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Pediatric Cervical Spine Injury Following Blunt Trauma in Children Younger Than 3 Years
The PEDSPINE II Study

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IMPORTANCE There is variability in practice and imaging usage to diagnose cervical spine injury (CSI) following blunt trauma in pediatric patients.

OBJECTIVE To develop a prediction model to guide imaging usage and to identify trends in imaging and to evaluate the PEDSPINE model.

DESIGN, SETTING, AND PARTICIPANTS This cohort study included pediatric patients (<3 years years) following blunt trauma between January 2007 and July 2017. Of 22 centers in PEDSPINE, 15 centers, comprising level 1 and 2 stand-alone pediatric hospitals, level 1 and 2 pediatric hospitals within an adult hospital, and level 1 adult hospitals, were included. Patients who died prior to obtaining cervical spine imaging were excluded. Descriptive analysis was performed to describe the population, use of imaging, and injury patterns. PEDSPINE model validation was performed. A new algorithm was derived using clinical criteria and formulation of a multiclass classification problem. Analysis took place from January to October 2022.

EXPOSURE Blunt trauma.

MAIN OUTCOMES AND MEASURES Primary outcome was CSI. The primary and secondary objectives were predetermined.

RESULTS The current study, PEDSPINE II, included 9389 patients, of which 128 (1.36%) had CSI, twice the rate in PEDSPINE (0.66%). The mean (SD) age was 1.3 (0.9) years; and 70 patients (54.7%) were male. Overall, 7113 children (80%) underwent cervical spine imaging, compared with 7882 (63%) in PEDSPINE. Several candidate models were fitted for the multiclass classification problem. After comparative analysis, the multinomial regression model was chosen with one-vs-rest area under the curve (AUC) of 0.903 (95% CI, 0.836-0.943) and was able to discriminate between bony and ligamentous injury. PEDSPINE and PEDSPINE II models' ability to identify CSI were compared. In predicting the presence of any injury, PEDSPINE II obtained a one-vs-rest AUC of 0.885 (95% CI, 0.804-0.934), outperforming the PEDSPINE score (AUC, 0.845; 95% CI, 0.769-0.915).

CONCLUSION AND RELEVANCE This study found wide clinical variability in the evaluation of pediatric trauma patients with increased use of cervical spine imaging. This has implications of increased cost, increased radiation exposure, and a potential for overdiagnosis. This prediction tool could help to decrease the use of imaging, aid in clinical decision-making, and decrease hospital resource use and cost.

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Supplemental content

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Pediatric cervical spine injury (CSI) following blunt trauma has an incidence of 0.6% to 2%.[1-6] For the youngest trauma patients, those younger than 3 years, clearance of the cervical spine may be difficult because patients can be nonverbal or nonparticipatory in the trauma evaluation.

In the adult trauma population, NEXUS and the Canadian C-Spine Rule have become well-established cervical spine clearance tools that can be applied to certain adult patients.[7,8] Over the years, these adult-specific decision-making paradigms have been shown to significantly reduce the need for imaging in patients who meet certain exclusion criteria.[9] These criteria, despite having an overall low number of very young patients in their study cohorts, have been extrapolated to the pediatric trauma population in an attempt to reduce radiation exposure, cost, and unnecessary use of imaging studies.[10-12] Limitations of this approach, in addition to the unclear applicability of these criteria in the young pediatric population, includes the variability in clinician comfort in evaluating young children.[13-16] Even in the absence of clinical symptoms, the default for many centers is to obtain imaging.

A handful of studies have attempted to create pediatric-specific guidelines for the use of imaging in the trauma setting.[2,17,18] Included in these is the PEDSPINE trial, which proposed an easy-to-use scoring system with a high negative predictive value for CSI.[2] Nevertheless, there continues to be widespread variability in clinical practice and continued overusage of radiographic imaging.[19] Therefore, the purpose of this study was (1) to identify current trends in pediatric CSI and imaging of the pediatric trauma patient (age <3 years) following blunt trauma; (2) to evaluate the previously created scoring system proposed in the PEDSPINE trial; and (3) to develop prediction models aimed at guiding the use of imaging in this patient population following blunt trauma.

Key Points

Question What are the trends in imaging used to diagnose cervical spine injury (CSI) following blunt trauma in pediatric patients (age <3 years) and how can clinicians better identify which patients benefit from radiographic evaluation?

