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ORIGINAL ARTICLE

Radiation dose levels of thoracic–lumbar spine CT in pediatric trauma patients and assessment of scan parameters for dose optimization

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Abstract

Background CT is frequently used for assessing spinal trauma in children.

Objective To establish the local diagnostic reference levels of spine CT examinations in pediatric spinal trauma patients and analyze scan parameters to enable dose optimization.

Materials and methods In this retrospective study, we included 192 pediatric spinal trauma patients who underwent spine CT. Children were divided into two age groups: 0–10 years (group 1) and 11–17 years (group 2). Each group was subdivided into thoracic, thoracolumbar and lumbar CT groups. CT acquisition parameters (tube potential, in kilovoltage [kV]; mean tube current–time product, in milliamperes [mAs]; reference mAs; collimated slice width; tube rotation time; pitch; scan length) and radiation dose descriptors (volume CT dose index [$\mathrm{CTDI}_{\mathrm{vol}}$] and dose–length product [DLP]) were recorded. The $\mathrm{CTDI}_{\mathrm{vol}}$ and DLP values of spine CTs obtained with different tube potential and collimated slice width values were compared for each group.

Results $\mathrm{CTDI}_{\mathrm{vol}}$ and DLP values of thoracolumbar spine CTs in group 1 and lumbar spine CTs in group 2 were significantly lower in CTs acquired with low tube potential levels ($P<0.05$). $\mathrm{CTDI}_{\mathrm{vol}}$ and DLP values of thoracolumbar spine CTs in both groups and lumbar spine CTs in group 2 acquired with high collimated slice width values were significantly lower than in corresponding CTs acquired with low collimated slice width values ($P<0.05$).

Conclusion Pediatric spine CT radiation doses can be notably reduced from the manufacturers' default protocols while preserving image quality.

Keywords Children · Computed tomography · Radiation dose · Spine · Trauma

Introduction

Pediatric spinal fractures constitute 1–9% of all spinal fractures occurring in all age groups. Hospital admission in 1–2% of all traumatic pediatric patients occurs for spine fracture [1, 2]. CT is being more frequently used in the assessment of spinal trauma in children in accordance with the significant increase in the number of all types of CT examinations in recent years [3–5]. Lower doses in newly manufactured devices and reduced motion artifacts through fast gantry rotation cycles has led to increased utilization of this powerful diagnostic tool in the pediatric population.

Because ionizing radiation exposure from medical circumstances in children mostly results from CT examinations, each CT examination should be performed only after its use is justified by its potential clinical benefit to the child. CT radiation dose mainly depends on patient-related factors and CT acquisition parameters. Body habitus of patients and external hardware such as trauma bed during CT scan constitute patient-related factors affecting the dose exposure. CT acquisition parameters differ from patient-related factors in terms of modifiability because CT technicians can perform CT examinations with decreased radiation dose levels by using optimum CT acquisition parameters. Understanding the role of CT acquisition parameters on spine CT radiation dose is essential for the configuration of low-dose CT protocols in children. Although 1–2% of all pediatric fractures occur in the thoracolumbar spine, previous studies regarding pediatric

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spine trauma were mostly conducted with cervical spine trauma [6–9]. In this study, we aimed to provide local diagnostic reference levels of pediatric spine CTs and review the effect of each CT acquisition parameter on the resultant radiation dose of thoracic, thoracolumbar and lumbar CT examinations in children with spinal trauma. To the best of our knowledge, local diagnostic reference levels of pediatric spine CTs have not been described in the literature. Our findings help to establish diagnostic reference levels of pediatric spine CTs and should lead to future dose reduction studies on spine CT of children with spinal trauma.

Materials and methods

Patients and ethical approval

Our institutional human research ethics committee approved this observational retrospective single-center study and waived written informed consent. The study evaluated deidentified data and brought no potential risk to patients. We conducted this study in a large tertiary-care university hospital that is a center for adult and pediatric emergency medicine and adult and pediatric trauma. We included children who were admitted to our pediatric emergency department with spinal trauma and underwent dedicated spine CT between January 2010 and September 2019. Spine CTs reconstructed from thoracoabdominal CTs were excluded from the study. Children who had CT scans on a trauma bed were also excluded.

Computed tomography

The CT examinations were performed with pediatric-specific dose protocols on five multi-detector CT scanners with different detector configurations. CT parameters are summarized in Table 1. On all CT scanners, the automatic exposure control system was used for all examinations. Filtered back-projection or iterative reconstruction algorithm was used for image reconstruction, depending on the scanner type.

Radiation dose assessment

We divided spine CTs into three subgroups — thoracic, thoracolumbar and lumbar CT — according to the examined area of the spine. Using hospital information and the picture archiving and communication system, we collected the following information: patient gender and age, scan length (centimeters), CT acquisition parameters including tube potential in kilovolts (kV), tube current–time product in milliamperes (mAs), reference tube current–time product (reference mAs), collimated slice width, tube inversion time (TI), pitch, as well as dose descriptors expressed as both volume CT dose index ($CTDI_{vol}$, in milligrays [mGy]) and dose–length product (DLP, in milligrays × centimeters). $CTDI_{vol}$ and DLP values of spine CT examinations were recorded using the 32-cm-diameter phantom as a reference. Local diagnostic reference levels of spine CTs were provided in terms of the 2nd and 3rd quartiles of $CTDI_{vol}$, DLP and effective dose. We calculated estimated effective doses for spine CTs from DLP using the age-specific conversion coefficients (k) from European guidelines [10]. Finally, we interrogated correlations between CT acquisition parameters and CT dose values.

