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Clinical utility and radiation exposure assessment of radiography and CT in pediatric cervical spine disorders

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ABSTRACT

Background: Cervical spine injuries in children are uncommon but carry significant morbidity. Conventional radiography remains the initial imaging modality due to low radiation exposure, while computed tomography (CT) offers superior diagnostic accuracy at higher radiation dose. This study assessed the clinical utility, diagnostic performance, and radiation exposure of radiography versus CT in pediatric patients with suspected cervical spine disorders. ***Materials and Methods:*** This retrospective cohort study included 200 pediatric patients (<18 years) who underwent cervical spine radiography, CT, or both between January and December 2025. Diagnostic performance, incremental value of CT, clinical utility, image quality, and effective radiation doses (mSv) were evaluated. Age-stratified analyses and multivariable regression were performed. ***Results:*** Radiography showed 71.8% sensitivity and 95.4% specificity (accuracy 89.5%). CT identified 11 occult fractures and 8 ligamentous injuries missed on radiography, altering diagnosis in 17.7% and management in 15.6% of cases. High clinical utility was noted in 48% of radiographic and 76% of CT examinations ($p < 0.001$). Mean effective dose was 0.07 ± 0.03 mSv for radiography versus 2.42 ± 0.91 mSv for CT (34.6-fold higher; $p < 0.001$), with greater doses in younger children. Image quality was diagnostically acceptable in >93% of cases. ***Conclusion:*** Radiography suffices for most low-risk cases with minimal radiation, while selective CT use in high-risk or inconclusive scenarios provides substantial diagnostic and management benefits that justify its radiation burden when optimized with pediatric protocols.

INTRODUCTION

Cervical spine injuries (CSI) represent a critical concern in pediatric trauma care despite their relative rarity. The incidence of CSI in children following blunt trauma ranges from approximately 0.6% to 2%, accounting for a disproportionate share of spinal injuries compared with adults [1, 2]. Younger children exhibit distinct injury patterns due to anatomical differences, including a higher proportion of upper cervical injuries (C1–C3), ligamentous laxity, and incomplete ossification, which complicate clinical and radiographic assessment. Motor vehicle collisions, falls, and sports-related injuries predominate as mechanisms, with high-energy trauma posing the greatest risk [3, 4]. Prompt and accurate diagnosis is essential to prevent neurological deficits, which occur in up to one-third of pediatric CSI cases [5]. Clinical clearance protocols such as the National Emergency X-Radiography Utilization Study (NEXUS) or Pediatric Emergency Care Applied Research Network (PECARN) help stratify risk, but imaging is frequently required in non-low-risk patients or those with unreliable examinations [6]. Conventional radiography has historically served as the first-line modality because of its wide availability, low cost, and relatively low ionizing radiation exposure. However, its sensitivity is limited (often 70-85% for significant injuries), particularly for subtle fractures, ligamentous injuries, and upper cervical abnormalities in young children with large heads and short necks [7]. Computed tomography (CT) has emerged as a highly sensitive alternative, capable of detecting occult injuries missed on plain films and providing detailed multiplanar reconstructions valuable for surgical planning [8, 9]. Nevertheless, CT delivers substantially higher radiation doses, raising concerns about stochastic effects such as increased lifetime cancer risk in radiosensitive pediatric tissues (thyroid, bone marrow, brain). Children are 2-5 times more vulnerable to radiation-induced malignancy than adults due to longer life expectancy and higher cellular proliferation rates [10]. Balancing diagnostic accuracy with radiation safety is a core principle of pediatric imaging, embodied in the As Low As

