

Utility of Plain Radiographs in Detecting Traumatic Injuries of the Cervical Spine in Children

Lise E. Nigrovic, MD, MPH,* Alexander J. Rogers, MD,† Kathleen M. Adalgais, MD, MPH,‡§ Cody S. Olsen, MS,|| Jeffrey R. Leonard, MD,¶# David M. Jaffe, MD,# and Julie C. Leonard, MD, MPH,#
for the Pediatric Emergency Care Applied Research Network (PECARN) Cervical Spine Study Group

Objective: The objective of this study was to estimate the sensitivity of plain radiographs in identifying bony or ligamentous cervical spine injury in children.

Methods: We identified a retrospective cohort of children younger than 16 years with blunt trauma-related bony or ligamentous cervical spine injury evaluated between 2000 and 2004 at 1 of 17 hospitals participating in the Pediatric Emergency Care Applied Research Network. We excluded children who had a single or undocumented number of radiographic views or one of the following injuries types: isolated spinal cord injury, spinal cord injury without radiographic abnormalities, or atlantoaxial rotary subluxation. Using consensus methods, study investigators reviewed the radiology reports and assigned a classification (definite, possible, or no cervical spine injury) as well as film adequacy. A pediatric neurosurgeon, blinded to the classification of the radiology reports, reviewed complete case histories and assigned final cervical spine injury type.

Results: We identified 206 children who met inclusion criteria, of which 127 had definite and 41 had possible cervical spine injury identified by plain radiograph. Of the 186 children with adequate cervical spine radiographs, 168 had definite or possible cervical spine injury identified by plain radiograph for a sensitivity of 90% (95% confidence interval, 85%–94%). Cervical spine radiographs did not identify the following cervical spine injuries: fracture (15 children) and ligamentous injury alone (3 children). Nine children with normal cervical spine radiographs presented with 1 or more of the following: endotracheal intubation (4 children), altered mental status (5 children), or focal neurologic findings (5 children).

Conclusions: Plain radiographs had a high sensitivity for cervical spine injury in our pediatric cohort.

Key Words: cervical spine injury, radiography, sensitivity

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Cervical spine injury, although very rare in children, has potentially devastating consequences. After suffering blunt trauma requiring emergency department (ED) evaluation, many children undergo radiological evaluation as part of the process of cervical “clearance,” which may include cervical spine radiographs and/or cervical spine computed tomography (CT). The estimated amount of ionizing radiation exposure is 30-fold higher for cervical spine CT than plain cervical spine radiography (approximate dose of ionizing radiation 6 vs 0.2 mSv).¹ Although estimates of the magnitude of the risk vary significantly, ionizing radiation exposure increases later risks of lethal malignancy.² Children are at greater risk than adults both because certain structures (ie, the thyroid gland)³ are more radio-sensitive due to the larger proportion of dividing cells and the cumulative risk over a child’s life span is greater for the development of radiation-induced cancer when compared with an adult.^{2,4,5}

Minimizing unnecessary radiation exposure for children evaluated in the ED after blunt trauma without missing significant injuries is an easy way to reduce the risk of radiation-induced cancer. Plain radiography might serve as an effective screening test that reduces exposure to potentially dangerous ionizing radiation. In adult studies, cervical spine radiography had a sensitivity for cervical spine injury of 80% for a single cross-table lateral view⁶ and of greater than 90% for a 3-view series.^{6–8} However, these findings may not be applicable to children because of different injury patterns and greater anatomic variability.⁹ Limitations of previous studies of cervical spine injury in children include small numbers of children with cervical spine injury in one and a single institutional experience in the other, which may not be generalizable.^{10,11}

We assembled a retrospective cohort of children younger than 16 years with confirmed bony and/or ligamentous cervical spine injury who underwent cervical spine radiography as part of their initial evaluation. Our study objective was to estimate the sensitivity of cervical spine radiography to identify either bony or ligamentous cervical spine injury in children after blunt trauma.