Findings In this cohort study of 128 with CSI, variability was found in radiographic use, including increased usage of magnetic resonance imaging and subsequent diagnosis of ligamentous injury. A new prediction tool was created to help predict CSI.

Meaning This prediction tool could help to decrease the use of imaging, aid in clinical decision-making, and decrease hospital resource use.

Methods

Formatting and reporting of this cohort study were all performed in accordance with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Study Population

The 22 centers originally involved in the PEDSPINE study were invited, with renewed participation from 15. With approval of individual site institutional review boards, data were obtained from these 15 trauma centers, which were all located in the US. A list of participating institutions can be found in eTable 1 in Supplement 1. Consent was waived given the retrospective nature and minimal risk, approved by the institutional review board. Patients were included if they were younger than 3 years and had sustained blunt trauma during the 10.5-year study period (January 2007 and July 2017). Patients who died prior to obtaining cervical spine imaging in the emergency department were excluded.

Data and Outcome Measures

Basic demographic data and clinical variables were obtained from medical records for each patient, including age, sex, race, mechanism of injury (motor vehicle collision [MVC], pedestrian struck, fall, suspected physical abuse, other), Glasgow Coma Scale (GCS) score (eye, verbal, and motor), cervical spine imaging, CSI, and mortality. All cervical spine imaging was recorded for all patients, both at the treatment hospital and transferring hospitals, if applicable.

The primary outcome, CSI, was defined as osseous CSI or ligamentous CSI as seen on plain radiograph, computed tomography (CT), or magnetic resonance imaging (MRI). Also included was spinal cord injury without radiographic abnormality, which was diagnosed by clinical symptoms with or without adjunct MRI imaging. Other CSI injuries were also collected via free-text input. All injuries were evaluated in granular detail by trained evaluators, and clinically significant injuries were deemed those for which an intervention was performed, whether it be an invasive intervention (operation or halo vest application) or continuation of cervical spine immobilization (hard collar) after targeted assessment by a trained professional (ie, pediatric neurosurgery or pediatric orthopedic spine surgeon). Patients who died during trauma hospitalization and were diagnosed with a CSI were included in the CSI group.

PEDSPINE Validation

The PEDSPINE II study provided an external validation set for the CSI risk prediction score proposed in the PEDSPINE study.[2] The PEDSPINE risk score was derived using a logistic regression model. It assigns a risk score between 0 and 8, with 8 indicating the highest risk. The score is computed as: score = 3 × II (GCS score <14) + 2 × II (GCS eye score = 1) + 2 × II (injury type = MVC) + 1 × II (patient age >2 years).

This score was calculated for all patients in the new cohort and assessed using area under the curve (AUC), the area under the receiver operating characteristic (ROC) curve.

PEDSPINE II Model

All patients were categorized into 3 injury types: (1) no CSI, (2) osseous (ie, fractures and dislocations), and (3) ligamentous injuries, hematomas, and spinal cord injury without radiographic abnormality. For those patients with more than 1 classification of injury, the category was determined by the primary injury requiring intervention. A multiclass classification problem was formulated, which allowed for the prediction of a patient's likelihood of belonging to each of these 3

Table 1. Basic Demographics and Clinical Assessment[a]

Characteristic	No. (%) No CSI (n = 9261)	CSI (n = 128)	P value
Age, y, median (IQR)	1.2 (0.4-2.1)	1.5 (0.6-2.2)	.06
Male	5352 (57.8)	70 (54.7)	.54
Female	3909 (42.2)	58 (45.3)	
Race			
African American	1847 (19.9)	42 (32.8)	<.001
Asian	154 (1.7)	0 (0)	NA
Hispanic	977 (10.6)	13 (10.2)	>.99
White	5817 (62.8)	66 (51.6)	.01
Other[b]	785 (8.5)	13 (10.2)	.61
GCS score, median (IQR)			
Eye	4 (4.0-4.0)	2 (1.0-4.0)	<.001
Verbal	5 (5.0-5.0)	2 (1.0-5.0)	<.001
Motor	6 (6.0-6.0)	4 (1.0-6.0)	<.001
Total	15 (15.0-15.0)	8 (3.0-15.0)	<.001
Mechanism of injury			
Fall	5433 (58.7)	13 (10.2)	<.001
Suspected physical abuse	1608 (17.4)	46 (35.9)	<.001
MVC	748 (8.1)	44 (34.4)	<.001
Pedestrian struck	297 (3.2)	13 (10.2)	<.001
Other	1023 (11.1)	11 (8.6)	.46
Unknown	152 (1.6)	1 (0.8)	.68
Imaging			
Any imaging	7419 (80.1)	128 (100.0)	NA
Plain radiograph	3538 (38.2)	93 (72.7)	<.001
CT	6275 (67.8)	126 (98.4)	<.001
MRI	1319 (14.2)	108 (84.4)	<.001
Mortality	140 (1.5)	18 (13.5)	<.001

