Childs Nerv Syst (2013) 29:1333–1338
DOI 10.1007/s00381-013-2092-x

ORIGINAL PAPER

A retrospective comparison of CT and MRI in detecting pediatric cervical spine injury

Mark Henry · Ron I. Riesenburger · James Kryzanski · Andrew Jea · Steven W. Hwang

Received: 4 March 2013 / Accepted: 21 March 2013 / Published online: 13 April 2013

Abstract
Purpose Although clinical criteria have been applied in the assessment of pediatric cervical spine trauma, no consensus has been established when imaging is required. With the increasing prevalence of computed tomography (CT) use in pediatric trauma and the concern for radiation in children, we sought to evaluate magnetic resonance imaging (MRI) and CT in detecting pediatric cervical spine injuries.
Methods We retrospectively queried a pediatric trauma database and identified pediatric patients who underwent both CT and MRI studies of the cervical spine and derived the statistical measures of each imaging modality to detect osseous and ligamentous/soft tissue injury.
Results Eighty-four patients were identified with a mean age of 9.0±5.8 years (56 % male). Sixteen patients were identified with injury, 12 with soft tissue abnormalities on MRI (nine edema and six ligamentous), and 6 with osseous abnormalities on CTs (six osseous fractures and one discogenic injury). Of the six patients who presented with CT-identified osseous injuries, MRI detected all six fractures as well as an additional compression fracture.
Conclusion Using CT as the standard for osseous injury, MRI had a sensitivity of 100 %, specificity of 97 %, negative predictive value (NPV) of 75 %, and positive predictive value (PPV) of 100 %. Using MRI as the standard for soft tissue injury, CT had a sensitivity of 23 %, specificity of 100 %, NPV of 88 %, and PPV of 100 %. Further studies are required to investigate the use of MRI to detect osseous injuries.

Keywords MRI · STIR imaging · Pediatric · Cervical spine · Trauma · CT

Introduction

Cervical spine injury is an uncommon occurrence in the pediatric population [2, 10, 14, 21, 24]. It has been estimated that only 1–3 % of all traumatic pediatric patients present with potential cervical spine injury [12, 22, 26]. However, despite the low incidence of such injuries, the clinical impact of a missed diagnosis is significant. Five to 10 % of patients who have a missed cervical spine injury experience worsening of neurological symptoms [29] or complete disability [28]. This necessitates a protocol for fast and efficient cervical spine clearance in a trauma setting. Although protocols with significant impact have been validated in adult trauma, such as the NEXUS trial and the Canadian C-Spine Rules [18, 30, 31], similar criteria are less established in the pediatric setting. Given the paucity of literature in the pediatric population, adult protocols are often extrapolated and applied to children.

In the adult population, when a patient fails to meet clinical criteria of cervical spine clearance, plain radiographs have traditionally been obtained. However, this modality has recently been replaced by computed tomography (CT) because of a reportedly higher sensitivity [5, 6, 9, 13]. Nuñez et al. found that CT identified up to 40 % of cervical spine injuries missed by plain radiographs [25]. However, these findings may not be similarly reproduced in the pediatric population. Hernandez et al. found no additional benefit of CT imaging over plain radiographs in 606 pediatric trauma patients [17].

CT scans are also not reliable for evaluation of soft tissue injury, an area best assessed with the use of magnetic resonance imaging (MRI) [1] or dynamic radiographs. Flexion/extension radiographs play a crucial role as the gold standard in assessing the traumatic cervical spine for ligamentous instability [23], yet not all patients can tolerate flexion/extension films

M. Henry · R. I. Riesenburger · J. Kryzanski · S. W. Hwang (✉)
Department of Neurosurgery, Tufts Medical Center,
Floating Hospital for Children, 800 Washington Street,
Boston, MA, USA
e-mail: shwang@tuftsmedicalcenter.org

A. Jea
Department of Neurosurgery, Texas Children's Hospital,
Houston, TX, USA

or obtain adequate studies. Many patients arrive obtunded or uncooperative, rendering flexion/extension radiographs difficult. MRI can therefore serve as an adjuvant to assess for ligamentous injury in patients unable to undergo dynamic radiographs. MRI can also provide important prognostic factors in the setting of suspected cervical spine injury [23].