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Reasonably Achievable (ALARA) principle and Image Gently campaigns [11]. Dose-reduction techniques including automatic exposure control, iterative reconstruction, and protocol optimization have lowered CT doses significantly, but variability persists across institutions. Guidelines generally recommend radiography as initial imaging for lower-risk cases, reserving CT for high-risk mechanisms, abnormal radiographs, neurological deficits, or inconclusive findings [12]. Prior studies highlight the trade-offs: radiography offers excellent specificity but misses subtle injuries, while CT excels diagnostically yet contributes disproportionately to cumulative radiation burden in emergency settings [13]. Limited data exist on the incremental clinical utility of CT in real-world pediatric cohorts, particularly regarding its impact on management decisions such as immobilization, admission, or surgery, alongside quantified radiation exposure stratified by age [13]. The novelty of the present study lies in the simultaneous evaluation of diagnostic performance, incremental clinical utility (impact on management), and age-stratified radiation exposure of cervical spine radiography versus CT in a consecutive real-world pediatric cohort from a tertiary center, thereby providing evidence to support tiered imaging algorithms that balance diagnostic yield with radiation safety.

MATERIALS AND METHODS

Study design and population

This retrospective observational cohort study was conducted in the Department of Radiology and Pediatric Emergency Imaging Unit of a tertiary-care referral hospital. Medical records and imaging examinations performed between 1 January 2025 and 31 December 2025 were reviewed. Approximately 200 consecutive pediatric patients younger than 18 years who underwent cervical spine radiography, CT, or both for suspected cervical spine pathology were included. Clinical indications comprised traumatic injury, neck pain, neurological symptoms, suspected instability, congenital anomalies, infection/inflammatory disease, and developmental abnormalities. Exclusion criteria were incomplete examinations, non-diagnostic image quality due to severe motion or technical failure, prior cervical spine surgery that substantially altered anatomy, missing radiation dose data, or incomplete clinical documentation. When multiple examinations occurred during the same episode, only the first was included. Patients were stratified into three age groups reflecting developmental stage and cervical spine maturation: 0-5 years (infants and young children), 6-12 years (school-age), and 13-18 years (adolescents). The study protocol was approved by the Institutional Review Board/Ethics Committee; the requirement for informed consent was waived because of the retrospective use of anonymized routinely collected data. All identifiers were removed before analysis.

Clinical data collection

Demographic and clinical variables extracted from the electronic medical record included age, sex, height, body weight, body mass index (BMI), referral source, clinical indication, mechanism of injury (for trauma cases), presenting symptoms, neurological status, and cervical immobilization status. Pre- and post-imaging management decisions (continuation or removal of immobilization, admission, discharge, specialist consultation, additional imaging, or operative intervention) were recorded to assess clinical impact.

Imaging acquisition and interpretation

Digital cervical spine radiography was performed on a dedicated pediatric digital radiography system (Ysio Max, Siemens Healthineers, Erlangen, Germany) using standardized age- and size-adjusted protocols. Standard views comprised anteroposterior and lateral projections; open-mouth odontoid and additional targeted views were obtained when clinically feasible. Automatic exposure control was applied when appropriate. CT examinations were performed on a multidetector CT scanner (SOMATOM Definition Flash, Siemens Healthineers, Erlangen, Germany) equipped with pediatric dose-reduction technologies, including automatic tube current modulation, iterative reconstruction (SAFIRE), and restricted scan coverage. Acquisition parameters (tube voltage, tube current–time product, pitch, collimation, and reconstruction interval) were individualized according to age and body weight. Datasets were reconstructed in axial, sagittal, and coronal planes; three-dimensional volume-rendered images were generated when indicated. All examinations were independently reviewed by two fellowship-trained pediatric radiologists blinded to each other's interpretations. Discrepancies were resolved by consensus. Findings were categorized as normal, minor (without immediate clinical significance), or clinically significant. For patients who underwent both modalities, CT was considered to provide incremental diagnostic value when previously undetected abnormalities were identified, the final diagnosis was changed, management was altered, diagnostic uncertainty was reduced, additional imaging was avoided, or preoperative planning was improved. All examinations were independently reviewed by two fellowship-trained pediatric radiologists blinded to each other's interpretations. Discrepancies were resolved by consensus. Findings were categorized as normal, minor (without immediate clinical significance), or clinically significant. Representative examples of

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radiographic and CT images included in the study dataset are shown in figure 1.