Abbreviations: CSI, cervical spine injury; CT, computed tomography; GCS, Glasgow Coma Scale; MRI, magnetic resonance imaging; MVC, motor vehicle collision; NA, not applicable.

[a] A χ^2 test is performed for categorical features and a Wilcoxon rank sum test is performed for continuous features.

[b] Other indicates race not included in those listed or not identified.

classes. Age, sex, mechanism of injury, and GCS score were used as features to predict CSI type.

Several candidate models were fitted for this multiclass classification problem, including multinomial logistic regression, decision trees, and ensemble models.[20,21] The data were split into a training (75%) and testing (25%) set prior to model training. Details of the methods and model selection procedure are included in Supplement 1. The model was evaluated using a generalization of AUC. In the multiclass setting, the AUC can be computed in a one-vs-rest (OVR) manner: for each outcome, the model's ability to discriminate between the outcome of interest and any other outcome was assessed. We report the OVR AUC for each outcome of interest using each candidate model, computed on a holdout test set.

Clinical Criteria

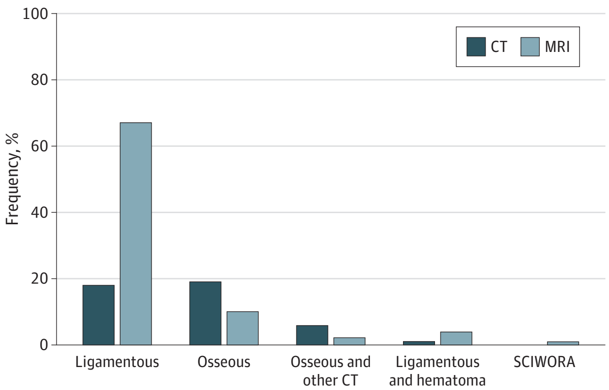
We performed 2 evaluations of the above models. We first considered the model in isolation, and we subsequently evaluated the model's performance on the subset of injured patients who did not meet a predefined set of clinical criteria.[22] The latter evaluation excluded patients who would be automatically imaged due to their clinical presentation, leaving the patients with more ambiguous cases who would likely be the primary use case of a predictive model. The clinical criteria are comprised of 8 clinically derived binary questions about the patient's presentation, detailed in eTable 2 in Supplement 1: if any of the conditions were met, we anticipated that these patients would already be imaged regardless of their risk score. Included in the clinical criteria were sensory or motor deficits, midline tenderness to palpation, decreased range of motion, abnormal head positioning, and significant distracting injury. The unexaminable patient was also considered positive under the criteria. Analysis took place from January to October 2022.

Results

Study Population

The PEDSPINE II database comprised 10 727 unique patients. After applying the exclusion criteria, the final data set included 9389 patients, of which 128 (1.36%) had CSI. The mean (SD) age was 1.3 (0.9) years; and 70 patients (54.7%) were male. **Table 1** presents a descriptive summary of all included patients, including basic demographics, mechanism of injury, GCS score, imaging usage, and mortality. Significance tests were performed to assess the difference between the injured and uninjured cohort, with P values shown in Table 1. **Figure 1** summarizes the frequency of each injury type, along with its diagnostic modality. Of 128 patients with diagnosed CSI, 25

Figure 1. Summary of Cervical Spine Injury Cases by Injury Type and Diagnostic Modality



CT indicates computed tomography; MRI, magnetic resonance imaging; SCIWORA, spinal cord injury without radiographic abnormality.

(19.5%) were treated with operative intervention and 101 patients (78.9%) were treated nonoperatively, with cervical spine immobilization via a hard collar. Two patients received no treatment.