Imaging assessment

Two radiologists with 5 (S.A.) and 7 (Y.S.) years of experience in pediatric imaging (reader 1 and reader 2, respectively) reviewed all CT examinations independently for the presence of vertebral fractures without prior knowledge of a potential vertebral column lesion. Cases with mismatch were then evaluated together, and a consensus was achieved.

Subjective assessment of image quality

Reader 1 and reader 2 reviewed all CT examinations independently without prior knowledge of image acquisition parameters. They assessed the image quality according to the image quality scoring criteria proposed by Padole et al. [11] (1 = unacceptable quality, 2 = limited quality, 3 = adequate quality, 4 = higher than needed quality).

Statistical analysis

We analyzed the data using SPSS v. 22.0 (IBM Corp., Armonk, NY), providing descriptive analyses based on frequencies, means and standard deviations for the variables. We evaluated numerical variables for normality of data distribution using the Kolmogorov–Smirnov and Shapiro–Wilk tests. We used the independent samples *t*-test to compare the means of two groups that followed normal distribution, and the Mann–Whitney *U* test to compare two groups for non-parametric data. We used the Kruskal–Wallis test to compare the variables that followed a nonparametric distribution in independent groups, and relied on the one-way analysis of variance (ANOVA) test to compare variables with a normal distribution. The homogeneity of variances was assessed through the Levene test. We used Bonferroni correction post hoc to test whether significance was detected among groups, and the kappa statistic to assess the interobserver variability of image quality. A value of $P<0.05$ was statistically significant.

Table 1 Summary of CT scan parameters

CT scan parameter	Scanner type				
	Somatom Emotion Duo[a]	Sensation 16[a]	Somatom Force[a]	Somatom Perspective[a]	Optima CT540[b]
Tube potential (kV)	130	120	130	130	120
Reference tube current–time product (mAs)	120	150	190	150	300 (max)
Pitch	1.0	0.8	0.8	1.0	0.938
Slice width (mm)	2×2.5	16×0.75	192×0.6	32×1.2	32×0.625
Reconstruction increment (mm)	3	1.5	1	3	0.625
Rotation time (s)	1.5	0.75	1	1	0.6
Slice thickness (mm)	3	1.5	1	3	1.25
Iterative reconstruction algorithm (strength)	NA	NA	ADMIRE (2)	ADMIRE (2)	ASiR (20%)
AEC system	Care Dose4D				SmartmA and AutomA

AEC automatic exposure control, *ASiR* adaptive statistical iterative reconstruction, *kV* kilovoltage, *mAs* milliamperes, *mm* millimeters, *NA* not applicable, *s* seconds

[a] Siemens Healthineers, Erlangen, Germany

[b] GE Healthcare, Chicago, IL

Results

We included 192 children (<18 years old; 91 male, 101 female; mean age 11.9 years, range 1–17 years) in this study. Of these, 115 were admitted after a motor vehicle accident, 52 after a fall from a height, and 25 after violence. One hundred fifty of the 192 patients (78.1%) had at least one spine radiograph before CT. Spine CT was requested by orthopedic surgeons for persistent back pain in 154 (80.2%) children, while 38 (19.8%) children underwent spine CT because of indeterminate findings on radiography. The spine CT scan protocol for each child was selected based on the child's weight. Body mass index (BMI) was not recorded as a separate parameter for all patients (it was available in 43 children), and therefore the age of the patient was used to group the records according to the following the criteria reported in Radiation Protection No. 185 [12]. The proposed local diagnostic reference levels according to age are summarized in Table 2. Because of the smaller number of children in some groups, we combined some age groups to provide a sufficient number of patients to interrogate the relationship between CT parameters and dose, resulting in a 0–10-years group (group 1) and an 11–17-years group (group 2). Group 1 included 61 children (27 male, 34 female; mean age 6.2 years, range 1–10 years) and group 2 included 131 children (64 male, 67 female; mean age 14.5 years, range 11–17 years).

The number of spine CT examinations in group 1 and group 2, respectively, were as follows: thoracic (10 and 18), thoracolumbar (41 and 67) and lumbar (10 and 46) (Fig. 1). Tube potential (kV), collimated slice width, TI and pitch values of overall spine CTs were similar between group 1 and group 2. The mean CTDI_{vol}, DLP, tube current–time product (mAs) and scan length values of thoracic, thoracolumbar and lumbar spine CT examinations in group 1 were significantly lower than in group 2, as expected ($P<0.05$). Mean reference tube current–time product value of thoracolumbar spine CT in group 1 was significantly lower than in group 2 (Online Supplementary Material 1).

The correlation results between CT acquisition parameters and CT dose values yielded positive correlation between dose values and age, mean tube potential, mean tube current–time product, reference tube current–time product and TI, while a negative correlation was noted between dose values and collimated slice width and pitch values (Table 3). Positive correlations of CTDI_{vol} and DLP values with age, mean tube current–time product and reference tube current–time product ($P<0.001$); and the positive correlation of CTDI_{vol} and TI ($P=0.033$) were significant. Negative correlations of CTDI_{vol} and DLP values with collimated slice width ($P<0.001$) and pitch ($P=0.002$ and $P=0.003$, respectively) were also significant.