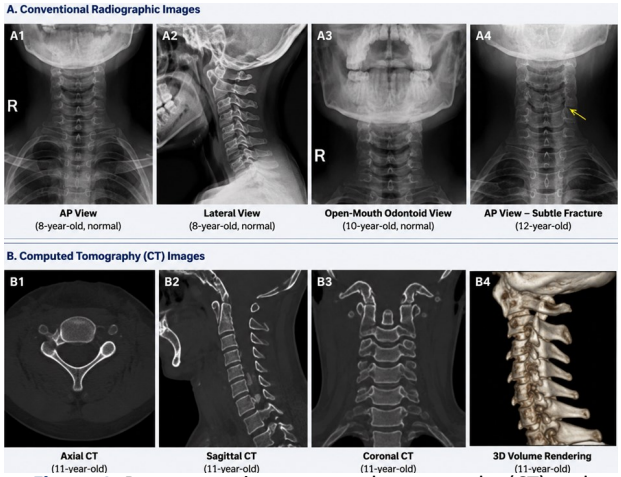


Figure 1. Representative computed tomography (CT) and radiographic images used for data curation in the study. Representative de-identified pediatric cervical spine imaging samples included in the dataset are shown. **(A)** Conventional cervical spine radiographs, including anteroposterior (AP), lateral, and open-mouth odontoid views, demonstrating normal examinations (A1–A3) and a subtle cervical spine abnormality identified on radiography (A4, arrow). **(B)** Corresponding CT imaging examples, including axial (B1), sagittal (B2), coronal (B3), and three-dimensional volume-rendered (B4) reconstructions, illustrating multiplanar evaluation of cervical spine anatomy and detection of clinically relevant abnormalities. These representative images demonstrate the complementary roles of radiography and CT in pediatric cervical spine assessment and reflect the imaging modalities included in the study's analysis. AP, anteroposterior; CT, computed tomography.

Radiation dose assessment (dosimetry)

Radiation exposure data were obtained directly from the imaging systems. For radiography, dose-area product (DAP) was recorded and effective dose (mSv) was estimated using published age-specific pediatric conversion coefficients applied to DAP. For CT, volume CT dose index (CTDIvol, mGy) and dose-length product (DLP, mGy·cm) were recorded from the dose report. Effective dose was calculated by multiplying DLP by age-specific pediatric conversion coefficients derived from published recommendations (International Commission on Radiological Protection and pediatric-specific literature). Radiation doses were compared by modality, age group, body weight, and clinical indication. The relationship between dose and image quality was examined to evaluate the effectiveness of pediatric dose-optimization strategies.

Clinical utility and image quality

Clinical utility was classified as high (directly influenced diagnosis, emergency management, treatment planning, or surgical decision-making), moderate (increased diagnostic confidence without substantially altering management), or low (minimal additional information and no meaningful impact on care). Image quality was independently scored by both radiologists on a five-point Likert scale (1 = non-diagnostic to 5 = excellent); scores ≥3 was considered diagnostically acceptable. Interobserver agreement was assessed with Cohen's kappa coefficient.

Statistical analysis

Statistical analyses were performed with IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range, IQR) according to distribution (Shapiro–Wilk test). Categorical variables were summarized as frequencies and percentages. Comparisons between modalities used the independent-samples t-test or Mann–Whitney U test; age-group comparisons used one-way analysis of variance or the Kruskal–Wallis test. Categorical comparisons used the chi-square or Fisher's exact test. Interobserver agreement was quantified with Cohen's kappa. Diagnostic performance metrics (sensitivity, specificity, predictive values, accuracy) were calculated against the final clinical diagnosis (incorporating CT, clinical follow-up, and surgical findings when available). Multivariable linear regression identified independent predictors of effective radiation dose. A two-sided p value < 0.05 was considered statistically significant.

