


Cervical spine flexion-extension radiography versus magnetic resonance imaging in pediatric patients following blunt traumatic injury

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ABSTRACT

Background In pediatric trauma patients, 60–80% of spinal cord injuries involve the cervical vertebrae. While the American College of Radiology offers guidelines for best imaging practices in the setting of acute pediatric trauma, there is a lack of uniformity in imaging-decision protocols across institutions. MRI has been shown to demonstrate high sensitivity for both bony and ligamentous injuries while also avoiding unnecessary radiation exposure in the pediatric patient population. However, the efficacy of flexion-extension (FE) radiography following initial MRI has not been evaluated in children. Our hypothesis is that FE radiography conducted following an initial MRI does not contribute significant diagnostic information or reduce time to cervical collar removal and thus can be removed from institutional protocols in order to avoid unnecessary testing and reduce pediatric radiation exposure.

Methods Trauma data were collected for pediatric patients presenting with suspected acute cervical spine injury from 2014 to 2021. A total of 108 patients were subdivided into 41 patients who received "MRI Only" and 67 patients who received both "MRI and FE" diagnostic cervical spine imaging. Chi-square testing and t-tests were performed to determine differences between MRI and FE radiographic detection rates of bony and ligamentous injuries in the subgroups.

Results In patients for whom FE did not find any injury, MRI detected bony and ligamentous injuries in 9/63 and 12/65 cases, respectively. In 3/21 (14.3%) cases in which MRI detected a bony and/or ligamentous injury and FE did not, patients eventually required surgical intervention for c-spine stabilization. No patients required surgical fixation when FE radiography showed an abnormality and MRI was normal. Addition of follow-up FE radiography after initial MRI did not have a significant effect on overall hospital length of stay (MRI Only vs MRI+FE: 9.2±12.0 days vs 8.6±13.5 days, p=0.816) or on rates of collar removal at discharge or greater than 48 hours after imaging (MRI Only vs MRI+FE: 41.5% vs 56.7%, p=0.124).

Conclusions FE radiography following initial MRI did not have a significant effect on reducing time to cervical collar removal or overall hospital length of stay. In addition, in 3 of 6 cases (50.0%) in which surgical fixation was required, MRI detected ligamentous and/or bony injury while FE radiography was normal.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The majority of spinal cord injuries in acute pediatric trauma patients involve the cervical spine. Prompt and accurate diagnostic imaging is crucial for reducing patient morbidity and mortality; however, rigorous guidelines have not yet been established due to insufficient evidence.

WHAT THIS STUDY ADDS

⇒ Our study found that flexion-extension radiography following initial MRI had low sensitivity for bony and ligamentous cervical spine injuries and had no significant role in facilitating cervical collar removal or hospital discharge.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study supports the elimination of follow-up flexion-extension radiography from institutional imaging protocols for cases of suspected cervical spine injury in order to reduce radiation exposure in this sensitive population. We hope our findings will inform larger studies in the future aimed at determining optimal imaging protocols for the evaluation of acute pediatric trauma.

Level of Evidence This study contributes Level 2b scientific evidence consistent with a well-designed cohort or case-control analytic study.

INTRODUCTION

In pediatric blunt trauma patients, spinal cord injury without radiographic abnormality (SCIWORA) more commonly occurs in the cervical spine compared with the thoracic and lumbar regions.¹ Thus, prompt and accurate diagnostic imaging is crucial for reducing patient morbidity and mortality in cases in which cervical spinal cord injury (SCI) is suspected. While the American College of Radiology (ACR) Appropriateness Criteria for Suspected Spine Trauma in pediatric patients offer guidelines for best imaging practices in the setting of acute trauma,² there is a lack of uniformity in imaging-decision protocols across institutions, resulting in variable use of

CT, MRI, plain radiographs (PFs), and flexion-extension (FE) radiographs as initial and secondary imaging modalities.