Overall comparison of CTDI_{vol} and DLP values of spine CTs obtained with different tube potential values yielded a significant difference in CTDI_{vol} and DLP values of thoracolumbar CTs in group 1 ($P=0.034$ vs. $P=0.034$) and in CTDI_{vol} values of lumbar CTs in group 2 ($P=0.039$) (Table 4). There was a significant difference between CTDI_{vol} and DLP values of overall CTs performed with different tube potential

Table 2 Second and third quartiles of volume CT dose index ($CTDI_{vol}$), dose–length product (DLP) and effective dose (E) for each type of spine CT examination according to age

CT examination	Age group (years)	Number of exams	2nd quartile			3rd quartile		
			$CTDI_{vol}$ (mGy)	DLP (mGy·cm)	E^a (mSv)	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)	E^a (mSv)
Thoracic spine CT	1–5	5	2.07	55	1.43	3.07	56	1.45
	5–10	5	3.72	106	1.90	3.83	110.79	1.99
	10–15	13	5.26	206	2.67	9.13	346.22	4.50
	15–17	5	8.25	287.15	4.02	9.21	322	4.50
Thoracolumbar spine CT	1–5	20	2.12	90.14	2.61	5.04	128.75	7.21
	5–10	21	3.43	163	6.19	4.11	205.04	7.79
	10–15	37	6.89	340.5	9.52	9.16	535.18	14.98
	15–17	30	8.51	521.57	15.64	11.77	725.85	21.77
Lumbar spine CT	1–5	1	NA	NA	NA	NA	NA	NA
	5–10	9	3.41	74.07	1.48	3.8	88	1.76
	10–15	30	6.48	200.89	3.01	8.34	246.93	3.70
	15–17	16	8.03	268.21	4.02	9.56	357.79	5.36

mGy milligrays, *mGy·cm* milligrays × centimeters, *mSv* millisieverts, *NA* not applicable

[a] Effective dose was calculated from DLP using age-specific conversion coefficients (k) from European guidelines [10]

value with a gradually increasing dose as tube potential increased (Fig. 2). Post hoc analysis of the results revealed significant $CTDI_{vol}$ and DLP increase between thoracolumbar CTs obtained with 110 kV and 120 kV in group 1 and significant $CTDI_{vol}$ increase between lumbar spine CTs obtained with 110 kV and 120 kV in group 2 (for *P*-values, refer to Online Supplementary Material 2).

Overall comparison of $CTDI_{vol}$ and DLP values of spine CTs obtained with different collimated slice width values yielded a significant difference in $CTDI_{vol}$ and DLP values

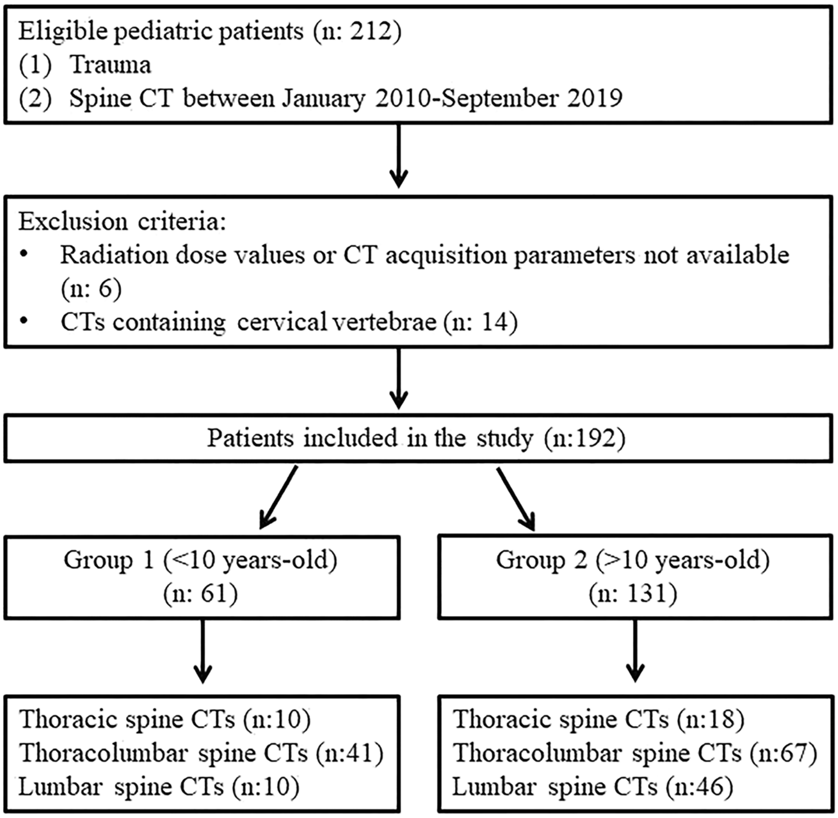

Fig. 1 Flow chart shows study population

Table 3 Correlation coefficients and significance levels among age, CT acquisition parameters and radiation dose values in pediatric spine CTs

