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# *Sensitivity of plain radiography for pediatric cervical spine injury*

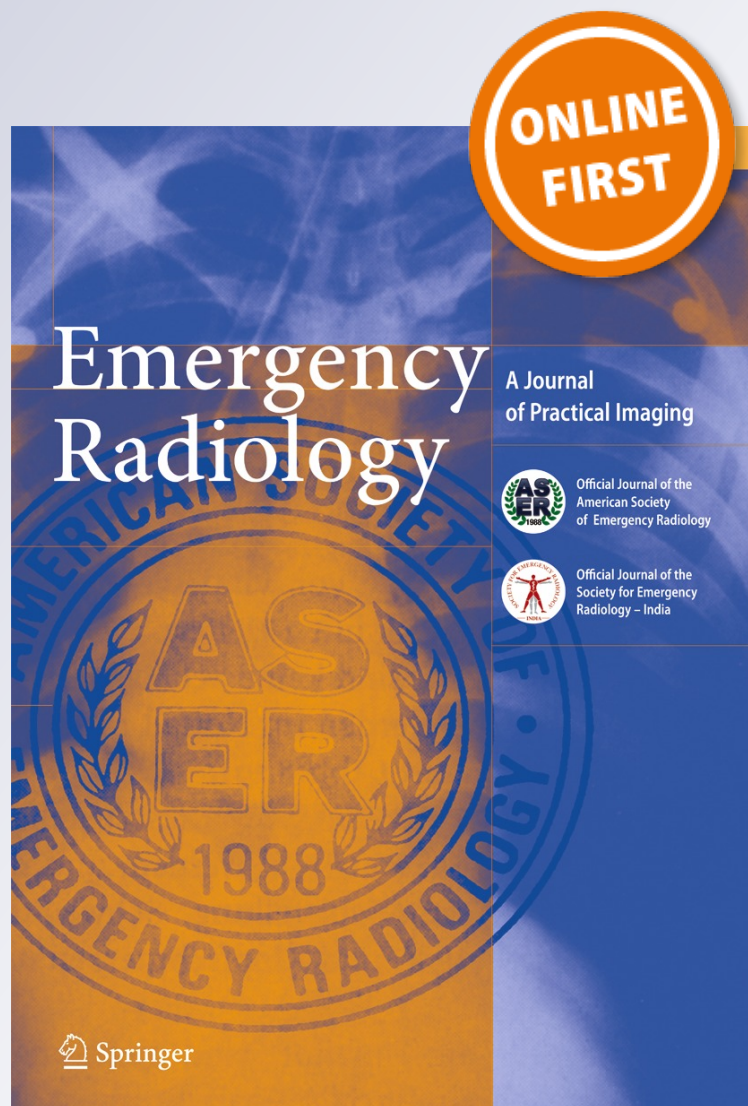
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# Sensitivity of plain radiography for pediatric cervical spine injury

Li W. Cui<sup>1</sup> · Marc A. Probst<sup>2</sup> · Jerome R. Hoffman<sup>3</sup> · William R. Mower<sup>4</sup>

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**Abstract** Pediatric patients with suspected cervical spine injuries (CSI) often receive a computed tomography (CT) scan as an initial diagnostic imaging test. While sensitive, CT of the cervical spine carries significant radiation and risk of lethal malignant transformation later in life. Plain radiographs carry significantly less radiation and could serve as the preferred screening tool, provided they have a high functional sensitivity in detecting pediatric patients with CSI. We hypothesize that plain cervical spine radiographs can reliably detect pediatric patients with CSI and seek to quantify the functional sensitivity of plain radiography as compared to CT. We analyzed data from the NEXUS cervical spine study to assess the sensitivity of plain radiographs in the evaluation of CSI. We identified all pediatric patients who underwent plain radiographic imaging, and all pediatric patients found to have CSI. We then determined the sensitivity of plain radiographs in detecting pediatric patients with CSI. We identified 44 pediatric patients with CSI in the dataset with age ranging from 2 to 18 years old. Thirty-two of the 44 pediatric patients received cervical spine plain films as a part of their workup. Plain films were able to identify all 32 pediatric patients with

CSI to yield a sensitivity of 100 % in detecting injury victims (95 % confidence interval 89.1–100.0 %). Plain radiography was highly sensitive for the identification of CSI in our cohort of pediatric patients and is useful as a screening tool in the evaluation of pediatric CSI.