Prior studies provided mixed evidence to support the use of either MRI or CT in the setting of acute pediatric trauma. However, MRI has demonstrated high sensitivity for both osseous and ligamentous injuries while also avoiding unnecessary radiation exposure in the pediatric patient population.³ Although initial MRI cervical spine evaluation in adult patients has been associated with a false-positive rate of between 25% and 40%,⁴ the effectiveness of MRI as an initial imaging modality for acute trauma followed by FE radiography has not been evaluated in the pediatric population. In this study, we assessed detection rates of bony and ligamentous injuries in both initial MRI evaluation and subsequent FE radiography in pediatric patients presenting with risk factors for cervical spinal cord injury in the setting of acute trauma. We also determined the subsequent impact of imaging findings on time to patient cervical collar clearance and time to hospital discharge. Our hypothesis is that FE radiography does not contribute significant diagnostic information following initial MRI or reduce time to cervical collar removal or discharge and thus can be removed from institutional protocols in order to avoid unnecessary testing and reduce pediatric radiation exposure.

METHODS

Following Institutional Review Board approval, we conducted a retrospective chart review of patients aged 18 years or younger who had been admitted to the pediatric intensive care unit (PICU) or pediatric medical floor for Level 1 or Level 2 acute trauma between January 1, 2014 and December 31, 2021. Only pediatric patients for whom a cervical collar was placed on or prior to admission for suspected cervical spine injury were included in this study. Trauma data were provided by our institution's Trauma Report Database, which is affiliated with our Level 1 American College of Surgeons accredited trauma program. Information related to patient demographics (age, weight, height, insurance coverage), characteristics on presentation (Glasgow Coma Score (GCS), Injury Severity Score (ISS), emergency department (ED) symptoms), operative management (if any), and discharge disposition was collected. ISS is a widely used scoring system created by the Association for the Advancement of Automotive Medicine which assigns points based on injury severity and the body part affected. Both total ISS score and Head ISS scores were collected for each patient for whom scores were available. Radiology reports were identified for each patient for trauma-related imaging, including plain film radiography, flexion-extension radiography, CT, and MRI. Report details related to each patient were recorded for imaging modality, time and date of examination, indication for imaging, and injury type detected (if any) on imaging. The time duration from patient injury to imaging and the lengths of PICU (if applicable) and hospital stays were manually calculated from information provided in the patients' charts. Cervical collar placement, removal, and duration were also recorded.

Patients were assigned unique identification numbers and personal identifiers were removed prior to statistical analysis. Chi-square testing and t-tests were performed to determine statistically significant differences between PF, FE, CT, and MRI detection rates of bony and ligamentous injuries. Pearson correlation coefficients were calculated for continuous variables; Spearman correlation coefficients were calculated for discrete variables. Continuous data are presented as mean \pm SD.

Ordinal data are presented as median and IQR (defined as third quartile value minus first quartile value).

RESULTS

Patient demographics

A total of 110 pediatric trauma patients meeting study criteria were included in our analysis. Data related to injury type ($n=103$), trauma level ($n=57$), length of PICU stay ($n=54$), time from injury to C-spine MRI ($n=47$), and time from injury to C-spine FE radiography ($n=27$) were only available for a specified subset of patients. For patients for whom data were available, the majority of patients presented following accidental trauma ($n=91$, 88.4%) and were admitted as a Level 1 trauma ($n=32$, 56.1%). The most common symptoms found on presentation to the ED were symptoms of neck pain ($n=60$, 54.5%) and neurological deficits ($n=60$, 54.5%), which included limb weakness, sensory changes, and word-finding difficulty. Of the patients admitted to the hospital, 67 patients (60.9%) were placed in the PICU. The mean length of PICU stay was found to be 208.0 hours (8.7 days); the mean length of overall hospital stay was also 8.7 days. The majority of patients were eventually discharged home ($n=88$, 80.0%). The mortality rate for this sample of hospitalizations was determined to be 2.7% ($n=3$). No significant correlation between the type of insurance that patients had on admission ("Insurance Type") and the type of imaging patients received while inpatient was found ($p=0.681$). Patient demographics are presented in [table 1](#).