PEDSPINE Validation

Using the current PEDSPINE II patient cohort, the PEDSPINE score was calculated for each patient. The AUC of the model was determined to be 0.813. In the PEDPSINE study, a threshold score of 2 was identified as the score under which CSI was unlikely. Thus, the sensitivity and specificity in this validation cohort were calculated using the threshold of 2, which showed a sensitivity of 75.9% (95% CI, 69.6%-83.2%) and specificity of 83.5% (95% CI, 82.8%-84.3%), respectively (AUC, 0.809; 95% CI, 0.769-0.851).

PEDSPINE II Model

Our final model had a mean OVR AUC of 0.903 (95% CI, 0.836-0.943) on the test set. This model used multinomial regression; in addition to its strong numerical performance, it had natural interpretability as an additive model. The clinical applications of this model can be seen in **Figure 2**. Details of both the final model and other candidate models are in Supplement 1.

Finally, we compared the PEDSPINE and PEDSPINE II models' ability to identify CSI. In predicting the presence of any injury on the holdout test set, PEDSPINE II obtained an OVR AUC of 0.885 (95% CI, 0.804-0.934), outperforming the PEDSPINE score on the same task (AUC, 0.845; 95% CI, 0.769-0.915). **Figure 3** shows the ROC curves of both models on the test set. The ROC curve shows the trade-off between sensitivity and specificity across all potential cutoff thresholds.

Discussion

Pediatric CSI is uncommon, but the associated morbidity has lifelong consequences. Fear of missing a clinically important CSI has led to the establishment of clinical clearance paradigms at most institutions that include variable radiography.[1,15,23,24] This is particularly true for children younger than 3 years, for whom many clinicians use imaging modalities liberally.[25] However, it has been shown that imaging in this age group is not without risk, including both the consequences of radiation exposure and the potential need for sedation.[26,27] Added cost and increased resource use also represent potential downsides of the overuse of imaging.

Large database studies have shown that risk factors for CSI in pediatric patients include younger age, mechanism of injury involving a MVC, higher composite Injury Severity Score, and presence of neurologic deficits.[1,28] Following these descriptive studies, 2 groups (PEDSPINE and the Pediatric Emergency Care Applied Research Network [PECARN]) developed high-performance, independent scoring systems to guide the need for imaging to detect CSI in this patient population.[2,17,18] Additionally, multiple studies have shown the benefits of protocol-based pediatric cervical spine clearance algorithms, both patient-centered and in terms of cost/hospital resource use.[19,29] Despite these results and recommendations, use of clinical decision-making rules continues to be highly variable.[30]

The first aim was to identify current trends in pediatric CSI (age <3 years) following blunt trauma. Of the 9389 patients meeting inclusion criteria, 128 patients were diagnosed with CSI, for a rate injury of 1.36%. This rate of CSI is consistent with the broadly reported literature, but interestingly, it is twice the rate seen in PEDSPINE (circa 2009) (0.66%).[1,2,18,28] Consistent with published data, there was a slight male predominance in the CSI group and the most common mechanism of CSI was MVC, including those in a vehicle and the pedestrians struck.[1,2,18,28] There was also a high rate of CSI associated with suspected physical abuse. Patients with CSI had a significantly lower total GCS score on presentation as well as significantly lower score on all 3 GCS score components. A breakdown of the types of CSI can be seen in Figure 1. The most common injury involved the spinal ligaments (ligamentous injury), which was diagnosed most frequently on MRI. Finally, there was a significantly higher mortality associated with CSI.

The initial purpose of the PEDSPINE trial was to help clinicians determine which pediatric trauma patients would not benefit from radiographic cervical spine evaluation, thus decreasing the overall usage of radiographic imaging. In PEDSPINE, approximately 63% of pediatric trauma patients underwent some form of cervical spine imaging (radiograph, CT, or MRI) and the overall rate of CSI was 0.66%. PEDSPINE II demonstrates a higher rate of imaging use, with 80% of children undergoing cervical spine imaging. Additionally, we report an increase in the use of multimodality imaging in many patients (39% had more than 1 cervical spine imaging study), as well as an increased use of MRI (15% compared with 4%) (**Table 2**).