Of particular importance in the pediatric cohort, MRI exposes patients to significantly less radiation than CT scans [8]. Research has shown that exposure to radiation in the form of imaging studies is a considerable variable in the development of malignancy, especially in children [3]. It is estimated that 2 % of future cancers may be attributable to radiation exposure, 15 % of which would be due to CT scans performed in patients under the age of 18 [27]. Radiation exposure, especially in the pediatric population, should be minimized to avoid possible long-term complications related to tissue damage on the cellular level that is directly due to radiation [8].

Given the increased use of CT imaging in pediatric trauma and the potential neoplastic risk, we sought to retrospectively evaluate the use of MRI as compared to CT in detecting injury to the cervical spine in the pediatric trauma setting. We were interested in investigating how reliable MRI is in assessing osseous injury, as well as how reliable CT is in assessing soft tissue injury.

Materials and methods

Upon IRB approval, a pediatric trauma database at Tufts Medical Center, a level 1 pediatric trauma center, was queried for patients who were treated for cervical spine injury and who met the inclusion criteria of (1) ≤18 years of age at time of injury, (2) involved in a trauma, and (3) had CT and MRI scans of the cervical spine performed within 48 h of injury. MRIs were performed using the following systems: Siemens Harmony 1.0®, Siemens Symphony 1.5®, GE Signa 12.0®, Philips Achieva MT3T®, and Philips Achieva 1.5XR®. Once the study cohort was compiled, we retrospectively collected all relevant demographic information for each patient, including the time course of imaging and the MRI and CT results. Each patient's imaging results were then analyzed to determine if osseous injury or soft tissue injury had occurred. CT was used as the standard for osseous injury, which we defined as fractures, locked facets, subluxations, and dislocations. However, MRI was also used to determine if compression fractures were present. MRI was used as the standard for soft tissue injury or neural injury, which we defined as soft tissue edema, ligamentous injury, muscular injury, and spinal cord injury. A finding on one modality, positive or negative (as determined by the radiographic report), was then correlated with the other modality to see whether a similar finding was found.

We sought to correlate MRI findings with CT findings in an attempt to determine the sensitivity and specificity parameters for CT imaging in picking up soft tissue injury, as well as the sensitivity and specificity of MRI imaging in picking up osseous injury. Osseous injury true positives and true negatives were determined by findings on CT, and soft tissue true positives and true negatives were determined by findings on MRI, while findings on the opposite modality in each case were considered the dependant variable. The only exception was the addition of compression fractures seen on MRI and not on CT into the fracture category. These findings were used to determine statistical parameters for CT scans in picking up soft tissue injury and for MRI scans in identifying osseous injury.

Results

One thousand three hundred thirty-six patients were identified through the pediatric trauma database, of which 84 patients

Table 1 Demographics of patient cohort and stratification based on the type of injury

	Patient cohort (*n*=84)	Soft tissue injury on MRI (*n*=12)	Osseous injury on CT (*n*=6)
Average age (years)	9.0±5.8	10.1±5.7	11.5±5.8
Male (%)	56	75	50
Average GCS	12.8 (3–15)	13.0 (3–15)	15 (3–15)
Time between injury and CT (average days)	0.3 (0–1)	0.2 (0–1)	0.3 (0–1)
Time between injury and MRI (average days)	0.7 (0–2)	0.9 (0–2)	0.8 (0–2)
Time between CT and MRI (average days)	0.4 (0–2)	0.8 (0–2)	0.5 (0–1)
Mechanism of injury (%)			
Sports/physical activity	24 (28)	3 (25)	3 (75)
MVA	28 (32)	5 (42)	0 (0)
Domestic violence	3 (6)	0 (0)	0 (0)
Fall	25 (29)	4 (33)	1 (25)
Self-inflicted	1(1)	0 (0)	0 (0)
Nonspecific/unclear	3 (4)	0 (0)	0 (0)

GCS Glasgow Coma Scale, *MVA* motor vehicle accident, *MRI* magnetic resonance imaging, *CT* computed tomography

Table 2 List of injuries by MRI and CT

Category of injury	CT findings	MRI findings
Soft tissue	• Prevertebral soft tissue edema	• Prevertebral swelling
		• Soft tissue edema
	• Soft tissue edema posteriorly	• Fluid within articular joint
Ligamentous	• Splaying of the spinous processes	• Ligamentous injury
Osseous	• Vertebral body fractures	• Edema around fracture
	• Wedging of vertebral body	• Edema within vertebral body
	• Osseous fractures	• Edema within pedicles/spinous process
		• Linear hyperintensity within bodies
		• Burst fracture
		• Discontinuity of atlas
Discogenic	• Disc herniation	• Annular tear