**Keywords** Cervical spine injury · CSI · Pediatric · Plain films · Plain radiography · X-ray

## Introduction

Pediatric cervical spine injuries (CSI) are rare but potentially devastating. As such, the rapid and accurate diagnosis of CSI is of vital importance in the emergency department (ED). Radiographic imaging provides the definitive means of identifying injury in most patients, and both plain radiography and computerized tomography (CT) of the cervical spine are the initial imaging modalities recommended in the evaluation of pediatric blunt trauma patients [1].

CT has been shown to have high sensitivity in the identification of CSI [2]. It is, however, associated with significant exposure to ionizing radiation thus increasing the risk of malignancy [3]. Pediatric radiation exposure is of significant concern because the pediatric population is particularly vulnerable to the carcinogenic effects of ionizing radiation due to their longer life years and more radiosensitive tissues as compared to adult patients [4]. These concerns are compounded by the fact that pediatric radiation exposure has significantly increased as the rate of cervical spine CT imaging has increased despite a stable incidence of pediatric CSI [5, 6].

Several studies have supported the role of plain radiography as the initial imaging modality for the identification of CSI in the low-risk adult population [2, 7, 8]. One recent retrospective study in children found plain radiography to

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have a sensitivity of 90 % for the identification of individuals with CSI [9]. Plain radiography offers advantage over CT in that it delivers much lower doses of ionizing radiation and, thus, a lower potential to cause malignant transformation [10].

We sought to evaluate whether plain films could be the preferred screening tool for pediatric blunt trauma patients. This would require a high functional sensitivity in identifying pediatric patients with CSI. We define functional sensitivity in this study as the ability to detect at least one lesion or structural abnormality that would prompt further evaluation. Under this paradigm, plain radiography would not need to identify all pediatric CSI but would need to identify at least one abnormality on each injured child, which in turn, would lead to further advanced imaging. Our objective was to measure the functional sensitivity of cervical spine plain radiography for the identification of CSI in children after blunt trauma. This is the first concurrent cohort study on this topic in children 18 years old and younger.

## Methods

### Study design

We analyzed data from the National Emergency X-Radiography Utilization Study (NEXUS). The methods for this multicenter study have been described in detail elsewhere [11]. Briefly, the NEXUS cervical spine study was a prospective observational study performed at 21 acute care hospitals across the USA varying in size, volume, and level of trauma. The original purpose of the NEXUS study was to validate a decision instrument and the treating physicians made imaging decisions independent from this instrument. The study received approval from the institutional review board of each participating site (Appendix).

### Study setting and population

The study included all patients who presented to any of the 21 participating hospital with blunt trauma who underwent cervical spine imaging. Exclusion criteria included patients with penetrating trauma and those that underwent cervical spine imaging for any reason unrelated to trauma. Physicians were informed to not rely on the decision instrument that was being tested to decide whether or not to order imaging. The collected data was attached to a unique identifying number with no identifiable information and stored in a central data bank.

### Study protocol

The standard set of plain films consisted of the anteroposterior (AP), cross-table lateral, and open-mouth odontoid views. This series was obtained in all patients except when deemed

impossible or impractical by the treating physician. Reasons for exemption included obvious signs of CSI are already present on arrival (i.e., focal neurological deficits) or if the patient presented in critical condition (i.e., hemodynamic instability). In these instances, CT or magnetic resonance imaging (MRI) of the entire cervical spine was performed. Additional imaging studies such as oblique views, flexion-extension view, and/or CT images were obtained if the initial screening plain films were deemed inadequate or at the treating physician's discretion. Formal interpretations of all radiographs were performed at each study site by trained, designated radiologists. The diagnosis of CSI and characterization of the type of fracture was made according to the final radiology report. For any ambiguous reports, the radiologists reviewed the original radiographs along with their reports to make the final determination of the type of fracture. If after such a review, the report remained unclear as to the nature of the injury, that injury was categorized as clinically significant.

Since only patients who underwent diagnostic imaging were enrolled, we reviewed neurosurgical records and quality assurance logs of each participating hospital 3 months after study completion to find patients with missed CSIs.