RESULTS

Patient demographics and clinical characteristics

A total of 200 pediatric patients were included (mean age 9.8 ± 4.7 years; range 0.4-18.0 years). Male patients comprised 59.0% of the cohort. Patients were distributed across age groups as follows: 0-5 years (27.0%), 6-12 years (41.0%), and 13-18 years (32.0%). Most examinations (76.0%) originated from the Emergency Department (table 1).

Table 1. Demographic and clinical characteristics of the study population (N = 200).

Characteristic	Overall (N = 200)
Age (years), mean ± SD	9.8 ± 4.7
Age (years), median (IQR)	10 (6–14)
Age range (years)	0.4–18.0
Male sex, n (%)	118 (59.0%)
Female sex, n (%)	82 (41.0%)
Height (cm), mean ± SD	132.6 ± 28.5
Weight (kg), mean ± SD	36.8 ± 17.9
BMI (kg/m²), mean ± SD	18.2 ± 3.6
Age 0–5 years, n (%)	54 (27.0%)
Age 6–12 years, n (%)	82 (41.0%)
Age 13–18 years, n (%)	64 (32.0%)
Emergency Department referral, n (%)	152 (76.0%)
Outpatient clinic referral, n (%)	48 (24.0%)

Abbreviations: BMI, body mass index; IQR, interquartile range; SD, standard deviation.

Clinical indications

Trauma was the predominant indication (64.0%),

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followed by neck pain (13.0%), neurological symptoms (7.5%), and congenital abnormalities (6.0%). Among trauma cases, motor vehicle collision (29.7%) and falls from height (24.2%) were the most frequent mechanisms (table 2).

Table 2. Clinical indications and trauma mechanisms for cervical spine imaging (N = 200).

Clinical Indication / Mechanism	n	%
Trauma	128	64.0
Neck pain	26	13.0
Neurological symptoms	15	7.5
Congenital abnormalities	12	6.0
Suspected cervical instability	8	4.0
Infection or inflammatory disease	6	3.0
Developmental abnormalities	5	2.5
Mechanism among trauma cases (n = 128)		
Motor vehicle collision	38	29.7
Fall from height	31	24.2
Sports-related injury	24	18.8
Low-energy fall	18	14.1
Bicycle accident	10	7.8
Other mechanisms	7	5.5

Note: Percentages for mechanisms are calculated among the 128 trauma cases.

Table 3. Radiographic findings on cervical spine radiography (N = 200).

Radiographic finding	n	%
Normal examination	142	71.0
Cervical fracture	14	7.0
Prevertebral soft tissue swelling	13	6.5
Vertebral malalignment	10	5.0
Congenital vertebral anomaly	9	4.5
Atlantoaxial instability	6	3.0
Degenerative/other findings	6	3.0

Note: Patients could have more than one abnormality; percentages may exceed 100%.

Table 4. Computed tomography findings in patients undergoing CT (n = 96).

CT Finding	n	%
Normal examination	49	51.0
Cervical fracture	24	25.0
Ligamentous injury	8	8.3
Vertebral subluxation/dislocation	5	5.2
Congenital vertebral anomaly	5	5.2
Spinal canal abnormality	3	3.1
Soft tissue injury	2	2.1

Abbreviations: CT, computed tomography. Note: CT detected 11 occult fractures (11.5%) and 8 ligamentous injuries not visible on radiography; diagnosis was modified in 17 patients (17.7%) and management in 15 patients (15.6%).

Imaging findings and diagnostic performance

Radiography was normal in 71.0% of examinations. Cervical fractures were identified in 7.0%, prevertebral soft-tissue swelling in 6.5%, and vertebral malalignment in 5.0% (table 3). Among the 96 patients who underwent CT, fractures were detected in 25.0% and ligamentous injuries in 8.3%. CT identified 11 occult fractures and 8 ligamentous injuries not visible on radiography, resulting in a change of diagnosis in 17.7% and alteration of management in 15.6% of CT cases (table 4). Using final clinical diagnosis (incorporating CT and clinical/surgical follow-up) as the reference standard, radiography demonstrated sensitivity of 71.8%, specificity of 95.4%, and overall accuracy of 89.5% (table 5).