METHODS

Study Design

We performed a planned secondary analysis of a retrospective cohort of children younger than 16 years with blunt trauma-related cervical spine injury. Details of the study design were published previously.¹² Study patients were evaluated and treated at 1 of 17 medical centers participating in the Pediatric

From the *Division of Emergency Medicine, Children’s Hospital Boston and Harvard Medical School, Boston, MA; †Departments of Emergency Medicine and Pediatrics, University of Michigan Medical Center and University of Michigan School of Medicine, Ann Arbor, MI; ‡Department of Emergency Medicine, Primary Children’s Medical Center and University of Utah, Salt Lake City, UT; §Division of Emergency Medicine, Children’s Hospital of Denver and University of Colorado, Aurora, CO; ||Central Data Management and Coordinating Center and University of Utah School of Medicine, Salt Lake City, UT; and Departments of ¶Neurosurgery and #Pediatrics, St Louis Children’s Hospital and Washington University in St Louis School of Medicine, St Louis, MO.

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Reprints: Lise E. Nigrovic, MD, MPH, Division of Emergency Medicine, Children’s Hospital, Boston, 300 Longwood Ave, Boston, MA 02115 (e-mail: lise.nigrovic@childrens.harvard.edu).

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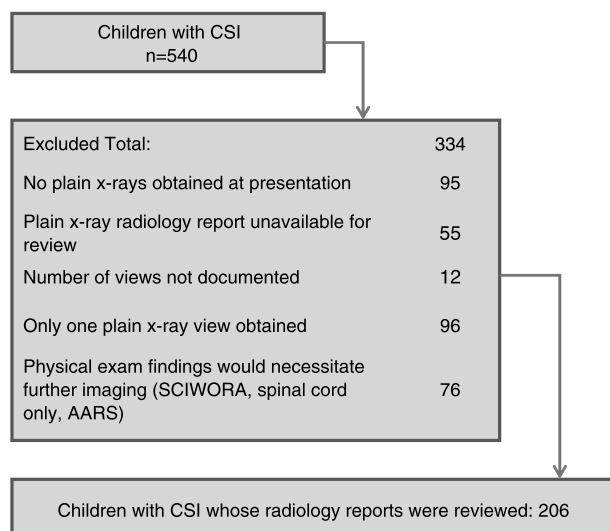


FIGURE 1. Flowchart illustration derivation of the study sample.

Emergency Care Applied Research Network (PECARN) between 2000 and 2004. Collectively, more than 1 million children per year were evaluated in the EDs of the participating centers. Requirement for informed consent was waived by the institutional review board at each participating center. Data-sharing agreements were established between each of the participating centers and the PECARN Central Data Monitoring and Coordinating Center at the University of Utah.

Patient Identification

Children with cervical spine injury were identified by an electronic query of the billing database at each participating site to identify *International Classification of Diseases, Ninth Revision, Clinical Modification* codes indicating injuries to the cervical spinal cord, vertebrae, and ligaments. For each potential study patient, the site principal investigator performed a structured screening of the medical record to confirm the presence of cervical spine injury and to collect data elements.

Inclusion Criteria

We included all patients with blunt trauma-related cervical spine injury who had cervical spine plain radiography with at least 2 distinct views obtained. Flexion and extension radiographs were counted as a single view because they are both lateral views.¹³ Patients who had radiographs obtained at a referring hospital were included only if the study site radiologist reviewed and provided a dictated radiology report.

Exclusion Criteria

We excluded children with the following types of cervical spine injuries: isolated spinal cord injury, spinal cord injury without radiographic abnormality (SCIWORA; defined as a normal plain radiograph, CT, and/or magnetic resonance imaging [MRI] with neurologic symptoms), or atlantoaxial rotary subluxation (AARS). Children with these injuries were excluded as these diagnoses always require advanced imaging based on clinical presentation and physical examination.