Comparison of MRI versus FE radiography injury detection rates

Of the 110 pediatric patients included in our study, 108 (98.2%) of them underwent MRI for further evaluation of their suspected cervical spine injury. This group of 108 patients was subdivided in our analysis into patients who only received MRI ("MRI Only," $n=41$, 38.0%) and those who received both MRI and FE cervical spine imaging ("MRI+FE," $n=67$, 62.0%).

In patients for whom FE did not find any injury, MRI detected bony and ligamentous injuries in 9/63 and 12/65 cases, respectively. These differences were found to be significant for bony injuries ($\chi^2=9.43$, $p=0.002$) but not significant for ligamentous injuries ($\chi^2=0.45$, $p=0.502$). These findings are depicted in [table 2](#). In 3/21 (14.3%) cases in which MRI detected a bony and/or ligamentous injury and FE did not, the patient eventually required surgical intervention for cervical spine stabilization. No cases of surgical fixation were found when FE radiography showed an abnormality and MRI was normal ([table 3](#)). Using MRI findings as our diagnostic gold standard, we calculated the sensitivity of FE radiography to detect ligamentous or bony injuries to be 12.5% (3/24) and the specificity of FE radiography to be 93.0% (40/43) in our study.

Mean length of overall hospital stay between the "MRI Only" and "MRI+FE" groups was not found to be significantly different between the two groups (MRI Only vs MRI+FE: 9.2 ± 12.0 days vs 8.6 ± 13.5 days, $p=0.816$). Proportions of patients who had their cervical collar remain in place at discharge or more than 48 hours after imaging are reported in [table 4](#) for each subgroup of MRI and FE radiography results. Rates of cervical collar clearance at the time of discharge or more than 48 hours after imaging were not found to be significantly different between the "MRI Only" group and the "MRI+FE" group ("Removed," MRI Only vs MRI+FE: 41.5% vs 56.7%, $p=0.124$).

Table 1 Patient demographics and discharge disposition

	Population (n=110)
Age (mean±SD) (years)	9.6±5.6
Male (n, %)	69 (62.7)
Female (n, %)	41 (27.3)
BMI (mean±SD)	23.2±18.2
Time from injury to C-spine MRI (mean±SD) (hours)	22.2±19.4
Time from injury to C-spine FE radiography (mean±SD) (hours)	605±905.9
Length of PICU stay (mean±SD) (hours)	208.0±267.2
Length of hospital stay (mean±SD) (days)	8.7±12.8
Injury type (n=103)	
Accidental (n, %)	91 (88.4)
Non-accidental (n, %)	12 (11.7)
Trauma level (n=57)	
Level 1 (n, %)	32 (56.1)
Level 2 (n, %)	25 (43.9)
ED presentation	
GCS (median, IQR)	15.0, 3.5
Injury Severity Score (median, IQR)	9, 13
Head Injury Severity Score (median, IQR)	5, 3
Neurological deficit (n, %)	60 (54.5)
Neck pain (n, %)	60 (54.5)
Skull fracture (n, %)	30 (27.3)
Loss of consciousness (n, %)	22 (20.0)
Tracheostomy placement (n, %)	4 (3.6)
Other bodily injury (n, %)	47 (42.7)
Discharge disposition	
Home (n, %)	88 (80.0)
Rehabilitation (n, %)	10 (9.1)
Death (n, %)	3 (2.7)
Other (n, %)	9 (8.2)
Insurance type	
Private (n, %)	82 (74.5)
Medicaid (n, %)	12 (10.9)
No fault (n, %)	4 (3.6)
Other (n, %)	8 (7.3)
Self-pay (n, %)	4 (7.3)

Patient demographics at presentation and discharge disposition. Rates of injury type (n=103), trauma level (n=57), and length of PICU stay (n=54) were calculated for the specified number of patients for whom data were provided. Time from injury to C-spine MRI (n=47) and to C-spine FE radiography (n=27) were calculated for those patients for whom an estimated time of initial injury was provided. Continuous data are presented as mean (±SD); ordinal data are presented as median and IQR (3rd quartile–1st quartile).