### Key outcome measures

CSIs were categorized into clinically significant or not clinically significant prior to data collection (Table 1). Injuries were categorized as not clinically significant if they typically require no treatment or if their missed identification would not be expected to result in harm [12]. CSIs identified on radiography were considered not clinically significant if they were isolated and there was no evidence of other bony, ligamentous, or spinal cord injury. All other injuries were considered clinically significant.

### Data analysis

We included all patients under 19 years of age in this sub-analysis. We considered pediatric patients who were found

**Table 1** Radiographically documented cervical spine injuries categorized as not clinically significant

Spinous process fracture
Simple wedge-compression fracture without loss of 25 % or more of vertebral body height
Isolated avulsion without associated ligamentous injury
Type I (Anderson-D'Alonzo) odontoid fracture
End-plate fracture
Osteophyte fracture, not including corner fracture or teardrop fracture
Injury to trabecular bone
Transverse process fracture



to have CSI on any imaging modality and who received plain film radiography that successfully identified any CSI as true positives. Pediatric patients who were found to have CSI on CT or MRI but received plain film radiography that were read as normal were considered false negatives.

**Results**

The NEXUS database contained 3701 patients under the age of 19 years. Forty-four of these children (1 %) were found to have CSI. We did not find any patients less than 2 years old with CSI. Of the 44 pediatric patients, 32 (73 %) received cervical spine plain radiography as a part of their workup. The other 12 patients (27 %) were excluded because they did not receive cervical spine plain films and had injuries identified on CT/MRI. Derivation of study sample is illustrated in Fig. 1. These 32 patients had a mean age of 15, with the majority over the age of 8 (91 %) and male (69 %). Detailed patient characteristics are presented in Table 2. Of the 32 patients above, 17 also received subsequent CT imaging.

Among the 32 included patients, there were a total of 53 CSIs. Of the 32 patients having at least one CSI, 10 patients (31 %) were found to have multiple lesions. Plain radiography was able to identify all 32 pediatric patients with CSI to yield a functional sensitivity of 100 % in detecting injuries (95 % [CI] 89.1–100.0 %).

In four patients with multiple CSIs, plain films were not able to identify all additional lesions. In two of these patients (both 16-year-old males), plain films identified fractures of the vertebral body but failed to identify laminar fractures on those same vertebrae. The second patient also had a C5–C6 subluxation that was identified on CT but not on plain films. The third patient, a 17-year-old male, was found to have a C5 flexion teardrop fracture as well as a C5 laminar fracture on plain films, while CT detected an additional C6 body fracture and a C5–C6 interfacet dislocation. The final patient, a 17-

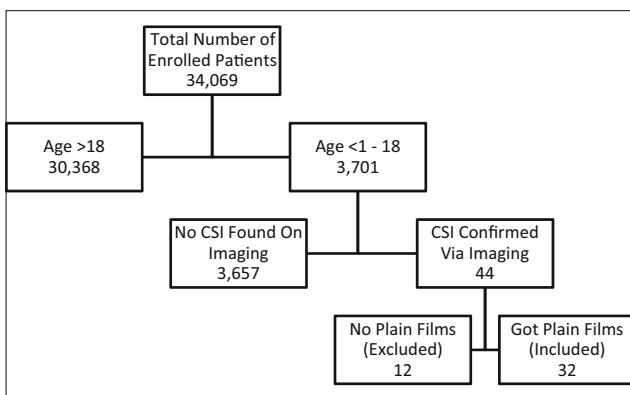
year-old male, was found to have C6 and C7 spinous process fractures, while CT additionally detected a C1 burst fracture.

Of the 32 included patients, we found three (9 %) under the age of nine with CSI. All three patients were found to have upper CSI (C3 and above). The first two patients in this group had occipital condyle fracture and cranial-cervical dissociation, respectively. The third patient had C1 anterior and posterior arch fractures, and a C2 type II odontoid fracture. The other 29 children (91 %) were in the age group of 9–18. Injuries in this older group were predominately of the lower cervical spine.

Of the 12 excluded patients with CSI, we found one child under the age of nine. This child suffered an injury in the upper cervical spine. In the 9–18 age group, the majority of children were found to have injury in the lower cervical spine. Further breakdown of location of injury by age group can be found in Table 3.