MRI magnetic resonance imaging, *CT* computed tomography

met the inclusion criteria (6 %; Table 1). The average patient age was 9.0±5.8 years old with 56 % being male. The mean Glasgow coma scale for these patients was 12.8 (range 3–15), and motor vehicle accidents accounted for a majority of sustained injuries (32 %). Eighty out of the 84 patients in the cohort had their MRI after their CT scan, while four had an MRI prior to the CT scan (these four patients did not have positive findings on either MRI or CT). Of the 84 patients identified, 16 were found to be positive for injury. Twelve of the 16 patients had soft tissue injury identified by MRI while 6 of the 16 patients had an osseous injury indentified by CT. Three of six patients who presented with osseous injury on CT also presented with soft tissue injury on MRI (Table 2).

Of the six patients who presented with CT-identified osseous injuries, MRI detected all six fractures as well as an additional compression fracture (Fig. 1). MRI had a sensitivity of 100 %, a specificity of 99 %, a negative predictive value of 100 % to detect both types of injury, and a positive predictive value of 86 % to detect fracture and 50 % to detect disc protrusion injury when CT findings are held as the standard (Table 3).

Of the 12 patients who presented with soft tissue injury, six presented with soft tissue edema, three presented with ligamentous injury, and three presented with both edema and ligamentous injury on MRI. No patient presented with spinal cord injury. CT scan detected one of nine patients who presented with edema as well as detecting edema that was not seen on MRI (false positive). The statistical parameters for CT picking up edema when MRI is held as the standard are a sensitivity of 11 %, specificity of 99 %, positive predictive value of 50 %, and negative predictive value of 90 %. CT scan detected one of six ligamentous injuries on MRI. The statistical parameters for CT picking up ligamentous injury when MRI is held as the standard are a sensitivity of 17 %, specificity of 100 %, positive predictive value of 100 %, and negative predictive value of 94 % (Table 4).

The overall ability of MRI to detect any osseous or discogenic abnormality based on the number of patients with injuries was: sensitivity of 100 %, specificity of 97 %, positive predictive value of 75 %, and negative predictive value of 100 % (Table 5). The overall utility for CT to identify soft tissue or ligamentous injuries based on the number of patients was: sensitivity of 23 %, specificity of 100 %, a positive predictive value of 100 %, and negative predictive value of 88 % (Table 6). If these parameters are derived from the total possible injuries for each patient (two possible injuries in each subgroup: ligamentous/edema for

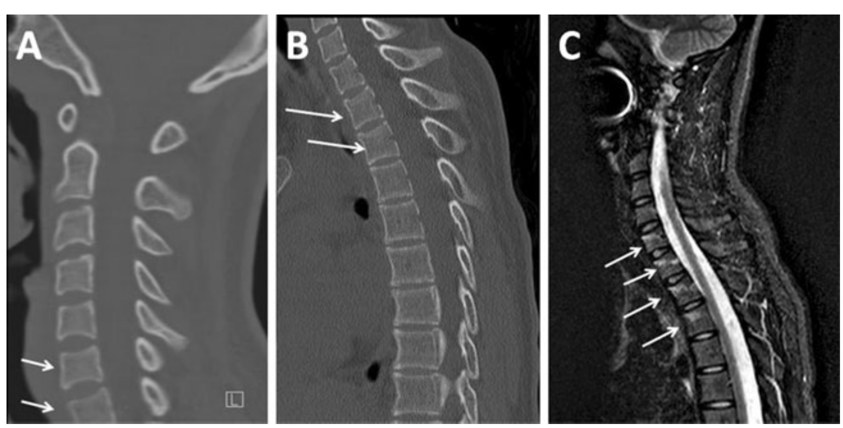

Fig. 1 Case illustration of a 16-year-old girl who fell off a moon bounce and had neck pain and transient foot numbness. **a** Sagittal CT reconstructions of the cervical spine with a normal interpretation. **b** Sagittal CT reconstructions of the thoracic spine with a normal interpretation. **c** Sagittal STIR (short T1 inversion recovery) sequence MRI showing edema in the superior endplates of C6, C7, T1, and T2