Table 5. Diagnostic performance of cervical spine radiography compared with CT/final clinical diagnosis.

Diagnostic parameter	Estimate (%)	95% Confidence interval
Sensitivity	71.8	60.4–81.2
Specificity	95.4	89.3–98.3
Positive predictive value	85.4	73.5–92.8
Negative predictive value	90.6	84.2–94.7
Diagnostic accuracy	89.5	82.4–94.2

Abbreviations: CT, computed tomography. Note: CT detected 11 occult fractures (11.5%) and 8 ligamentous injuries not visible on radiography; diagnosis was modified in 17 patients (17.7%) and management in 15 patients (15.6%).

Radiation dose assessment

Mean effective dose was significantly lower for radiography than for CT (0.07 ± 0.03 mSv vs 2.42 ± 0.91 mSv; p<0.001), corresponding to a 34.6-fold difference and a 97.1% relative dose reduction with radiography. Age-stratified analysis showed higher CT doses in younger children (0–5 years: 2.95 ± 0.84 mSv; 6–12 years: 2.38 ± 0.71 mSv; 13–18 years: 1.94 ± 0.63 mSv), while radiographic doses remained consistently low across all age groups (p<0.001 for all pairwise modality comparisons) (table 6).

Table 6. Comparison of radiation dose parameters between cervical spine radiography and CT according to modality and age group.

Radiation Parameter	Radiography (n = 200)	CT (n = 96)	p-value
Effective dose (mSv), mean±SD	0.07 ± 0.03	2.42 ± 0.91	<0.001
Median effective dose (mSv) (IQR)	0.07 (0.05-0.09)	2.31 (1.84-2.96)	<0.001
Effective dose range (mSv)	0.02-0.15	0.94–5.12	<0.001
Tube voltage (kVp), mean±SD	68.4 ± 7.3	100.6 ± 8.8	<0.001
Tube current–time product (mAs), mean±SD	5.8 ± 2.1	78.6 ± 24.7	<0.001
DAP (Gy·cm²), mean ± SD	0.38 ± 0.15	—	—
CTDIvol (mGy), mean ± SD	—	5.8 ± 2.0	—
DLP (mGy·cm), mean ± SD	—	112.4 ± 41.8	—
Effective dose 0–5 y (mSv)	0.06 ± 0.02	2.95 ± 0.84	<0.001
Effective dose 6–12 y (mSv)	0.07 ± 0.03	2.38 ± 0.71	<0.001
Effective dose 13–18 y (mSv)	0.08 ± 0.02	1.94 ± 0.63	<0.001
Fold increase with CT	—	34.6-fold	<0.001

Abbreviations: CT, computed tomography; CTDIvol, volume CT dose index; DAP, dose-area product; DLP, dose-length product; IQR, interquartile range; kVp, kilovoltage peak; mAs, milliampere-second; mGy, milligray; mSv, millisievert; SD, standard deviation; y, years. Effective dose for CT was estimated by multiplying DLP by age-specific pediatric conversion coefficients; effective dose for radiography was estimated from DAP using published pediatric conversion factors. Comparisons used independent-samples t-test or Mann–Whitney U test as appropriate.

Clinical utility and management impact

High clinical utility was significantly more frequent with CT than with radiography (76.0% vs 48.0%; p<0.001). After CT, immobilization was maintained in 29.2% and discontinued in 21.9% of patients; 51.0% were discharged from the emergency department, 24.0% required admission, and 12.5% underwent surgical consultation. CT modified the treatment plan in 15.6% and the final diagnosis in 17.7% of cases, and avoided additional imaging in

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17.7% (figures 2 and 3 - table 7).

Table 7. Clinical utility of cervical spine radiography and CT and impact of CT on clinical management.