Parameters	CTDI$_{vol}$		DLP	
	r-value[a]	*P*-value[b]	*r*-value[a]	*P*-value[b]
Age	0.609	<0.001	0.578	<0.001
Mean tube potential (kV)	0.209	0.083	0.035	0.809
Mean tube current–time product (mAs)	0.788	<0.001	0.694	<0.001
Reference tube current–time product (mAs)	0.433	<0.001	0.361	<0.001
TI	0.263	0.033	0.122	0.479
CSW	−0.356	<0.001	−0.377	<0.001
Pitch	−0.166	0.002	−0.152	0.003

CSW collimated slice width, *CTDI$_{vol}$* volume CT dose index, *DLP* dose–length product, *kV* kilovoltage, *mAs* milliamperes, *TI* inversion time

[a] Correlation coefficient

[b] Spearman correlation test. $P<0.05$ is significant

Table 4 Comparison between mean volume CT dose index (CTDI$_{vol}$) and dose–length product (DLP) values of spine CTs performed at different tube potential (kV) values

Group	CT	Tube potential (kV)	*n*	Age (mean)	Tube current–time product (mAs, mean)	Reference tube current–time product (mAs, mean)	CSW (mm, mean)	TI (s, mean)	Pitch (mean)	Scan length (cm)	CTDI$_{vol}$ (mGy, mean)	*P*-value	DLP (mGy·cm, mean)	*P*-value
1	Thoraco-lumbar spine CT	80	1	6	40	90	2.5	0.8	1	32.7	1.1		37.0	
		100	1	7	37	90	1.5	0.5	0.8	51.8	1.7		88.0	
		110	17	5.9	46.2	132	1.2	0.9	0.98	45.8	4.2	**0.034[a]**	216.8	**0.034[a]**
		120	3	5.7	88.5	150	0.7	0.7	0.84	40.5	7.1		260.4	
		130	19	5.8	28.3	89.5	2.1	0.8	1	41.0	3.1		127.5	
	Lumbar spine CT	110	3	9.5	35	150	0.6	0.9	1	19.1	2.6	0.210[a]	60.3	0.210[a]
		130	7	7.3	32	102.5	2.1	0.9	1	22.5	3.6		78.0	
	Thoracic spine CT	80	1	2	26	50	2.5	0.8	1	20.5	0.7		15.0	
		110	2	6.5	30	100	1.6	0.9	1	26.5	2.3	0.255[a]	65.4	0.255[a]
		130	7	6.1	32.9	94.3	2.0	0.9	0.97	26.9	3.8		102.9	
2	Thoraco-lumbar spine CT	110	24	14.5	98.1	133.3	1.6	0.8	0.99	63.4	7.3		464.4	
		120	13	14.7	104	127.8	1.2	0.7	0.81	59.6	8.2	0.440[b]	488.8	0.627[b]
		130	30	14.6	71.0	118.2	1.7	0.9	0.99	53.8	8.3		456.5	
	Lumbar spine CT	80	1	12	71	150	1.2	1	1	25.4	2.0		50.5	
		100	1	11	110	120	0.8	0.8	0.8	19.8	5.5		109.0	
		110	5	14.8	73.6	120	1.7	0.8	1	35.5	5.3	**0.039[a]**	194.5	0.127[a]
		120	7	15.1	112	117.9	0.9	0.7	0.82	34.0	8.5		280.8	
		130	32	14.5	70.3	126.6	1.7	0.9	1	30.8	7.7		244.8	
	Thoracic spine CT	100	1	17	130	150	0.6	1	0.93	31.9	5.5		175.0	
		110	2	14	55	60	1.2	0.8	0.9	37.6	3.1	0.543[a]	115.0	0.702[a]
		120	4	14.8	103	91.5	0.8	0.8	0.8	30.4	7.6		249.1	
		130	11	13.5	62.6	87.0	2.0	0.9	1	36.6	6.8		246.8	

cm centimeters, *CSW* collimated slice width, *kV* kilovoltage, *mAs* milliamperes, *mGy* milligrays, *mGy·cm* milligrays × centimeters, *mm* millimeters, *n* number of patients, *s* seconds, *TI* inversion time

[a] Kruskal–Wallis test was applied. $P<0.05$ is significant (bold)

[b] One-way analysis of variance (ANOVA) test was applied. $P<0.05$ is significant