Injury Classification

A single pediatric neurosurgeon reviewed the complete imaging history and spine consultation notes for every study patient and then assigned the final cervical spine injury classification. The study neurosurgeon (J.R.L.) was blinded to the

study investigators' classification of the radiology reports. Included patients were divided into ligamentous injury only and fracture (which included fractures with ligamentous injuries).

Radiological Review

Investigators reviewing radiology reports were board-certified pediatric emergency medicine physicians and were blinded to the cervical spine injury classification. Each study patient had the plain radiography reports independently reviewed by 2 investigators. If any discrepancy was noted, the reports were reviewed again by 4 investigators (L.E.N., A.J.R., K.M.A., J.C.L.), and differences resolved using consensus methods.

Investigators assessed dictated radiology reports for the following: adequacy, presence of congenital abnormalities, and injury classification. The reports for adequate cervical spine radiographs contained a statement that there was appropriate visualization from C1 through the C7 to T1 vertebral body junction. Reports that indicated a demonstrable injury were considered adequate. Reports for inadequate radiographs contained statements that indicate incomplete visualization or poor radiological technique (eg, a radiopaque foreign body that obscured a portion of the cervical spine). When the radiology report did not specifically mention adequacy, radiographs were assumed to be adequate. Next, investigators assessed for the presence of congenital cervical spine abnormalities documented on the plain radiograph report. Finally, investigators determined if cervical spine injury was identified by plain radiographs. Radiology reports were classified into the following 3 categories: definite, possible, or no injury. Examples of possible injury descriptions included, but were not limited to the following: widening of the intervertebral space suggesting possible ligamentous injury, prevertebral soft tissue swelling, or lucencies suggesting possible fracture.

Cervical Spine Plain Radiograph Performance

We calculated the sensitivity of the 2 or more cervical spine radiographs to identify bony or ligamentous injury in children

TABLE 1. Comparison of Patients Included in the Study Versus Those Who Were Excluded for Lack of Plain Radiographs on Presentation, Missing Radiology Reports, or Having Only a Single View Obtained

	Included (n = 206), n (%) [*]	Excluded (n = 334), n (%) [*]
Age <8 y	58 (28)	109 (33)
Critical illness or focal neurologic deficit [†]	77 (39)	210 (65)
Endotracheal intubation	29	83
Altered mental status	42	109
Focal neurologic findings	45	131
Injury classification [†]		
Ligamentous	33 (16)	54 (16)
Fracture +/- ligamentous	173 (84)	141 (42)
Neurosurgical intervention [†]	75 (36)	87 (26)
Outcome of injury [†]		
Normal	158 (77)	228 (68)
Neurologic deficit	42 (20)	72 (22)
Death	6 (3)	34 (10)

^{*}Unknown (missing) values were excluded from calculations of percentages.

[†]P < 0.05 from Fisher exact test comparing included and excluded children.

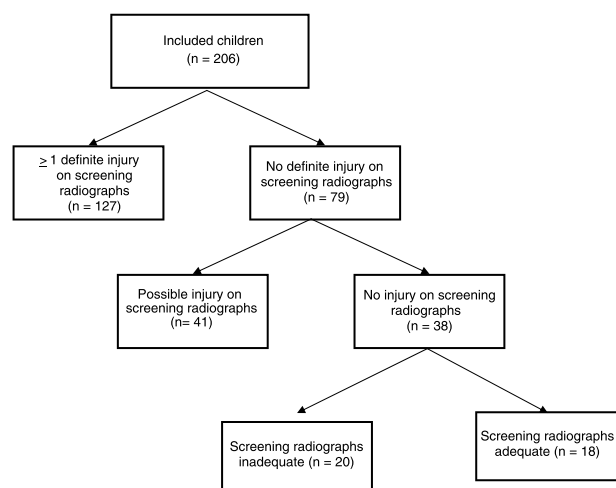


FIGURE 2. Classification of study patients by findings from screening radiography.