Clinical Utility / Management Outcome	Radiography (n = 200)	CT (n = 96)	p-value
High clinical utility	96 (48.0%)	73 (76.0%)	<0.001
Moderate clinical utility	70 (35.0%)	18 (18.8%)	0.006
Low clinical utility	34 (17.0%)	5 (5.2%)	0.011
Surgical consultation required	—	12 (12.5%)	—
Cervical immobilization maintained	—	28 (29.2%)	—
Cervical immobilization discontinued	—	21 (21.9%)	—
Additional imaging avoided	—	17 (17.7%)	—
Hospital admission	—	23 (24.0%)	—
Emergency department discharge after CT	—	49 (51.0%)	—
Treatment plan modified after CT	—	15 (15.6%)	—
Final diagnosis changed after CT	—	17 (17.7%)	—

Predictors of radiation dose, image quality, and interobserver agreement

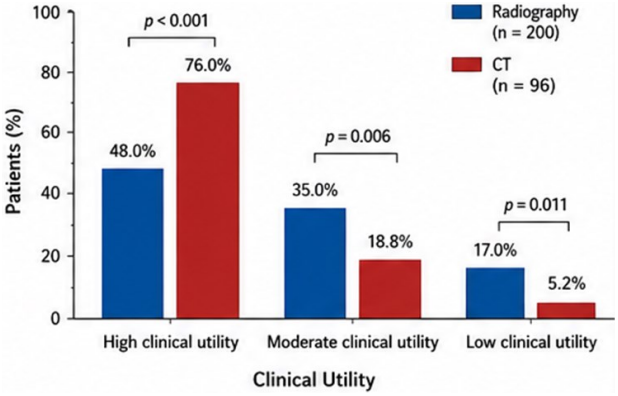


Figure 2. Comparison of clinical utility between cervical spine radiography (n = 200) and CT (n = 96), demonstrating a significantly higher proportion of examinations with high clinical utility for CT than for radiography (p < 0.001).

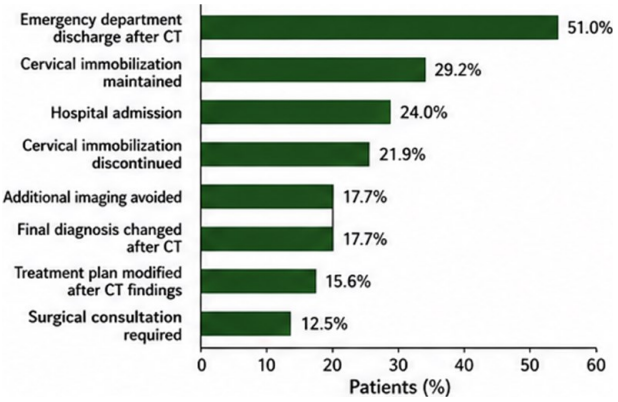


Figure 3. Clinical management outcomes following CT examination, including emergency department discharge, continuation or discontinuation of cervical immobilization, hospital admission, additional imaging avoidance, treatment modification, diagnosis change, and surgical consultation.

Multivariable linear regression identified CT examination as the strongest independent predictor of effective dose (standardized β = 0.69, p<0.001), followed by scan length (β = 0.29, p<0.001) and body weight (β = 0.27, p<0.001). Age was negatively associated with dose (β = −0.19, p=0.003), and traumatic indication was positively associated (β = 0.17, p=0.011). The model explained 69% of dose variability (R^2 = 0.69) (Table 8). Image quality was diagnostically acceptable (Likert score ≥3) in 93.0% of radiographic and 97.9% of CT examinations. Excellent quality (score 5) was more frequent with CT (33.3% vs 23.0%). Interobserver agreement was almost perfect across parameters (Cohen's κ = 0.83-0.91; overall diagnostic agreement κ = 0.89) (figures 4-7).

Table 8. Multivariable linear regression analysis of predictors of effective radiation dose.