BMI, body mass index; C-spine, cervical spine; ED, emergency department; FE, flexion-extension; GCS, Glasgow Coma Score; PICU, pediatric intensive care unit.

Patient characteristics associated with MRI and FE radiography injury detection rates

Correlations were determined between the detection of bony or ligamentous injuries on MRI and FE radiography and the following patient characteristics recorded on presentation to the emergency department: age (years), weight (kg), ISS, and GCS. No strong correlations were found between the detection of bony or ligamentous injuries on FE and MRI and any of the tested characteristics (table 5).

DISCUSSION

While pediatric patients comprise an estimated 5% of total cases of SCI,⁵ the vast majority of injuries in this age group (60–80%)

Table 2 MRI and FE radiographic detection of bony and ligamentous injuries

		MRI bony injury		
		Yes	No	Total
FE bony injury	Yes	3	1	4
	No	9	54	63
	Total	12	55	67
		MRI ligamentous injury		
		Yes	No	Total
FE ligamentous injury	Yes	0	2	2
	No	12	53	65
	Total	12	55	67

Detection of bony and ligamentous injuries by MRI vs FE radiography. P value for χ^2 analysis of bony injuries was 0.002; p value for analysis of ligamentous injuries was 0.502.

FE, flexion-extension.

involve the cervical region.⁶ This injury pattern is in contrast to adult SCI, in which only 30–40% of cases show damage to the cervical vertebrae.⁷ These differences in presentation between pediatric and adult patient populations are thought to be due to increased movement within the pediatric cervical spine caused by a combination of incomplete vertebral ossification, ligament laxity, weaker cervical musculature, and an increased head-to-torso ratio which transmits shearing forces to the cervical region during traumatic impact.⁷ Because of this increased flexibility, pediatric patients are much more likely to present with SCIWORA injuries, requiring admitting physicians to maintain a high level of suspicion in order to determine further clinical management. Presenting symptoms that would necessitate additional cervical spine evaluation have generally been thought of as those involving neck pain, decreased level of consciousness, neurological deficits, or distracting injuries. Due to biomechanical changes in the spine throughout maturation, spinal injuries in children above the age of 8 (when the pediatric cervical spine begins to take on characteristics of an adult cervical spine) often occur with simultaneous ligamentous or soft-tissue injury.⁷ Such injuries have been shown to be a source of significant morbidity and increased mortality. The rate of inpatient mortality for pediatric patients presenting with SCI has been estimated to be 7.3%⁸ and those patients who survive often have persistent motor

Table 3 MRI and FE radiography results requiring surgical intervention

	N	Surgical intervention
MRI normal	53	0
MRI abnormal	55	7
FE normal	55	3
FE abnormal	12	3
Only MRI	41	1
MRI+FE	67	6
MRI normal, FE normal	34	0
MRI abnormal, FE abnormal	9	3
MRI normal, FE abnormal	3	0
MRI abnormal, FE normal	21	3

Distribution of n=108 patients by findings on MRI and/or FE radiography. The number of patients requiring surgical intervention for cervical spine stabilization was recorded for each subgroup. An "Abnormal" result was defined as a bony and/or ligamentous injury detected on imaging.

FE, flexion-extension.

Table 4 Proportions of failed cervical collar clearance by MRI and FE results

	MRI normal	MRI abnormal	
FE normal	12/34 (35.3%)	8/21 (38.1%)	
FE abnormal	2/3 (66.7%)	7/9 (77.8%)	
	MRI only	MRI+FE	Total
Removed	17 (41.5%)	38 (56.7%)	55
Not removed	24 (58.5%)	29 (43.3%)	53
Total	41	67	108

Distribution of patients with cervical collar remaining at discharge or greater than 48 hours after MRI and/or FE radiographic imaging. Fractions were expressed as patients with failed cervical collar clearance divided by total subgroup population. An "Abnormal" result was defined as a bony and/or ligamentous injury detected on imaging. P value for χ^2 analysis of collar removal was 0.124. FE, flexion-extension.