with blunt trauma–related cervical spine injury. We considered all patients with radiographs showing definite or possible injuries to have positive studies. Of the study patients with negative radiographs, we excluded the patients with inadequate studies. We did not exclude inadequate studies that showed an injury, as these radiographs were sufficient to show the cervical spine injury, and results would be used for medical decision making by the treating clinician. The sensitivity was calculated by dividing the number of patients with definite or possible injuries by the total number of included patients. Sensitivity was calculated for age groups (0–7 vs 8–15 years of age) and injury type (fracture vs ligamentous). Exact 95% confidence intervals (CIs) for the sensitivity were calculated for the sample overall and for the age and injury type subgroups. Fisher exact test for homogeneity was used to test for a difference in sensitivity of plain radiographs between age groups and between injury types and to compare characteristics of included and excluded children. For all analyses, we used SAS/STAT software (version 9; SAS Institute Inc, Cary, NC).

RESULTS

Of the 540 children with cervical spine injury, 445 (82%) had plain radiography obtained. Of these children, 390 (88%)

had their radiographs reviewed by the study site radiologist. Two or more radiographic views were obtained for 282 (72%) of these children. We excluded 76 children with cervical spine injury that is not usually detected by plain radiography alone (isolated spinal cord injury [$n = 1$], SCIWORA [$n = 46$], or AARS [$n = 29$]). We included the remaining 206 children in our study (Fig. 1). Included patients had a similar age but different presenting symptoms, injury classification, and clinical outcome as those who were excluded from this analysis (Table 1).

For the 206 included study patients, the median age was 12.7 years (interquartile range, 7.1–14.6 years) with 130 male patients (63%). Fifty-three percent of patients were first evaluated at referring hospitals and then were transferred for evaluation at the study site. Included children had the following types of cervical spine injury: isolated ligamentous injury (33, 16%) and fracture (173, 84%). Sixty-seven (33% of study patients) had 2 radiographic views obtained, and 139 (67%) had 3 or more views. Study patients had associated substantial injuries: head ($n = 26$), other thoracic trauma ($n = 12$), and extremity ($n = 13$). Of the study patients, 42 (20%) were left with persistent neurologic deficits, and 6 (3%) died as a result of their injuries. One hundred fifty-eight children (77%) recovered completely from their cervical spine injuries.

Of the 206 study patients, 186 (90%) had adequate plain radiographs of the cervical spine. Of the 206 patients, 168 (82%) had definite or possible cervical spine injury identified by plain radiograph. Of the remaining 38 children, 20 had radiographs of inadequate quality. Of the 186 children with adequate radiographs, 168 had definite or positive cervical spine injury visualized on plain radiograph for a sensitivity of 90% (168/186; 95% CI, 85%–94%) (Fig. 2; Table 2).

The sensitivities of plain radiographs for cervical spine injury by patient age and injury type are presented in Table 2. The sensitivity for all cervical spine injury was higher for older than for younger children, but the sensitivities for fracture and isolated ligamentous injury were similar. Table 3 lists the characteristics and the injury types for the following 3 groups of children with cervical spine injuries: those with normal and adequate radiographs, those with abnormal radiographs, and those with normal but inadequate radiographs.

Cervical spine radiographs failed to identify 18 children with the following cervical spine injury types (Table 4): fracture (15 children) and isolated ligamentous injury (3 children). Nine of the children with cervical spine injury missed by plain radiograph presented with 1 or more of the following: endotracheal intubation (4 children), altered mental status (5 children),

TABLE 2. The Sensitivity of Plain Radiographs for Cervical Spine Injury in Children

	Abnormal Plain Radiographs, No. (Row %)	Normal and Adequate Plain Radiographs, No. (Row %)	Inadequate Radiographs,* No. (Row %)	Estimated Sensitivity of Plain Radiographs, [†] % (95% CI)
Study sample (n = 206)	168 (82)	18 (9)	20 (10)	90 (85–94)
Age				
0–7 y (n = 58)	44 (76)	9 (16)	5 (9)	83 (70–92)
8–15 y (n = 148)	124 (84)	9 (6)	15 (10)	93 (88–97)
Injury classification				
Ligamentous (n = 33)	22 (67)	3 (9)	8 (24)	88 (69–97)
Fracture +/- ligamentous (n = 173)	146 (84)	15 (9)	12 (7)	91 (85–95)

*Excluded from the sensitivity calculation.