Predictor Variable	B	SE	β	95% CI	p-value
Constant	0.42	0.18	—	0.07 to 0.77	0.021
Age (years)	-0.21	0.05	-0.19	-0.31 to -0.09	0.003
Body weight (kg)	0.28	0.07	0.27	0.14 to 0.42	<0.001
CT examination (Yes vs No)	0.74	0.08	0.69	0.58 to 0.90	<0.001
Trauma indication (Yes vs No)	0.19	0.06	0.17	0.05 to 0.33	0.011
Scan length (cm)	0.31	0.09	0.29	0.13 to 0.49	<0.001

Abbreviations: B, unstandardized coefficient; β, standardized coefficient; CI, confidence interval; CT, computed tomography; SE, standard error. Model: F = 34.8, p<0.001; R^2 = 0.69; adjusted R^2 = 0.67; Durbin-Watson = 1.94; root mean square error = 0.42 mSv.

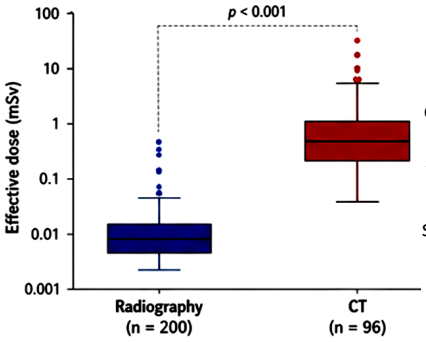


Figure 4. Box-and-whisker plot comparing the estimated effective radiation dose between radiography and CT, showing significantly greater radiation exposure associated with CT (p < 0.001).

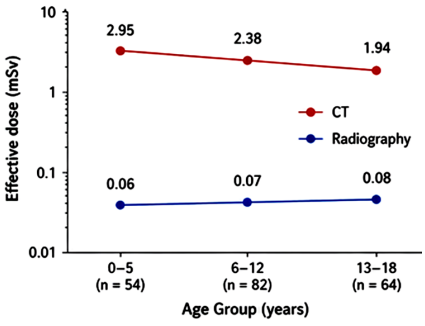


Figure 5. Estimated effective radiation dose stratified by age group, demonstrating decreasing CT radiation dose with increasing patient age, whereas radiographic doses remained consistently low across all age groups.

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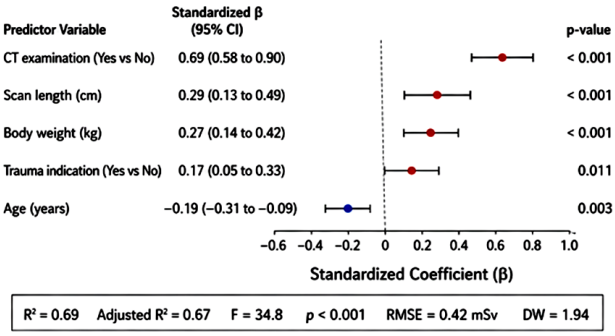


Figure 6. Forest plot of the multivariable linear regression analysis showing standardized regression coefficients (β) and 95% confidence intervals for independent predictors of increased radiation dose; CT examination was the strongest predictor, followed by scan length and body weight.

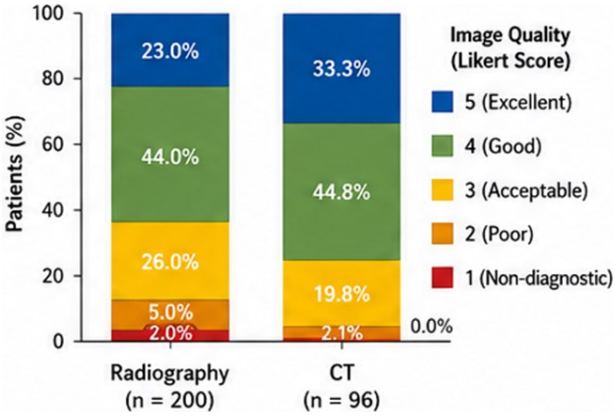


Figure 7. Distribution of image quality scores using a five-point Likert scale, illustrating a higher proportion of excellent-quality examinations with CT while maintaining a high percentage of diagnostically acceptable images for both modalities.