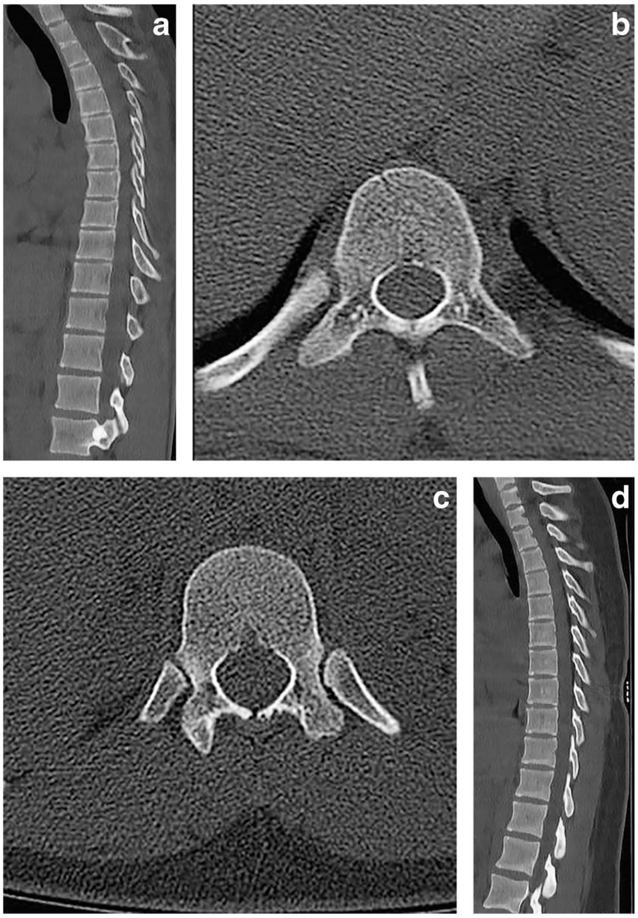

Fig. 2 Image comparisons at different dose levels. **a, b** CT images at level T11 in a 15-year-old girl reformatted in sagittal (**a**) and axial (**b**) planes. Images were obtained with 130 kV, 113 mAs and a collimated slice width value of 1.2 mm. The scan length was 58.8 cm and the dose–length product (DLP) was 731.5 mGy·cm. The girl's body mass index (BMI) was 22.7 kg/m^2. **c, d** CT images of the T11 vertebra in a 16-year-old boy reformatted in the axial (**c**) and sagittal (**d**) planes. Images were obtained with 110 kV, 115 mAs and a collimated slice width value of 1.2 mm. The scan length was 57.4 cm and the DLP was 500.7 mGy·cm. The boy's BMI was 24.8 kg/m^2. In the second patient, DLP was lower than in the first patient, with preserved image quality, although the second patient's BMI was higher

of thoracolumbar CTs in group 1 (P<0.001 vs. P<0.001), and thoracolumbar (P<0.001 vs. P<0.001) and lumbar CTs (P=0.001 vs. P=0.005) in group 2 (Table 5). CT dose values gradually decreased as collimated slice width increased. Post hoc analysis of the results yielded a significant CTDI_{vol} and DLP decrease between collimated slice widths of 0.6 mm and 1.5 mm of thoracolumbar CTs in group 1; and between collimated slice widths of 0.6 mm and 2.5 mm, 0.8 mm and 2.5 mm, and 1.2 mm and 2.5 mm of thoracolumbar CTs in group 2 (Fig. 3). Mean CTDI_{vol} value of lumbar CTs obtained with a collimated slice width of 0.8 mm was significantly higher than lumbar CTs obtained with collimated slice widths of 1.5 mm and 2.5 mm in group 2. The mean CTDI_{vol} value of lumbar CTs obtained with a collimated slice width of 1.2 mm was significantly higher than in lumbar CTs obtained with a collimated slice width of 1.5 mm in group 2. CTDI_{vol} and DLP values of lumbar CTs obtained with a collimated slice width of 1.2 mm were significantly higher than in lumbar CTs obtained with a collimated slice width of 2.5 mm in group 2 (for P-values, refer to Online Supplementary Material 3).

Although there were variations in subjective image-quality scores, all spine CT exams were assigned as diagnostically sufficient (score of 3 for 143 [reader 1] and 154 [reader 2] exams; score of 4 for 49 [reader 1] and 38 [reader 2] exams). No CT exam was scored as 1 or 2. Interobserver agreement was substantial (κ=0.804, P=0.034). The incidence of traumatic injury in spine CTs was 29 (15.1%) (compression fracture, n=14; transverse process fracture, n=6; burst fracture, n=5; Chance fracture, n=2; vertical spinous process fracture, n=2). Of these 29 fractures, 7 were unstable fractures (24.1%) (Fig. 4).

Discussion

Spine CT performed for traumatic injuries might be an unnecessary source of ionizing radiation exposure in children. Optimization of spine CT protocols, especially in children, is of utmost importance in radiation dose reduction. In this study, we depicted local diagnostic reference levels of thoracic, thoracolumbar and lumbar spine CT examinations and showed that significant dose reduction could be obtained in spine CT protocols of children with spinal trauma with the use of lower tube potential and higher collimated slice width — without significant differences in subjective image quality.

Justification is one of the mainstay steps in radiation dose reduction in CT examinations. The American College of Radiology (ACR) appropriateness criteria for suspected spinal trauma recommend spine CT as the initial imaging in patients 16 years and older who meet blunt trauma criteria for thoracic and lumbar imaging. Although there is no consensus regarding the suggested criteria for CT of the thoracolumbar spine in trauma patients, several criteria — including back pain, thoracolumbar tenderness, indeterminate findings on radiography, neurologic deficit and high-risk mechanism of injury — are widely accepted [13]. Contrary to its recommendations for adults, the ACR in its appropriateness criteria recommends radiographs of the thoracic and lumbar spine for initial imaging of children with suspicion of thoracolumbar spinal trauma. Spine CT can be performed in symptomatic pediatric patients without significant findings on radiographs and in symptomatic or asymptomatic children with abnormal radiographic findings. MRI should also be considered as an alternative imaging method, particularly in children with an abnormal neurologic examination [14]. In our study, the proportion of abnormal CTs in all requested spine CTs was 15%, while only 7 unstable fractures (3.6%) were detected in overall CTs. This

Table 5 Comparison between mean volume CT dose index ($CTDI_{vol}$) and dose–length product (DLP) values of pediatric spine CTs at different collimated slice width (CSW) values