[†]Sensitivity = $100 \times \text{abnormal plain radiographs} / (\text{abnormal} + \text{normal plain radiographs})$.

TABLE 3. Comparison of Patients With Abnormal Radiographs to Those With Normal (Adequate and Inadequate) Radiographs

	Abnormal Plain Radiographs, n = 168	Normal and Adequate Plain Radiographs, n = 18	Inadequate Radiographs, n = 20
	No. (Row %)	No. (Row %)	No. (Row %)
Critical illness or focal neurologic findings (n = 77)	54 (70)	9 (12)	14 (18)
Endotracheal intubation	16	4	9
Altered mental status	27	5	10
Focal neurologic findings	35	5	5
Neurosurgical intervention (n = 75)	66 (80)	4 (5)	5 (7)
Outcome of injury			
Normal (n = 158)	131 (83)	15 (9)	12 (8)
Neurologic deficit (n = 42)	32 (76)	3 (7)	7 (17)
Death (n = 6)	5 (73)	0 (0)	1 (17)

TABLE 4. Characteristics and Injury Types for the 18 Children With Cervical Spine Injuries and Normal and Adequate Cervical Spine Radiographs

Age	Altered Mental Status	Focal Neurologic Findings	Intubated	Injury Mechanism	Cervical Spine Injury	Neurologic Outcome*	Operative Stabilization
1.9	No	No	No	Fall from elevation	Jefferson fracture	Normal	No
2.0	No	No	No	Fall from elevation	Axial single level ligamentous injury	Normal	No
2.7	No	Yes	No	Motor vehicle crash	Atlanta-occipital dislocation	Deficit	Yes
3.0	Yes	Missing	No	Motor vehicle crash	Occipital condyle fracture	Deficit	No
3.8	Yes	Yes	Yes	Motor vehicle crash	Subaxial single level ligamentous injury	Normal	No
4.8	No	No	No	Fall from standing/ walking/running	Subaxial unilateral pedicle fracture	Normal	No
5.0	No	No	No	Fall from elevation	C1 arch fracture	Normal	No
5.8	No	Yes	No	Back flip	Os odontoideum	Normal	Yes
5.9	No	No	No	Fall from standing/ walking/running	C1 arch fracture	Normal	No
8.6	Yes	No	Yes	Bike rider struck by moving vehicle	Transverse process fracture	Normal	No
9.2	No	No	No	Motor vehicle crash	Spinous process fracture	Normal	No
9.5	No	No	No	Motorized transport crash (eg, motorcycle)	Spinous process fracture	Normal	No
11.2	No	Yes	No	Fall from elevation	Os odontoideum	Normal	Yes
12.1	No	Yes	No	Trampoline	Unilateral facet fracture-dislocation	Normal	Yes
13.0	Yes	No	Yes	Pedestrian struck by moving vehicle	Subaxial compression fracture	Deficit	No
14.9	Missing	No	No	Sports injury	Spinous process fracture	Normal	No
15.3	No	No	No	Sports injury	Subaxial unilateral pedicle fracture	Normal	No
15.7	Yes	No	Yes	Motor vehicle crash	Multilevel vertebral body burst fractures	Normal	No

*Neurologic outcome assessed at the time of hospital discharge.

or focal neurologic findings on examination (5 children). Two of the children with focal neurologic deficits also had congenital abnormalities (os odontoideum), which can be visualized on plain radiography and prompt clinicians to obtain additional imaging.