deficits associated with significant developmental challenges as well as increased risk for long-term pneumonia-associated mortality secondary to respiratory muscle weakness.⁹

In patients older than 16 years, the ACR Appropriateness Criteria recommends the use of cervical spine CT without intravenous contrast as the initial imaging modality in cases of acute traumatic injury, followed by MRI without intravenous contrast when cervical spinal cord or nerve root injury are suspected.¹⁰ While a number of adult studies^{11–13} have suggested that CT is sufficient for the initial assessment of cervical SCI, the use of CT in younger pediatric patients is controversial due to the desire to reduce radiation exposure in this population.¹⁴ It has been estimated that the rate of fatal cancer development in children exposed to CT imaging may be as high as 1 patient for every 1000 scans.¹⁵ In pediatric patients aged 3 to 16 with at least one risk factor for cervical spine injury (based on Pediatric Emergency Care Applied Research Network or National Emergency X-ray Utilization Study criteria) and in patients younger than

3 years of age with Pieretti-Vanmarcke weighted score of greater than or equal to 2 to 8 points, the ACR recommends plain radiography for initial evaluation.² However, it has been suggested that in patients under the age of 5, the majority of cervical spine injuries occur in the upper cervical spine, where radiographs are prone to misdiagnosing C2/3 pseudo-subluxations, variability in epiphyseal growth centers, and unfused synchondroses as acute trauma-related injuries.¹⁶ Although these guidelines acknowledge the limitations of radiography for visualization of soft-tissue injuries, the use of CT without contrast and MRI without contrast in the pediatric population are both currently placed at a lower level of recommendation ("May be Appropriate") in cases of ambiguous radiographic findings due to insufficient evidence for which imaging technique may be superior.

In order to limit pediatric radiation exposure, the imaging protocol for evaluating acute cervical spine injury in pediatric patients at our institution involves initial PF radiography in the ED, followed by MRI and possible FE radiography if MRI results are inconclusive. In our study, we found that 67 of 108 (62.0%) patients receiving initial MRI later received follow-up FE radiography to further evaluate for cervical spine instability and facilitate cervical collar removal (if negative). While a preponderance of adult studies have increasingly shown that FE radiography has no role in the acute setting if initial PF or CT images are normal,^{4,17–21} it is currently unclear what role FE radiography has in follow-up cervical spine evaluation in pediatric patients, especially following initial MRI. FE radiography in pediatric patients has already been noted by the ACR guidelines to be unlikely to yield additional information following negative CT results due to muscle spasms in the acute setting which limit the proper patient positioning required for adequate imaging to take place.² In addition, cervical FE imaging in the acute setting is frequently complicated by limited patient motion due to altered consciousness, soft-tissue swelling and tenderness, and focal neurological symptoms. A review by Oh and Asha in

Table 5 Correlations between patient demographics and injuries detected on MRI or FE radiography

	ISS	GCS at presentation	MRI bony injury	FE bony injury
ISS	1.000			
GCS at presentation	−0.641	1.000		
MRI bony injury	0.060	0.112	1.000	
FE bony injury	−0.103	0.186	0.369	1.000
	Age	Weight	MRI bony injury	FE bony injury
Age	1.000			
Weight	0.846	1.000		
MRI bony injury	−0.215	−0.129	1.000	
FE bony injury	0.138	0.162	0.369	1.000
	ISS	GCS at presentation	MRI ligamentous injury	FE ligamentous injury
ISS	1.000			
GCS at presentation	−0.652	1.000		
MRI ligamentous injury	0.093	0.008	1.000	
FE ligamentous injury	−0.056	−0.111	−0.085	1.000
	Age	Weight	MRI ligamentous injury	FE ligamentous injury
Age	1.000			
Weight	0.889	1.000		
MRI ligamentous injury	0.054	−0.002	1.000	
FE ligamentous injury	−0.080	−0.131	−0.085	1.000

Correlation coefficients calculated between patient characteristics on presentation to the ED and detection of bony or ligamentous injury by MRI or FE radiography. Pearson correlation coefficients were calculated for continuous variables; Spearman correlation coefficients were calculated for discrete variables. FE, flexion-extension; GCS, Glasgow Coma Score; ISS, Injury Severity Score.