Table 3 MRI to detect osseous fracture or discogenic injury

	CT+	CT−	PPV	NPV
Fracture				
MRI+	6	1	86 %	
MRI−	0	77		100 %
Sensitivity	100 %			
Specificity		99 %		
Disc protrusion				
MRI+	1	1	50 %	
MRI−	0	82		100 %
Sensitivity	100 %			
Specificity		99 %		

PPV positive predictive value, *NPV* negative predictive value, *MRI* magnetic resonance imaging, *CT* computed tomography

MRI and fracture/discogenic for CT), the parameters for MRI would be a sensitivity of 100 %, specificity of 99 %, positive predictive value of 78 %, and a negative predictive value of 100 %, while the parameters for CT would be a sensitivity of 13 %, a specificity of 99 %, a positive predictive value of 66 %, and a negative predictive value of 92 %.

Discussion

Significant anatomic and physiological differences between the adult and pediatric cervical spine limit attempt to apply results from adult studies to the pediatric population [4, 7, 27]. The cervical spine of the pediatric patient contains ossification centers as well as un-calcified areas, thus potentially lowering the yield of CT evaluation [2, 14, 16, 17], especially in patients under 10 years of age. Furthermore, a majority of pediatric cervical spine injury is localized to the non-osseous component of the spine [23]. It is worth noting

Table 4 CT to detect soft tissue or ligamentous injury

	MRI+	MRI−	PPV	NPV
Soft tissue edema				
CT+	1	1	50 %	
CT−	8	74		90 %
Sensitivity	11 %			
Specificity		99 %		
Ligamentous injury				
CT+	1	0	100 %	
CT−	5	78		94 %
Sensitivity	17 %			
Specificity		100 %		

PPV positive predictive value, *NPV* negative predictive value, *MRI* magnetic resonance imaging, *CT* computed tomography

Table 5 Overall MRI ability in detecting osseous injury based on patient count

	CT+	CT−	PPV	NPV
MRI+	6	2	75 %	
MRI−	0	76		100 %
Sensitivity	100 %			
Specificity		97 %		

PPV positive predictive value, *NPV* negative predictive value, *MRI* magnetic resonance imaging, *CT* computed tomography

that the most common type of injury in children is soft tissue as opposed to osseous injury, further lowering the diagnostic yield of CT in the pediatric population [11, 15, 23].

CT imaging also increases the risk of radiation exposure and potential cancer development [12]. Many physicians underestimate the impact of radiation on the pediatric population [32]. Compared to flexion/extension films, CT exposes a patient to 90–200 times more radiation [12, 20], leading to an increased risk of cancer, especially that of the thyroid gland. It is important therefore to investigate other options for imaging and determine their utility in detecting injury. In our series, we found that MRI is able to rule in osseous injury with a specificity of 97 % and had a sensitivity of 100 %. Given the injury–epidemiology and physiological differences between adults and children, balanced with a significant radiation concern in the latter, MRI may be an alternative option to assess the cervical spine when clinical suspicion of injury is high. Advanced imaging may still be needed to better define the injury once it is identified, but MRI may serve as a screening tool to further limit radiation exposure in children.

Holmes et al. conducted a similar study on a multicenter scale comparing CT and MRI in detecting adult cervical spine injuries in a prospective, observational cohort [19]. Of the 688 patients identified in their study, 66 had both CT and MRI (9 %), similar to our cohort (6 %). These 66 patients had a total of 130 osseous injuries, 65 of which were inferred by MRI (52 %), and 25 ligamentous injuries, 3 of which were inferred by CT (12 %). When strictly comparing results for fractures, we found that the sensitivity of MRI to detect fractures was 100 %. Our results investigating the ability of CT to identify

Table 6 Overall CT ability in detecting soft tissue injury based on patient count

	MRI+	MRI−	PPV	NPV
CT+	3	0	100 %	
CT−	10	71		88 %
Sensitivity	23 %			
Specificity		100 %		

PPV positive predictive value, *NPV* negative predictive value, *MRI* magnetic resonance imaging, *CT* computed tomography ligamentous injuries were comparable. We found that CT inferred 17 % of the ligamentous injuries detected by MRI, similarly to Holmes et al. who determined that value to be 12 %. The variation in patient ages and hence injury types may partially account for the differences in MRI findings between both studies. Furthermore, their results were reported per fracture, whereas we reported injuries by patient numbers and hence have smaller sample sizes.