As the rate of MRI usage in PEDSPINE II was found to be higher in this cohort, so too was the prevalence of ligamentous injury. Specifically, of the 128 CSI patients in this study, 65 patients were diagnosed with a ligamentous injury by MRI and, on evaluation by a trained spine specialist, were treated on discharge with hard collar immobilization. In comparison, not 1 patient in the PEDSPINE trial was diagnosed with a CSI

Figure 2. Application Interface With Patient Examples

A Patient with fall injury

Feature	Value
Age	2 y
Sex	Male
GCS score	
Eye response	4
Verbal response	5
Motor response	6

Injury risk profile, %	
Osseous	0.1
Ligamentous	0.2
No CSI	99.7

B Patient with injury from suspected physical abuse

Feature	Value
Age	1 y
Sex	Female
GCS score	
Eye response	2
Verbal response	3
Motor response	3

Injury risk profile, %	
Osseous	0.9
Ligamentous	3.6
No CSI	95.5

C Patient from MVC with GCS scores of 4

Feature	Value
Age	1.5 y
Sex	Male
GCS score	
Eye response	4
Verbal response	4
Motor response	4

Injury risk profile, %	
Osseous	3.2
Ligamentous	2.1
No CSI	94.7

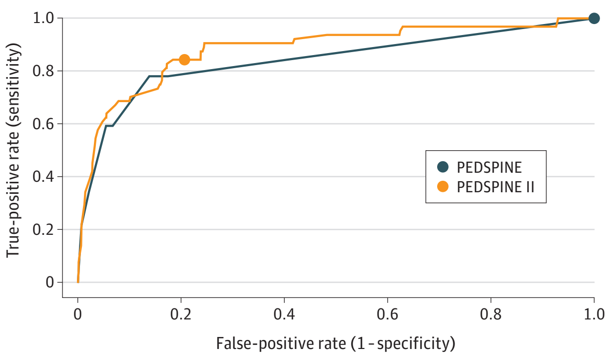
D Patient from MVC with GCS scores ≤2

Feature	Value
Age	1.5 y
Sex	Male
GCS score	
Eye response	2
Verbal response	2
Motor response	1

Injury risk profile, %	
Osseous	11.8
Ligamentous	8.3
No CSI	79.9

GCS indicates Glasgow Coma Scale; CSI, cervical spine injury; MVC, motor vehicle collision.

Figure 3. Receiver Operating Characteristic Curves for PEDSPINE and PEDSPINE II



Receiver operating characteristic curves were evaluated on the holdout test set. The blue and orange circles indicate the optimal sensitivity and specificity that can be achieved by the PEDSPINE and PEDSPINE II models, respectively, when a sensitivity requirement of at least 80% is enforced.

Table 2. Breakdown of Diagnostic Imaging Modalities

	No. (%)	
Imaging modality	Overall	Patients with CSI
No imaging	1842 (20)	0 (0)
Radiograph only	481 (5)	0 (0)
CT only	2845 (32)	7 (6)
MRI only	135 (2)	0 (0)
CT and radiograph	2360 (26)	13 (10)
MRI and radiograph	96 (1)	2 (1)
CT and MRI	502 (6)	28 (22)
CT, MRI, and radiograph	694 (8)	78 (61)

Abbreviations: CSI, cervical spine injury; CT, computed tomography; MRI, magnetic resonance imaging.

by MRI. Additionally, there was significant variability in treatment of ligamentous injuries, with some patients being treated with hard collar immobilization (and thus meeting inclusion criteria as CSI), some with soft collar placement and some with nothing. While it is beyond the scope of this study to opine on whether these ligamentous injuries are clinically important, these results raise several questions. First, are these injuries clinically important? Second, how does the impact of practice variability impact their management? Third, what are the potential implications of both diagnosis and treatment to patients and their families? We intend to evaluate these questions in future work.