2016 of both adult and pediatric patients reported that various studies had found that between 30% and 95% of FE imaging were inconclusive due to restricted range of motion and poor visualization of the cervical spine.²² Similarly, a study conducted by Dwek and Chung in 2000 including 247 pediatric trauma patients did not find a diagnostic benefit to conducting FE radiography following negative cervical PF radiographs, noting that patient swallowing was the source for a number of false positives that had been misdiagnosed as soft-tissue edema.²³

Our study did not find a diagnostic benefit for utilization of follow-up FE radiography after initial cervical spine MRI in acute pediatric trauma patients. Sensitivity and specificity of FE radiography following MRI was found to be 12.5% and 93.0%, respectively, for cervical spine injuries found in our study. It was notable that all patients in our study who required surgical fixation for cervical spine stabilization had their injuries detected on MRI, while FE was only abnormal in 3 out of 6 (50.0%) of these cases for which both MRI and FE were performed. In 3 of 6 cases (50.0%) in which surgical fixation was required, MRI found ligamentous and/or bony injury while FE radiography was found to be normal. In addition, FE radiography was not found to have a statistically significant role in reducing hospital length of stay or in facilitating faster cervical collar removal. Limitations of our study include smaller subgroup population sizes, an inability to perform appropriate matching between “MRI Only” and “MRI+FE” patients, and a lack of grading to assess the adequacy or inadequacy of FE films from which data were drawn for our analysis. While the results of our study do not demonstrate a meaningful role for FE radiography in the evaluation of cervical SCI, we would suggest that larger, multi-center studies are necessary in the future to determine the most appropriate and efficient imaging protocol for pediatric patients in the setting of acute trauma.

CONCLUSIONS

FE radiography following initial MRI did not have a significant effect on reducing time to cervical collar removal or time to hospital discharge. In addition, FE radiography missed half of cases in which surgical fixation for cervical spine instability was indicated and detected on MRI.