The small sample size in our series further limits our results because of underrepresentation of injury types. Another limitation of this study is its retrospective nature. This is especially an issue in regards to the osseous injury inferred by MRI, as radiologists who interpreted MRIs may have had access to the CT study results prior to viewing the MRI. This may potentially increase MRI sensitivity, a problem also faced by Holmes et al. However, this is not a significant problem for the reverse with CT scans, as 95 % of all CT scans were done prior to MRIs in our study (the 6 % translates to four patients, all of which were negative for injury). Our study is also limited by a selection bias. Similar to the Holmes study, we were able to view the real-time clearance decisions done at a level 1 trauma center, yet this gives rise to a potential for selection bias, as patients with positive CT findings may not have undergone further imaging.

Conclusions

In our study, despite a potential of limitations, MRI had a high sensitivity at excluding osseous injuries, whereas CT had a low sensitivity to rule-out soft tissue/ligamentous injury. MRI may therefore have potential in screening for osseous injury in a select pediatric cohort.

Conflict of interest The authors declare they have no conflicts of interest.

References

1. Ackland HM, Cooper DJ, Malham GM, Stuckey SL (2006) Magnetic resonance imaging for clearing the cervical spine in unconscious intensive care trauma patients. J Trauma 60(3):668–673. doi:10.1097/01.ta.0000196825.50790.e8
2. Aufdermaur M (1974) Spinal injuries in juveniles: necropsy findings in twelve cases. J Bone Joint Surg Br 56:513–519
3. Baysson H, Etard C, Brisse HJ, Bernier MO (2012) Diagnostic radiation exposure in children and cancer risk: current knowledge and perspectives. Arch Pediatr 19(1):64–73. doi:10.1016/j.arcped.2011.10.023
4. Birney TJ, Hanley EN (1989) Traumatic cervical spine injuries in childhood and adolescence. Spine 14(12):1277–1282. doi:10.1097/00007632-198912000-00001
5. Blackmore CC, Mann FA, Wilson AJ (2000) Helical CT in the primary trauma evaluation of the cervical spine: an evidence-based approach. Skeletal Radiol 29:632–639. doi:10.1007/s002560000270
6. Blackmore CC, Ramsey SD, Mann FA, Deyo RA (1999) Cervical spine screening with CT in trauma patients: a cost-effectiveness analysis. Radiology 212(1):117–125
7. Blauth M, Schmidt U, Otte D, Krettek C (1996) Fractures of the odontoid process in small children: biomechanical analysis and report of three cases. Eur Spine J 5(1):63–70. doi:10.1007/BF00307830
8. Brenner DJ, Hall EJ (2007) Computed tomography—an increasing source of radiation exposure. N Engl J Med 357(22):2277–2284. doi:10.1056/NEJMra072149
9. Broder J, Fordham LA, Warshuaer DM (2007) Increasing utilization of computed tomography in the pediatric emergency department 2000–2006. Emerg Radiol 14:227–232. doi:10.1007/s10140-007-0618-9
10. Brown RL, Brunn MA, Garcia VF (2001) Cervical spine injuries in children: a review of 103 patients treated consecutively at a level 1 pediatric trauma center. J Pediatr Surg 36:1107–1114. doi:10.1053/jpsu.2001.25665
11. Dickman CA, Rekate HL, Sonntag VK, Zabramski JM (1989) Pediatric spinal trauma: vertebral column and spinal cord injuries in children. Pediatr Neurosci 15:237–256. doi:10.1159/000120476
12. Egloff AM, Kadom N, Vezina G, Bulas D (2009) Pediatric cervical spine trauma imaging: a practical approach. Pediatr Radiol 39(5):447–456. doi:10.1007/s00247-008-1043-2
13. Griffen MM, Frykberg ER, Kerwin AJ, Schinco MA, Tepas JJ, Rowe K et al (2003) Radiographic clearance of blunt cervical spine injury: plain radiograph or computed tomography scan? J Trauma 55:222–227. doi:10.1097/01.TA.0000083332.93868.E2
14. Hachen HJ (1977) Spinal cord injury in children and adolescents diagnostic pitfalls and therapeutic consideration in the acute stage [proceedings]. Paraplegia 15:55–64
15. Hadley MN, Zabramski JM, Browner CM, Rekate H, Sonntag VK (1988) Pediatric spinal trauma. Review of 122 cases of spinal cord and vertebral column injuries. J Neurosurg 68:18–24. doi:10.3171/jns.1988.68.1.0018
16. Hegenbarth R, Ebel KD (1976) Roentgen findings in fractures of the vertebral column in childhood. Examination of 35 patients and its results. Pediatr Radiol 5:34–39. doi:10.1007/BF00988660
17. Hernandez JA, Chupik C, Swischuk LE (2004) Cervical spine trauma in children under 5 years: productivity of CT. Emerg Radiol 10(4):176–178. doi:10.1007/s10140-003-0320-5
18. Hoffman JR, Mower WR, Wolfson AB, Todd KH, Zucker MI, National Emergency X-Radiography Utilization Study Group (2000) Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. N Engl J Med 343(2):94–99. doi:10.1056/NEJM200007133430203
19. Holmes JF, Mirvis SE, Panacek EA, Hoffman JR, Mower WR, Velmahos GC et al (2002) Variability in computed tomography and magnetic resonance imaging in patients with cervical spine injuries. J Trauma 53(3):524–529
20. Lorenzo RL, Karrellas A, Shiran S, Deguzman MA, Jimenez RR (2008) CT versus plain radiographs for evaluation of c-spine injury in young children: do benefits outweigh risks? Pediatr Radiol 38(6):635–644. doi:10.1007/s00247-007-0728-2
21. Kewalramani LS, Kraus JF, Sterling HM (1980) Acute spinal-cord lesions in a pediatric population: epidemiological and clinical features. Paraplegia 18:206–219. doi:10.1038/sc.1980.36
22. Kokoska ER, Keller MS, Rallo MC, Weber TR (2001) Characteristics of pediatric cervical spine injuries. J Pediatr Surg 36:100–105. doi:10.1053/jpsu.2001.20022
23. Mccall T, Fassett D, Brockmeyer D (2006) Cervical spine trauma in children: a review. Neurosurg Focus 20(2):E5. doi:10.3171/foc.2006.20.2.6