DISCUSSION

The present study quantifies the complementary roles of radiography and CT in pediatric cervical spine evaluation and the associated radiation trade-offs. Radiography demonstrated high specificity (95.4%) but only moderate sensitivity (71.8%), consistent with prior reports that place radiographic sensitivity for significant CSI in the 70–85% range [7]. CT provided substantial incremental value by detecting occult fractures and ligamentous injuries that altered diagnosis in 17.7% and management in 15.6% of selected patients, supporting selective rather than routine CT use [8, 9, 12]. These findings align with guideline recommendations that reserve CT for high-risk mechanisms, abnormal or inconclusive radiographs, or persistent clinical suspicion [12]. Radiation exposure differences were marked: CT delivered a mean effective dose approximately 34.6 times higher than radiography (2.42 vs 0.07 mSv; p<0.001). The absolute CT doses observed here are lower than many historical series (often 4-8 mSv), reflecting institutional implementation of iterative reconstruction, automatic tube-current modulation, and pediatric-specific protocols [11, 12]. Younger children received higher CT doses, underscoring the need for continued age-adapted optimization. Multivariable analysis confirmed imaging modality, body weight, and scan length as the dominant independent predictors of dose (table 8), identifying practical targets for further reduction (limited scan ranges, strict adherence to pediatric protocols). Clinically, the higher proportion of high-utility examinations with CT (76% vs 48%; p<0.001) translated into safer discontinuation of immobilization, targeted admissions, and avoidance of additional imaging in a meaningful subset of patients (table 7). The observation that 51% of CT examinations led to emergency-department discharge after negative findings also suggests residual opportunity for improved upfront risk stratification to further limit low-yield CT. Image quality remained diagnostically acceptable in >93% of examinations for both modalities, validating the effectiveness of dose-reduction strategies without compromising diagnostic confidence. Interobserver agreement was almost perfect (κ 0.83-0.91), supporting the reliability of the reported findings. Limitations of this study include its retrospective single-center design, the use of a composite final clinical diagnosis that incorporated CT (introducing potential incorporation bias), and the fact that not all patients underwent both modalities, creating selection bias toward higher -risk cases for CT. Future prospective multicenter studies evaluating ultra-low-dose CT protocols and artificial - intelligence - assisted radiographic interpretation may further narrow the diagnostic gap while minimizing radiation. Overall, the data reinforce a tiered imaging strategy radiography for most patients and selective CT for those with persistent suspicion, abnormal radiographs, or high-energy trauma consistent with ALARA principles and efforts to reduce unnecessary advanced imaging in children [11–13].

CONCLUSION

In this cohort of 200 pediatric patients, cervical spine radiography provided an effective low-radiation initial imaging tool with high specificity, while selective CT yielded critical incremental diagnostic information that meaningfully altered management in high-risk or inconclusive cases. Judicious, protocol-driven CT utilization, combined with pediatric dose optimization, balances diagnostic accuracy with radiation safety in this vulnerable population.

Ethical considerations: The study protocol was approved by the Institutional Review Board/Ethics Committee of the participating tertiary-care hospital. Because the study was retrospective and used anonymized routinely collected clinical and imaging

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data, the requirement for informed consent was waived in accordance with institutional ethical guidelines and applicable national regulations. All patient identifiers were removed prior to data extraction and analysis to ensure confidentiality.

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Conflict of interest**:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions**:** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by the authors. The first draft of the manuscript was written by the corresponding author and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Use of artificial intelligence**:** Artificial intelligence tools were used solely for language editing and formatting assistance during manuscript preparation. All scientific content, data interpretation, statistical analyses, and conclusions were generated and verified by the authors. No AI tool was used for data fabrication, image generation of patient examinations, or alteration of study results.

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