Group	Study	CSW (mm)	*n*	Age (years, mean)	Tube–current product (mAs, mean)	Reference tube–current product (mAs, mean)	Tube potential (kV, mean)	TI (s, mean)	Pitch (mean)	Scan length (cm)	$CTDI_{vol}$ (mGy, mean)	*P*-value	DLP (mGy·cm, mean)	*P*-value
1	Thoraco-lumbar spine CT	0.6	9	7.3	56.9	167.1	113.3	0.81	0.99	49.0	4.9		240.7	
		0.8	3	5.3	105	100	116.7	0.75	0.8	37.8	7.3		259.0	
		1.2	6	4.9	41.3	123.3	110	0.93	1	50.5	3.1	<0.001[a]	157.0	<0.001[a]
		1.5	7	4.6	19.8	88.3	125.7	0.75	0.97	45.7	1.8		81.6	
		2.5	16	6.1	28.8	83.4	123.1	0.8	1	36.6	2.9		104.7	
	Lumbar spine CT	0.6	3	9	32.3	123.3	110	0.86	1	24.1	2.6		60.3	
		1.2	2	7.5	47	150	130	1	1	22.3	5.2	0.094[a]	115.5	0.094[a]
		2.5	5	7	27	90	130	0.8	1	20.3	3.0		63.0	
	Thoracic spine CT	0.6	1	6	48	150	110	1	1	28.9	3.8		110.8	
		1.2	2	7.5	41.5	150	130	1	0.9	30.5	4.6	0.464[a]	140.5	0.364[a]
		1.5	2	4	17.5	60	130	0.8	1	27.0	1.9		51.0	
		2.5	5	5.8	30	68	116	0.8	1	23.6	3.0		74.4	
2	Thoraco-lumbar spine CT	0.6	8	15.3	115	184.9	116.3	0.83	0.96	59.0	10.2		598.2	
		0.8	12	14.6	106	109.8	120	0.75	0.8	61.0	8.4	<0.001[b]	506.2	<0.001[b]
		1.2	25	15.4	97.4	141.6	118.8	0.92	0.99	63	9.2		575.7	
		2.5	22	13.5	56.1	86.1	125.5	0.8	1	51.4	5.4		270.0	
	Lumbar spine CT	0.8	7	14.4	117	143.6	117.1	0.75	0.82	30.4	8.6		263.9	
		1.2	23	14.9	83.0	148.7	125.2	0.98	1	33.0	8.5	0.001[a]	283.6	0.005[a]
		1.5	2	14.5	58	90	125	0.65	0.9	33.8	4.9		168.0	
		2.5	14	13.9	52.4	90	127.1	0.8	1	28.9	5.4		159.0	
	Thoracic spine CT	0.6	1	17	130	150	100	1	0.93	31.9	5.5		175.0	
		0.8	5	14.8	96.5	91.5	118	0.75	0.8	31.6	6.9		228.1	
		1.2	1	14	25	120	130	1	1	38.1	9.1	0.180[a]	347.4	0.110[a]
		1.5	5	13	62.8	84	126	0.8	1	34.2	3.2		109.2	
		2.5	6	13.8	63.7	78	130	1.03	1	38.6	8.7		317.8	

kV kilovoltage, *mAs* milliamperes, *mGy* milligrays, *mGy·cm* milligrays × centimeters, *n* number of patients, *s* seconds, *TI* inversion time

[a] Kruskal–Wallis test

[b] One-way analysis of variance

result implies the necessity of justifying CT requests as the first step in radiation dose reduction.

Currently, CT scanners provide $CTDI_{vol}$ and DLP values as radiation dose output. However, these values do not truly reflect the individualized patient radiation dose, which is affected by the child's size and BMI. The size-specific dose estimate (SSDE) is an individualized radiation dose corrected to the child's size. SSDE is calculated from $CTDI_{vol}$ using a conversion factor that considers anteroposterior and lateral skin-to-skin patient diameters [15]. SSDE can be easily obtained using the Dose Archiving and Communication System, which integrates several parameters, including height, weight and age, to radiation dose calculation. The Dose Archiving and Communication System can also help in collecting and archiving the dose data, real-time monitoring of dose exposure, and assessing and optimizing practices [16]. In this study, we interrogated radiation dose values of spine CTs according to age groups of patients because weight and BMI values were not recorded in all children. This drawback prevented us from acquiring SSDE values of these children through the Dose Archiving and Communication System.

Dose reduction in CT can be accomplished with the use of automatic exposure control systems, lower tube potential, higher slice width and higher pitch values. Furthermore, the iterative reconstruction algorithm, as an image reconstruction technique, allows for radiation dose reduction in CT by lowering scanning parameters, such as tube current or tube potential, while preserving image quality because of its ability to