24. Mulligan RP, Friedman JA, Mahabir RC (2010) A nationwide review of the associations among cervical spine injuries, head injuries, and facial fractures. J Trauma 68(3):587–592. doi:10.1097/TA.0b013e3181b16bc5
25. Nuñez DB, Zuluaga A, Fuentes-bernardo DA, Rivas LA, Becerra JL (1996) Cervical spine trauma: how much more do we learn by routinely using helical CT? Radiographics 16(6):1307–1318
26. Patel JC, Tepas JJ III, Mollitt DL, Pieper P (2001) Pediatric cervical spine injuries: defining the disease. J Pediatr Surg 36:373–376. doi:10.1053/jpsu.2001.20720
27. Rahimi SY, Stevens EA, Yeh DJ, Flannery AM, Choudhri HF, Lee MR (2003) Treatment of atlantoaxial instability in pediatric patients. Neurosurg Focus 15(6):ECP1. doi:10.3171/foc.2003.15.6.7
28. Rathore N, Eissa HM, Margolin JF, Liu H, Wu MF, Horton T et al (2012) Pediatric Hodgkin lymphoma: are we over-scanning our patients? Pediatr Hematol Oncol 29(5):415–423. doi:10.3109/08880018.2012.684198
29. Schuster R, Waxman K, Sanchez B, Becerra S, Chung R, Conner S et al (2005) 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 140(8):762–766. doi:10.1001/archsurg.140.8.762
30. Stiell IG, Clement CM, Mcknight RD, Brison R, Schull MJ, Rowe BH et al (2003) The Canadian C-spine rule versus the NEXUS low-risk criteria in patients with trauma. N Engl J Med 349(26):2510–2518. doi:10.1056/NEJMoa031375
31. Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ et al (2001) The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA 286(15):1841–1848. doi:10.1001/jama.286.15.1841
32. Thomas KE, Parnell-Parmley JE, Haidar S, Moineddin R, Charkot E, Ben DG et al (2006) Assessment of radiation dose awareness among pediatricians. Pediatr Radiol 36(8):823–832. doi:10.1007/s00247-006-0170-x