The clinical characteristics of the 9 other patients with cervical spine injury and normal and adequate radiographs are described in Table 4. These 9 children with cervical spine injury and normal adequate radiographs presented without documented altered mental status, endotracheal intubation, or a focal neurologic deficit. Eight of these children had fractures, and 1 child had isolated ligamentous injury. Of these 9, none required neurosurgical intervention or were left with persistent neurologic deficits.

DISCUSSION

In this study, the sensitivity of 2 or more plain radiographic views to detect cervical spine injury in a large multicenter cohort of children with confirmed injuries was 90% (95% CI, 85%–94%). None of the children with normal neurologic examinations and injuries missed by plain radiography required neurosurgical intervention. Our large multicenter cohort study of children with confirmed injuries, the largest pediatric series to date, included a wide variety of cervical spine injury types. Importantly, we did not include patients with injuries not normally identified by plain radiography (ie, isolated cord injuries, SCIWORA, or AARS). Data were gathered from 17 different EDs, including pediatric, general, and community emergency practice settings. These features support the generalizability of our results to pediatric patients seeking care following blunt trauma.

Other investigators have reported the sensitivity of cervical spine plain radiographs. A previous study prospectively evaluated 34,069 patients of all ages and found a combined sensitivity of the 3-view series (anterior-posterior, lateral, and open-mouth views) to be 89% (95% CI, 87%–91%).⁸ The majority of injuries that were missed on plain radiographs in that prospective cohort were located in the posterior elements, typically at the level of C6–C7. The majority of patients in this study were adults, with only 30 patients with cervical spine injury younger than 18 years. In our pediatric study, the missed injuries were evenly distributed between the anterior and posterior elements and axial (C1–C2) and subaxial (C3–C7) regions of the cervical spine.

Several previous pediatric studies evaluated the sensitivity of plain radiography to detect cervical spine injury. In a retrospective series of 59 children, all but 1 injury (a case of SCIWORA) was detected by anterior-posterior or lateral x-ray views (98% sensitivity; 95% CI, 91%–100%).¹⁴ A second retrospective cohort of 72 children aged 0 to 15 years with cervical spine injury reported a sensitivity of 79% for a single lateral view (95% CI, 65%–86%) and 94% for a 3-view series (95% CI, 86%–98%).⁷ However, the CIs around those point estimates were wide, given the small sample sizes in these 2 studies. The third, a retrospective cohort of 187 children aged 0 to 19 years, found an overall sensitivity of 90% for a 3-view series (95% CI, 85%–94%).¹⁵ They evaluated their patient population in 2 cohorts: 0 to 8 years and 9 to 19 years of age. Similar to our study cohort, the sensitivity of plain radiographs was lower for the younger age group (75% for children 0–8 years vs 93% for children 9–19 years). In addition, the investigators found that CT of C1–C3 increased the sensitivity of injury detection to 94% to 97%.¹⁵ Each of these was a single-site study and included a standardized 3-view cervical spine series for all study patients. Our study included all children who had 2 or more distinct views rather than a standardized radiograph series

because we felt that this more accurately reflected current clinical practice in the care of these children.

We excluded children with isolated spinal cord injury, SCIWORA, and AARS from this study because these injuries are seldom identified by standard cervical spine plain radiography alone. By definition, children with isolated cord injury or SCIWORA will have normal plain cervical spine radiographs and require additional imaging to diagnosis.¹⁶ The diagnosis of AARS can also be challenging on plain radiographs, although the injury can sometimes be diagnosed by visualizing asymmetry of the lateral masses of C1 on the open-mouth view.¹⁷ However, the open-mouth view was uncommonly performed in our study sample. In addition, children with AARS often present with their head rotated, making obtaining adequate plain radiography challenging. For adequate demonstration of the relationship between C1 and C2, recent literature supports the routine use of dynamic CT when AARS is suspected.¹⁸