The differences in MRI usage since 2009 also highlights the current debate in which imaging modality is best for the diagnosis of CSI in the pediatric population. While CT remains central in the clearance of the cervical spine in adults, several studies have demonstrated conflicting results in the pediatric population. Some studies have shown that CT scans increase detection of bony injuries that are missed on plain radiographs, while others show no significant difference in diagnosis between modalities.[31-33] Regardless, the use of CT is favored by most as the primary screening modality, and CT remains the primary modality in the multiple-trauma patient, those considered high risk due to mechanism of injury, and those with concern for head injury.[31,34] Despite a high sensitivity for diagnosing osseus injury, findings suggestive of clinically relevant soft tissue, ligamentous, or spinal cord injury may be subtle, and a negative CT scan does not rule out the presence of these injuries.[35] Furthermore, the known risk of radiation exposure associated with CT imaging is a significant drawback.[26,36] On the other hand, MRI has emerged as the most sensitive and specific modality for diagnosing these injuries, including previously unrecognized soft tissue and ligamentous injuries.[24,37-39] This increased use of MRI has allowed for radiographic diagnosis of many patients previously given a diagnosis of spinal cord injury without radiographic abnormality and aids in prognostication of neurologic outcomes in these patients.[24,37,40] Despite the radiographic and diagnostic benefits, it is important to consider the drawbacks of MRI usage, including the long imaging time and potential need for sedation, as well as the limited availability, and potential for over-calling injuries.[35,41]

The second aim of this study was to perform a validation of the previously proposed scoring system in PEDSPINE. In the original study, 4 independent predictors (total GCS score <14, GCS eye score = 1, MVC, age ≥2 years) were used to create a formulated weighted scoring system with a 93% sensitivity and an AUC of 0.92.[2] In PEDSPINE, a score of less than 2 had a negative predictive value of 99.3%, thus obviating the need for cervical spine imaging, in the absence of clinical examination findings.[2] This was followed by a collaborative study using optimal classification trees to create an artificial intelligence model that also boasted a 93% sensitivity and an AUC of 0.90.[17] As noted above, the current patient cohort demonstrates nearly double the incidence of CSI, as well as a significantly increased use of MRI. Thus, while there is a strong AUC (0.813) when validating the previously proposed algorithm with the current patient cohort, the overall sensitivity and specificity show a decrease in performance with 76.6% and 83.5%, respectively. This is likely attributable to the changes in the patient population, as seen with the significantly higher rates of ligamentous injury and MRI use.

Given these differences, a new model was derived. The goal of this new predictive model was not only to identify which children would benefit from radiographic evaluation but also to aid in selection of the most beneficial imaging modality to detect their injury. We were able to produce a multinomial model that provides clinicians with both the likelihood of CSI (%), as well as the probability CSI subtype, thereby guiding which diagnostic imaging modality to use. We envision using this decision aid as a bedside, handheld application system, examples of which are depicted in Figure 2. In each patient presented, the model can help determine the risk of injury and provide information on the likelihood of injury subtype. While this tool may be helpful in determining risk, it does not supersede the clinical presentation. By combining the clinical criteria (eTable 2 in Supplement 1) with the PEDSPINE II model, the sensitivity increases from 84.4% to 96.9%. In practice, the handheld application includes first a guided set of clinical questions, which if positive indicate the need for imaging. If no clinical criteria are met, the model then aids in prediction of CSI and suggests which imaging modality would be the most beneficial.

Of note, the use of MRI for the evaluation of the cervical spine in cases of suspected physical abuse has evolved over the past several years and is now a part of many standard child abuse evaluation protocols. The indication for these studies differs from those obtained for unintentional mechanisms; the examination is not only obtained to evaluate for clinically significant injuries, but rather for any type of abnormality that could provide further evidence to support the diagnosis of abuse. Therefore, for individuals who potentially experienced child abuse, the utility of a cervical spine MRI may be primarily from a medicolegal perspective and thus would fall outside the scope of this decision rule.

Limitations

There are several limitations of our study, including those inherent to the retrospective nature of the design. Despite being a multi-institutional study, the breadth of the data obtained from each institution was limited, primarily due to differences in data collection among institutions. Additionally, the role of plain radiographs in the evaluation of CSI was not included in our model, which may be a point of criticism. Notably, there were no patients in this cohort who had a CSI diagnosed by plain radiograph, with only 5% of patients being evaluated with radiograph series alone. Thus, we did not evaluate the role of plain radiographs in the evaluation of CSI in this model.

Conclusion

Despite improved knowledge surrounding traumatic pediatric CSI, wide variability in clinical practice persists. There has been increased use of CT and MRI imaging in the interval between PEDSPINE and PEDSPINE II, which has implications of increased cost, increased radiation exposure, and most importantly a potential for overdiagnosis of injuries. While there is no substitute for clinical judgment in the acute setting, this prediction tool has the potential to help decrease the use of imaging, aid in clinical decision-making, and decrease hospital resource utilization and cost.

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