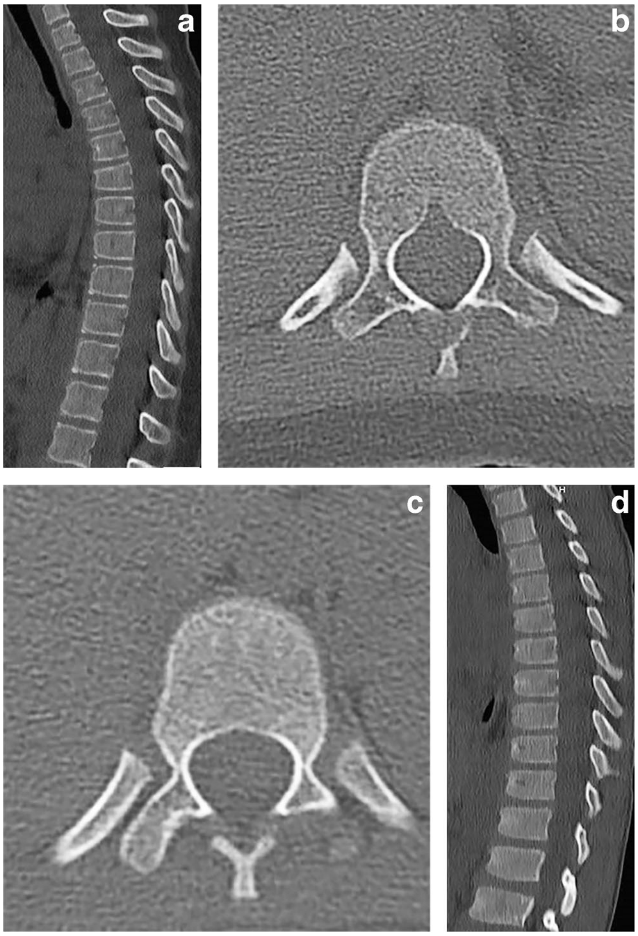

Fig. 3 Image comparisons at different dose levels. **a, b** Thoracolumbar spine CT images reformatted in the sagittal plane (**a**) and axial plane (**b**) at the T11 level in a 9-year-old girl. Images were obtained with 110 kV, 85 mAs and collimated slice width value of 0.6 mm. The scan length was 58.4 cm and the dose–length product (DLP) was 397.0 mGy·cm. The girl's body mass index (BMI) was 20.8 kg/m^2. **c, d** Thoracolumbar spine CT images reformatted in the axial (**c**) and sagittal (**d**) planes at the level of the T11 vertebra in a 9-year-old boy. Images were obtained with 110 kV, 81 mAs and collimated slice width value of 1.2 mm. The scan length was 59.7 cm and the DLP was 187.4 mGy·cm. The boy's BMI was 21.3 kg/m^2. Note that both studies provide optimal contrast resolution for image interpretation

lower image noise [17]. High intrinsic contrast between the bone structure and surrounding soft tissues enables the use of iterative reconstruction in pediatric spine CT [18]. Positioning children accurately along with avoiding over-beaming and over-range scanning are also critical for lowering radiation dose [4–6, 18–24]. In this study, we found that CT acquisition parameters varied in different CT protocols (thoracic, thoracolumbar and lumbar) within the same age group, and also that different CT acquisition parameters were used in the same CT protocol in the same age group. Comparison between scan lengths of spine CT examinations revealed that the ratio of mean scan length between group 1 and group 2 was highest in lumbar CT compared to the thoracic spine and thoracolumbar spine CTs, which implies the tendency of over-scanning in lumbar CT examinations in the adolescent age group. Limiting scan length as a dose-reduction maneuver would be helpful in lumbar CT examinations. Furthermore, it is important to review the clinical information. If the child's signs and symptoms are limited to a given level, CT scanning of the entire spine might be unnecessary [25, 26].

Correlation results between CT acquisition parameters and CT dose values revealed a positive correlation between DLP values and mean tube potential, mean tube current–time product, reference tube current–time product and TI values of spine CTs. In contrast, DLP values were negatively correlated with collimated slice width and pitch values. These correlation results were in concordance with general CT dose principles defined in previous reports [27–29]. Tube potential is one of the most effective CT acquisition parameters that affect radiation dose in CT. The radiation dose for the assessment of bone structure might be substantially reduced using low tube potential (i.e. 80 kV) because increased noise is tolerable owing to high intrinsic contrast between the bone structure and surrounding soft tissue [23]. In our study, lower tube potential levels resulted in decreased radiation dose in both age groups without a statistically significant difference in image quality. However, dose values of thoracolumbar CTs performed with 130 kV in group 1 were lower than in CTs performed with 120 kV and 110 kV, which could be attributed to higher collimated slice width values of thoracolumbar CTs performed with 130 kV. This result implies the importance of optimizing other CT acquisition parameters besides tube potential, such as tube current–time product, TI, collimated slice width and pitch values, in radiation dose reduction strategy. A comparison of CT dose values and scan acquisition parameters yielded that a significant increase in mean tube current–time product and scan length was the major cause of higher dose in group 2 than group 1. We also noted that collimated slice width and pitch values in spine CTs were lower in group 2 compared to group 1 patients, which also caused a dose increase in group 2 patients. Increasing the collimated slice width and pitch values would decrease the radiation dose without significantly lowering the image quality or decreasing the reconstruction ability of appropriate image section thickness. However, it should be noted that modern CT scanners using automatic exposure control increase the tube current to keep a constant signal-to-noise ratio if the pitch is increased. Therefore, increasing the pitch alone might not be an effective method for decreasing radiation dose in modern CT scanners [30]. Decreasing the TI as the CT scanner allows would also contribute to a decrease in radiation dose.