Over the past decade, cervical spine CT among pediatric patients has increased dramatically.¹⁹ Published literature suggests that CT is more sensitive and possibly more cost-effective in detecting cervical spine injury in patients considered at moderate to high risk for injury.^{20–27} These were primarily adult studies where the rate of reported cervical spine injury is almost 3-fold higher than children, and the risks associated with ionizing radiation are much lower.² In recognition of this growing body of literature, the Eastern Association for the Surgery of Trauma recently changed their guidelines for cervical spine screening to recommend use of CT as the initial screen for adult blunt trauma patients.²⁸

Published guidelines regarding the imaging of the pediatric cervical spine recommend plain radiographs for the initial imaging modality of the cervical spine in children after blunt trauma (2-view series for children <10 years and 3-view series for children >10 years).^{29,30} Appropriate use of cervical spine CT for the evaluation of pediatric cervical spine has not been well defined. Given the low prevalence of cervical spine injury, occurring in approximately 1% of children presenting to an ED for evaluation of blunt trauma,³¹ and the relatively high sensitivity of plain radiographs, our study supports the use of plain radiographs and not CT as the initial screening study for the pediatric blunt trauma patient. Overall, the chance that a child with normal cervical spine radiographs has a cervical spine injury is extremely low. We realize, however, that clinically important injuries may be missed if we rely on the plain cervical spine radiographs alone, and efforts need to be made to define those children who will benefit most from advanced imaging following blunt trauma.

Careful review of our study patients with cervical spine injury and normal and adequate cervical spine radiographs identified several factors that could potentially identify children at higher risk of cervical spine injury despite normal screening radiographs. These clinical factors included abnormal mental status, endotracheal intubation, or focal neurologic deficits at presentation. Also, patients with congenital abnormalities of the cervical spine have a higher incidence of cervical spine injury than children without these findings.¹² Therefore, children with any of these clinical findings or congenital cervical spine abnormalities should be strongly considered for advanced imaging even if plain radiography does not reveal a cervical spine injury.

The National Cancer Institute has recommended measures to minimize CT radiation in children. These recommendations suggest that practitioners “perform only necessary CT examinations” and “encourage development and adoption of pediatric CT protocols.”^{32,33} Consistent with prior studies, our findings support the use of plain radiography as an initial screen

for pediatric cervical spine injury. With increasing evidence about the performance of plain radiography in children, we can begin to refine existing evidence-based protocols for appropriate imaging of the pediatric cervical spine.

Our study has the following limitations. First, in our retrospective study, we had access only to the dictated radiology reports rather than the actual images, and thus we were unable to standardize the interpretation of the radiographs. We tried to minimize this variability by including only patients who had plain radiographs officially read by a radiologist at the study site. Second, we were missing dictated reports for some children with cervical spine injury who had plain radiographs obtained, but we describe those that were excluded from the study. Third, radiographs were interpreted by a heterogeneous group of radiologists with potentially different techniques of reviewing cervical spine radiographs; however, this may better replicate the situation faced by ED clinicians making real-time clinical decisions for patients with possible cervical spine injury. Fourth, we cannot determine whether radiologists used results from adjuvant radiological studies in making their interpretations of the screening radiographs. To avoid contamination in interpretation of the plain radiographs, whenever possible, we selected radiology reports dictated before review of CT or MRI of the patient's cervical spine. Also, at the majority of the study sites, the radiologist who interpreted plain radiography was not simultaneously reading spine CT or MRI scans. Finally, we cannot comment regarding the added benefit of particular views to the diagnosis of cervical spine injury.

CONCLUSIONS

Plain radiography identified most cervical spine injuries in our large cohort of children with known cervical spine injuries. Among the children with missed injuries, half had either altered mental status or focal neurologic findings. Although advanced imaging likely provides a higher sensitivity for cervical spine injury, it often comes with increased costs and significantly higher radiation exposure. Further prospective study is needed to determine exactly which children after blunt cervical spine trauma will benefit from advanced imaging.

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