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REFERENCES

- 1 Konovalev N, Peev N, Zileli M, Sharif S, Kaprovoy S, Timonin S. Pediatric cervical spine injuries and SCIWORA: WFNS Spine Committee recommendations. *Neurospine* 2020;17:797–808.
- 2 Kadom N, Palasis S, Pruthi S, Biffi WL, Booth TN, Desai NK, Falcone RA, Jones JY, Joseph MM, Kulkarni AV, et al. ACR Appropriateness Criteria® Suspected Spine Trauma-Child. *J Am Coll Radiol* 2019;16:S286–99.
- 3 Qualls D, Leonard JR, Keller M, Pineda J, Leonard JC. Utility of magnetic resonance imaging in diagnosing cervical spine injury in children with severe traumatic brain injury. *J Trauma Acute Care Surg* 2015;78:1122–8.
- 4 Hennessy D, Widder S, Zygun D, Hurlbert RJ, Burrows P, Kortbeek JB. Cervical spine clearance in obtunded blunt trauma patients: a prospective study. *J Trauma* 2010;68:576–82.
- 5 Apple DF, Anson CA, Hunter JD, Bell RB. Spinal cord injury in youth. *Clin Pediatr (Phila)* 1995;34:90–5.
- 6 Rosati SF, Maarouf R, Wolfe L, Parrish D, Poppe M, Manners R, Brown K, Haynes JH. Implementation of pediatric cervical spine clearance guidelines at a combined trauma center: twelve-month impact. *J Trauma Acute Care Surg* 2015;78:1117–21.
- 7 Kreykes NS, Letton RW. Current issues in the diagnosis of pediatric cervical spine injury. *Semin Pediatr Surg* 2010;19:257–64.
- 8 Jain A, Brooks JT, Rao SS, Ain MC, Sponseller PD. Cervical fractures with associated spinal cord injury in children and adolescents: epidemiology, costs, and in-hospital mortality rates in 4418 patients. *J Child Orthop* 2015;9:171–5.
- 9 Burns SP. Acute respiratory infections in persons with spinal cord injury. *Phys Med Rehabil Clin N Am* 2007;18:203–16.
- 10 Beckmann NM, West OC, Nunez D, Kirsch CFE, Aulino JM, Broder JS, Cassidy RC, Czuczman GJ, Demertzis JL, Johnson MM, et al. ACR Appropriateness Criteria® Suspected Spine Trauma. *J Am Coll Radiol* 2019;16:S264–85.
- 11 Schuster R, Waxman K, Sanchez B, Becerra S, Chung R, Conner S, Jones T. Magnetic resonance imaging is not needed to clear cervical spines in blunt trauma patients with normal computed tomographic results and no motor deficits. *Arch Surg* 2005;140:762–6.
- 12 Raza M, Elkhodair S, Zaheer A, Yousaf S. Safe cervical spine clearance in adult obtunded blunt trauma patients on the basis of a normal multidetector CT scan—a meta-analysis and cohort study. *Injury* 2013;44:1589–95.
- 13 Badhiwala JH, Lai CK, Alhazzani W, Farrokhfar F, Nassiri F, Meade M, Mansouri A, Sne N, Aref M, Murty N, et al. Cervical spine clearance in obtunded patients after blunt traumatic injury: a systematic review. *Ann Intern Med* 2015;162:429–37.
- 14 Pannu GS, Shah MP, Herman MJ. Cervical spine clearance in pediatric trauma centers: the need for standardization and an evidence-based protocol. *J Pediatr Orthop* 2017;37:e145–9.
- 15 Rice HE, Frush DP, Farmer D, Waldhausen JH, Committee AE. Review of radiation risks from computed tomography: essentials for the pediatric surgeon. *J Pediatr Surg* 2007;42:603–7.
- 16 Al-Sarheed S, Alwatban J, Alkhaibary A, Babgi Y, Al-Mohamadi W, Masuadi EM, Al Babbain I, Azzubi M. Cervical spine clearance in unconscious pediatric trauma patients: a level I trauma center experience. *Childs Nerv Syst* 2020;36:811–7.
- 17 Nasir S, Hussain M, Mahmud R. Flexion/extension cervical spine views in blunt cervical trauma. *Chin J Traumatol* 2012;15:166–9.
- 18 Goodnight TJ, Helmer SD, Dort JM, Nold RJ, Smith RS. A comparison of flexion and extension radiographs with computed tomography of the cervical spine in blunt trauma. *Am Surg* 2008;74:855–7.
- 19 Insko EK, Gracias VH, Gupta R, Goettler CE, Gaieski DF, Dalinka MK. Utility of flexion and extension radiographs of the cervical spine in the acute evaluation of blunt trauma. *J Trauma* 2002;53:426–9.
- 20 Pollack CV Jr, Hendey GW, Martin DR, Hoffman JR, Mower WR, NEXUS Group. Use of flexion-extension radiographs of the cervical spine in blunt trauma. *Ann Emerg Med* 2001;38:8–11.
- 21 Sierink JC, van Lieshout WAM, Beenen LFM, Schep NWL, Vandertop WP, Goslings JC. Systematic review of flexion/extension radiography of the cervical spine in trauma patients. *Eur J Radiol* 2013;82:974–81.
- 22 Oh JJ, Asha SE. Utility of flexion-extension radiography for the detection of ligamentous cervical spine injury and its current role in the clearance of the cervical spine. *Emerg Med Australas* 2016;28:216–23.
- 23 Dwek JR, Chung CB. Radiography of cervical spine injury in children: are flexion-extension radiographs useful for acute trauma? *AJR Am J Roentgenol* 2000;174:1617–9.