The collimated slice width should be determined based on the type of study performed and the desired slice width for multiplane reformations. As the collimated slice width is lowered, thinner reconstructed slice width is achievable. For example, if 2 mm of reconstructed slice width is needed, 0.75 mm or 1.5 mm of collimated slice width can be used without significant difference in the reconstructed image quality; however, thinner collimated slice width results in a higher radiation dose [24]. In our study, a comparison of dose values between CT examinations obtained with different collimated slice width values depicted significant differences in CTDI_{vol} and DLP values of overall thoracolumbar CTs in groups 1 and 2, and lumbar CTs in group 2. Radiation dose values decreased as the collimated slice width values increased. However, CTDI_{vol} and DLP values of CTs obtained with the highest collimated slice width values (2.5 mm) in thoracolumbar CTs in group 1 were higher than in CTs obtained with lower collimated slice width values (1.5 mm), which was an unexpected finding. Interrogation of CT acquisition parameters yielded that although reference tube current–time product, mean tube current–time product, tube potential, TI and pitch values were not significantly different, the mean scan length for CTs performed with a collimated slice width of 1.5 mm was longer than for CTs performed with collimated slice width of 2.5 mm, which increased radiation dose in CTs performed with collimated slice width of 1.5 mm. We observed a similar discrepancy in thoracic and lumbar CT examinations in group 1 patients; however, the number of patients in these two groups (n=10 for both groups) was low to interrogate the underlying cause. This contrary result might be attributed to different BMI values of the patient groups. According to post hoc analysis results, the significant difference in dose when using various collimated slice width values implies the importance of slice width in radiation dose exposure in pediatric spine CTs. Increasing collimated slice width values to decrease radiation dose might be controversial in terms of detecting subtle spine fractures. However, subtle fractures do not require surgical repair, and conservative management is preferred except in critical fractures such as dens fracture of the C2 and a three-column fracture of the spondylotic thorax. Severe fractures with contour deformity and decreased vertebra height can be detected on scout images. Therefore, scout images could be used as a guide in the determination of spine CT acquisition parameters. The presence of vertebra contour deformity and height decrease on scout images might support acquiring CT images with low tube potential and high collimated slice width values [31].

Our study has some limitations. First, there were relatively lower numbers of children with thoracic and lumbar CTs in group 1 and BMI values were absent in some children. Using children's BMI rather than age ranges would be more reproducible for further radiation dose studies on pediatric spine CT. Second, although the age distributions within groups were wide, the children's ages in the two groups showed a normal distribution pattern, and scan length, CTDI_{vol} and DLP values in all spine CT categories showed statistically significant differences between the two groups, which makes them appropriate for comparison. Third, our study included five CT scanners, all with different scan settings. Further studies using similar scan parameters might be helpful for dose optimization of pediatric spine CTs. Another important limitation of this study was subjective image-quality scoring by visual assessment rather than quantitative analysis of the signal-to-noise ratio. We also must mention that this study did not include the whole-dose optimization strategies in pediatric spine CT examinations.

Conclusion

Local diagnostic reference levels presented in this study might be helpful to establish diagnostic reference levels for pediatric spine CTs and lead to future dose reduction studies on spine CT in children with spinal trauma. Being familiar with CT acquisition parameters and the effect of these parameters on ionizing radiation exposure is essential for optimizing CT examinations. Thanks to the intrinsic contrast between the bone structure and surrounding soft tissue, low tube potential values

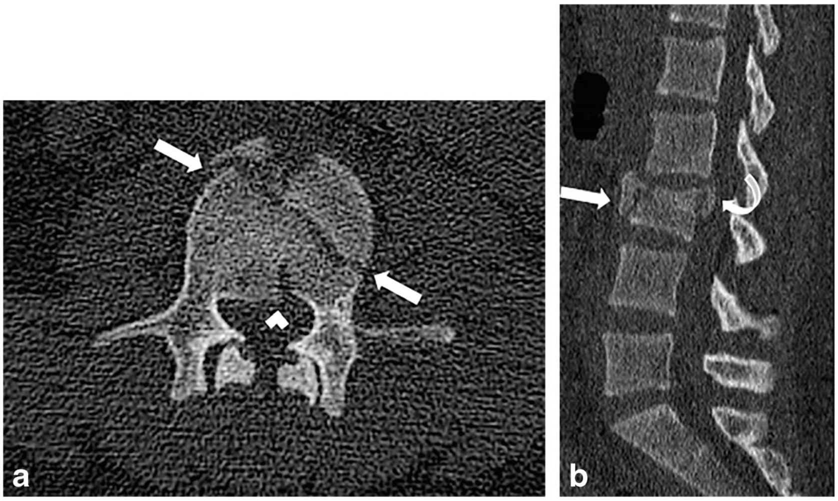

Fig. 4 Burst fracture in a 14-year-old girl who presented to emergency service with back pain after falling from a height of 4 m. **a** Axial CT image demonstrates vertebral body fracture (*arrows*) with involvement of the posterior vertebral body cortex (*arrowhead*). **b** Sagittal CT image shows the burst fracture of the L3 vertebra (*straight arrow*) with retropulsion of the bone fragment into the spinal canal (*curved arrow*)

can be used to achieve lower radiation dose in spine CTs. Using optimal collimated slice width value according to the desired reconstructed slice width is of utmost importance in lowering the radiation dose. Our study demonstrated the importance of tube potential and collimated slice width values in reducing radiation dose in pediatric spine CTs.

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Declarations

Conflicts of interest None

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