the cervical spine, ligamentous injury, or spinal cord injury	Cervical spine injury
Reference standard	Radiographic imaging in the form of plain radiography, CT, and/or MRI, or clinical follow-up (if the index test was scored negative) will be our reference standards	Radiographic imaging or clinical follow-up
Outcome	N/A	Sufficient data to construct a 2x2 table
Study design	Diagnostic studies with cross-sectional or cohort designs (retrospective or prospective) and randomized controlled trials, most favorable direct comparison studies	Diagnostic studies with cross-sectional or cohort designs (retrospective or prospective) and randomized controlled trials

N/A: not applicable.

Table 3. Assessment of methodological quality: QUADAS-2 and additional items

	Risk of bias		**Applicability**	
Quality item	**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 a selected group of patients was enrolled, or if a case control study was performed **Unclear:** if there is insufficient information on enrolled patients	1. Were the patients included in the study children presented at the emergency department for evaluation following blunt trauma?	**Yes**: The included population were children (0 - 18 years old) presenting at the emergency department following blunt trauma. **No:** (a) Only adult patients were included, OR (b) if patients were included without blunt trauma OR (c) if the patients included were not presenting at the emergency department. **Unclear:** (a) The study population contained adults and children, OR (b) insufficient information was given on the setting, selection criteria, or selection procedure to make a judgment
	2. Did the study avoid inappropriate exclusions?	**Yes:** if there were no inappropriate exclusions **No:** if there were inappropriate exclusions **Unclear:** if there is insufficient information on exclusions	2. Were the participants planned for evaluation of the cervical spine?	**Yes:** if the participants were planned for evaluation of the cervical spine **No:** if participants were not planned for evaluation of the cervical spine **Unclear:** if there is insufficient information

Table 3. 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?	This will always be rated as **yes**, because the index test is performed before the reference standard.	1. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	**Yes:** if clinical data would normally be available when the test is interpreted in practice and similar data were available when interpreting the index test in the study **No:** if clinical data were not available when index test(s) was/were interpreted **Unclear:** if insufficient information was given to explain which clinical data were available at the time of assessment
	2. Was the threshold used prespecified?	**Yes:** if a clear description of the threshold is given before start of the study **No:** if no clear description is given beforehand **Unclear:** if there is insufficient information to determine whether or not a prespecified threshold was used	2. Did the study provide a clear definition of what was considered to be a "positive" result for the index test?	**Yes:** if the study provides a clear definition of a positive test result **No:** if no definition of a positive test result is given **Unclear:** if insufficient information was given to permit judgment
	3. Could the conduct or interpretation of the index test have introduced bias?	**Yes:** If the items of the triage tool were not the same as the items in the index test **No:** if the items of the index test were the same in all patients **Unclear:** if insufficient information is provided	-	-
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 preference 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 reference standard was plain radiography, CT, MRI or clinical follow-up **No:** if the reference standard was not plain radiography, CT, MRI, or clinical follow-up **Unclear**: if the reference standard was not clearly reported	1. Did the study provide a clear definition of what was considered to be a "positive" result for the reference standard?	**Yes:** if a clear description is given about when the reference standard is positive or negative (CSI yes/no) **No:** if there is no clear description of the results of the reference standard **Unclear:** if the definition of the reference standard is not clearly reported
	2. Were the reference standard results interpreted without knowl-	**Yes:** if the radiologist was blinded for the results of the index tests **No:** if the radiologist was aware of the results of the index test	-	-

Table 3. Assessment of methodological quality: QUADAS-2 and additional items *(Continued)*

	edge of the results of the index test?	**Unclear:** if insufficient information was given 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 reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	**Yes:** if the reference standard was performed directly after trauma presentation up to 72 hours after trauma presentation **No:** if the average interval between reference standard and index test was longer than 72 hours **Unclear:** if the interval between the trauma and reference standard was not clearly reported	-	-
	2. Did all patients receive the same reference standard?	**Yes:** if all patients underwent the same reference standard **No:** if not all patients underwent reference standard; also those with a negative index test did not undergo reference test **Unclear**: if insufficient information is provided	-	-
	3. Were all patients included in the analysis?	**Yes:** if all patients entered in the study are included in the analysis **No:** if not all patients in the study are included in the analysis **Unclear:** if it is not clear whether all patients were accounted for	-	--
	4. Were withdrawals from the study reported?	**Yes**: if the number of and reasons for all withdrawals from the study were explained (ideally by a flow chart) or if no participants were excluded from the analysis **No:** if the reason for withdrawal from the study was not explained **Unclear**: if insufficient information was given on the withdrawals	-	-

APPENDICES

Appendix 1. Search strategies

MEDLINE

Search 24 Feb 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 [cervial 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 Feb 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 Feb 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 Feb 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 Feb 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 Feb 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 Feb 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 Feb 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))

ClinicalTrialsgov

Search 24 Feb 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 Feb 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 Feb 2015

clearance:ti,ab,kw or cervical spine

ARIF

Search 24 Feb 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”

CONTRIBUTIONS OF AUTHORS

- Conceiving the review: Slaar, Fockens
- Designing the review: Slaar
- Co-ordinating the review: Van Rijn, Schep
- Data collection for the review: Information Specialist of the Cochrane Back and Neck Group
- Designing search strategies: Information Specialist of the Cochrane Back and Neck Group
- Undertaking searches: Information Specialist of the Cochrane Back and Neck Group
- Screening search results: Fockens, Slaar, Schep
- Organizing retrieval of papers: Fockens
- Screening retrieved papers against inclusion criteria: Fockens, Slaar, Schep
- Appraising quality of papers: Slaar, Fockens
- Extracting data from papers: Slaar, Fockens
- Writing to authors of papers for additional information: Slaar, Van Rijn
- Providing additional data about papers: Slaar
- Obtaining and screening data on unpublished studies: Slaar, Fockens
- Data management for the review: Slaar, Wang, Schep
- Entering data into Review Manager 5: Slaar, Wang
- Analysis of data: Wang
- Interpretation of data: Schep, Slaar, Wang
- Providing a methodological perspective: Schep, Van Rijn, Wang
- Providing a clinical perspective: Maas, Goslings, Van Rijn, Wilson
- Writing the review: Slaar
- Providing general advice on the review: Goslings, Wilson, Maas

DECLARATIONS OF INTEREST

Annelie Slaar has no conflicts of interest.
M. Matthijs Fockens has no conflicts of interest.
Junfeng Wang has no conflicts of interest.
Mario Maas has no conflicts of interest.
David J Wilson has no conflicts of interest.
J Carel Goslings has no conflicts of interest.
Niels WL Schep has no conflicts of interest.
Rick R van Rijn has no conflicts of interest

SOURCES OF SUPPORT

Internal sources

- Academic Medical Center, Amsterdam, Netherlands.

External sources

- No sources of support supplied

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

We planned to meta-analyse the sensitivity and specificity of the tools with a bivariate model. However, we identified only three 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 this data.

INDEX TERMS

Medical Subject Headings (MeSH)

*Decision Support Techniques; Cervical Vertebrae [diagnostic imaging] [*injuries]; Checklist; Cohort Studies; 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