**Discussion**

In this concurrent cohort study based on the NEXUS cervical spine data, we found plain films to be highly sensitive (100 %, 95 % [CI] 89.1–100 %) for the identification of children with CSI. All 32 children with CSI, including those with multiple lesions, were identified by plain radiography as having at least one CSI. Of the ten patients with multiple CSIs, four of them had additional injuries identified on CT that were previously missed on plain radiography. We did not take these missed additional injuries into the calculation of our functional sensitivity because plain radiography, as a screening test, is not meant to pick up all injuries. As found in other studies, plain radiography's high functional sensitivity for CSI in children makes it an effective initial screening tool that could be followed by CT or MRI for further workup as needed [13–15]. We excluded children with injuries categorized as "not clinically significant" (Table 1) as they almost never



**Fig. 1** Flowchart illustrating derivation of study sample

**Table 2** Patient characteristics breakdown by age and gender

	Included*, % of column	Excluded**, % of column
Total	32 (100)	12 (100)
Age		
2–8	3 (9)	1 (8)
9–18	29 (91)	11 (92)
Gender		
Male	22 (69)	10 (83)
Female	10 (31)	2 (17)

\*Patients with cervical spine injury and had plain films

\*\*Patients with cervical spine injury and did not have plain films

**Table 3** Patient breakdown by location (upper versus lower) of cervical spine injury

	Included patients ( <i>n</i> = 32)		Excluded patients ( <i>n</i> = 12)	
	Age 2–8 ( <i>n</i> = 3) (%)	Age 9–18 ( <i>n</i> = 29) (%)	Age 2–8 ( <i>n</i> = 1) (%)	Age 9–18 ( <i>n</i> = 11) (%)
Upper only (C3 and above)	3 (100)	7 (24)	1 (100)	2 (18)
Lower only (C4 and below)	0 (0)	19 (66)	0 (0)	7 (64)
Upper and lower	0 (0)	3 (10)	0 (0)	2 (18)

cause permanent disabilities [12]. SCIWORA injuries are classically not detected on plain films and thus were not included in the injury count for sensitivity.

Our current work is a secondary analysis of a large prospective cohort study first reported a number of years ago [11]. Although its database was not primarily intended to evaluate the sensitivity of plain radiography for the detection of pediatric CSI, all data was gathered prospectively and thus does not suffer from many of the inevitable biases present in chart review studies. Several such chart review studies (discussed below) do attempt to address this question, but we believe ours is the first for which high-quality prospective data is available. Our study analyzed data collected from 21 hospitals representing a variety of EDs across the USA, which lends to its generalizability.

Children under 9 years of age have cervical spines that differ from their older peers in that the fulcrum of motion of their cervical spine occurs at C2-C3, making injury of the upper cervical spine much more common [16]. Of the three patients under the age of nine with CSI in our study, all three were found to have upper cervical spine injury (C3 and above), as is expected in this age group. Of the 41 patients in the 9–18 age group, 30 patients (73 %) had injury either solely in the lower cervical spine or a combination of lower and upper cervical spine injury. This pattern of injury in the older pediatric group reflects their matured cervical spine, which has a fulcrum of motion at the C5-C6 level [16].

A concurrent cohort study using the same data set as our study found that plain radiography was able to identify 498 of 557 patients (both adult and pediatric) with CSI, yielding a functional sensitivity of 89.4 % (95 % CI 86.9 to 91.4 %) [7]. There is a difference in the prevalence of CSI after blunt trauma between adults and children, 2–6 and 1.5 %, respectively [17, 18]. Several recent retrospective studies focusing on the pediatric population have found high sensitivities for plain radiography in the detection of CSI. A large, multicenter retrospective study utilizing the Pediatric Emergency Care Applied Research Network (PECARN) data found that plain radiography was able to identify 168 of 186 children with CSI for a sensitivity of 90 % (95 % CI 85–94 %) [9]. In another retrospective study involving 59 children with CSI, 58 were found to have CSI on plain radiography (anterior-posterior or

lateral view), yielding a sensitivity of 98 % (95 % CI 91–100 %) [19]. The higher sensitivity of cervical plain radiography in children could be explained by the absence of age-related calcifications and degenerative changes present in the adult population.

Another consideration is the need for a balance between the sensitivity of the initial imaging modality and the amount of ionizing radiation exposure, which increases the risk of malignant transformation [3, 20]. While sensitive, CT carries the risk of fatal malignant transformation through radiation exposure. Based on roughly 600,000 CT scans performed on children annually under the age of 15, Brenner et al. calculated an estimate of 500 deaths that result from cancers attributable to CT radiation each year [21]. The National Cancer Institute supports minimizing ionizing radiation in children, stating “perform only necessary CT examinations” and “encourage development and adoption of pediatric CT protocols” [22]. This balance could be struck through the application of a risk stratification tool. One study combined the probabilities of CSI via the NEXUS criteria and the long-term risks of malignancy after CT to create a decision tree for the initial evaluation of CSI [8]. The authors concluded that “unless the probability of cervical spine injury is high, clinical clearance or screening radiographs should predominate the current management strategies when radiation risk is considered.” While we welcome newer CT scanners and protocols that offer radiation reductions, such reductions do not yet approach the low radiation dosages of a plain film cervical spine series.

Our calculated 100 % sensitivity does come with a large confidence interval and it should be expected that plain film’s sensitivity for CSI is likely lower in clinical practice. However, the small risk of missed injuries from plain films must be balanced against the increased risk of malignant transformation from performing CT scans on all children with suspected CSI.

## Limitations

The number of patients evaluated in this study is fairly small. While the NEXUS study itself involved a full 34,069 patients, the number of children with CSI was far less, resulting in

relatively large CIs. Given the rarity of CSI in the pediatric population, this is essentially inevitable, absent a truly massive cohort that would be extremely difficult to achieve in a prospective study. In addition, CT was not performed on all study patients, which may have falsely inflated our estimate of sensitivity, due to verification bias. Fortunately, follow-up data using neurosurgical and risk-management logs did not identify any missed injuries, suggesting that this problem is at most a very small one. Similarly, potential false negative CT scans could also have led to our failing to identify some injuries; however, CT is widely considered the gold standard for CSI, so this seems more a theoretical rather than a real concern. Finally, it is possible that plain radiographs were interpreted in conjunction with other imaging modalities (CT, MRI), and false negatives were avoided simply due to incorporation bias (since the reading radiologists were made aware of the presence of injury based on these other images). We doubt that this had a substantial effect on our findings however, as most study sites interpreted the plain films prior to the completion of CT; in addition, plain films and CT scans were interpreted by different radiologists at most of our study sites.

## Conclusion

Plain radiography was highly sensitive for the identification of CSI in our cohort of pediatric patients. The data from our prospective study is consistent with the results of several recent large retrospective studies on this topic. Our study therefore adds to existing literature that suggests plain radiography is useful as a screening tool in the evaluation of pediatric CSI.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Appendix** The following centers and investigators collaborated in the NEXUS study: principal investigator—W. Mower; co-investigator—J. Hoffman; steering committee—J. Hoffman, W. Mower, K. Todd, A. Wolfson, and M. Zucker; site investigators—Antelope Valley Medical Center (Los Angeles): M. Brown and R. Sisson; Bellevue Hospital (New York): W. Goldberg and R. Siegmann; Cedars–Sinai Medical Center (Los Angeles): J. Geiderman and B. Pressman; Crawford Long Hospital (Atlanta): S. Pitts and W. Davis; Egleston Children's Hospital (Atlanta): H. Simon and T. Ball; Emory University Medical Center (Atlanta): D. Lowery and S. Tigges; Grady Hospital (Atlanta): C. Finney and S. Tigges; Hennepin County Medical Center (Minneapolis): B. Mahoney and J. Hollerman; Jacobi Medical Center (Bronx, N.Y.): M. Touger, P. Gennis, and N. Nathanson; Maricopa Medical Center (Phoenix, Ariz.): C. Pollack and M. Connell; Mercy Hospital of Pittsburgh (Pittsburgh): M. Turturo and B. Carlin; Midway Hospital (Los Angeles): D. Kalmanson and G. Berman; Ohio State University Medical Center (Columbus): D. Martin and C. Mueller; Southern Regional Hospital (Decatur, Ga.): W. Watkins and E. Hadley; State University of New York at Stony Brook

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#### Author contributions

LWC, MAP, WRM, and JRH participated in the project development, data analysis, manuscript composition, and critical review. WRM and JRH participated in data collection.