A new approach for dose reference levels in pediatric CT: age and size-specific dose estimation

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Conflict of interests

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Abstract

Background: Although paediatrics' are more radio-sensitivity than adults, the number of requested paediatric CT examinations is increasing globally. Significant efforts have been focused on achieving the lowest possible radiation dose for paediatric patients particularly with a focus on adjusting for size differences. This study aims to establish Diagnostic Reference Levels (DRLs) for paediatric patients based on size-specific dose estimates (SSDE).

Method: In this retrospective national study, CT scans for brain, chest, abdominopelvic, and chest, abdomen, and pelvis (CAP) were collected from four hospitals in Jordan undergoing paediatric CT scans. A total of 1,818 cases were randomly selected in four age categories (<1 year, 1-4 years, 5-10 years, 11-18 years). The SSDE values were determined by multiplying the volume CT dose index ($CTDI_{vol}$) with the conversion factor extracted from the American Association of Physicists in Medicine Report 204.

Results: Variations exist between the DRLs between the different hospitals, age groups, and variations in protocols with different types of CT scanners. The DRL values ($CTDI_{vol}$, dose-length product (DLP) and SSDE) for the four age categories were as follows; <1years: brain (47.88 mGy, 741.67 mGy.cm and 58.40 mGy), chest (5.65 mGy, 124 mGy.cm and 13.91 mGy), abdominopelvic (12.65 mGy, 321.5 mGy.cm and 28.72 mGy) and CAP (16.12 mGy, 507.72 mGy.cm and 38.04 mGy). 1-4 years, brain (54.79 mGy, 979.12 mGy.cm and 55.88 mGy), chest (7.37 mGy, 220.85 mGy.cm and 14.68 mGy), abdominopelvic (16.16 mGy, 424.72 mGy.cm and 32.68 mGy) and CAP (16.13 mGy, 742.1 mGy.cm and 33.54 mGy). 5-10 years: brain (65.03 mGy, 1129.94 mGy.cm and 55.92 mGy), chest (12.57 mGy, 383.9 mGy.cm and 22.45 mGy), abdominopelvic (12.34 mGy, 450.75 mGy.cm and 22.23 mGy) and CAP (13.46 mGy, 748.85 mGy.cm and 25.69 mGy). 11-18 years, brain (60.7 mGy, 1207.9 mGy.cm and 41.81 mGy), chest examination (12.94 mGy, 496.2 mGy.cm and 20.49 mGy), abdominopelvic (16.13 mGy, 803.07 mGy.cm and 23.06 mGy) and CAP (16.13 mGy, 1101.5 mGy.cm and 23.85 mGy).

Conclusion: There were increases in $CTDI_{vol}$, DLP, and SSDE with ascending age groups. SSDE and age are closely matched to delivered radiation in paediatric CT; however, radiation dose levels still remain high in Jordan. This work highlights the need for caution when administering radiation in the paediatric population.

Keywords; $CTDI_{vol}$, DLP, Jordan, radiation dose, CT optimization

Abbreviation

Diagnostic Reference Levels (DRLs)

Size-specific dose estimates (SSDE)

Chest, abdomen, and pelvis (CAP)

Computerized tomography (CT)

CT dose index ($CTDI_{vol}$)

Introduction

The rapid increase in the number of CT scanners and examinations is of concern in the World [1]. In the United States alone, more than 62 million CT scans are performed each year, of which 4 million are performed on children. With increased numbers, an increased emphasis is needed on Justification, Optimisation, and DRLs. Radiation dose reduction strategies, especially in the paediatric population are critical to mitigate the risk of later cancer development [2, 3]. Risk-benefit evaluation should be considered for all CT scans [4], and more emphasis should be put on the paediatric population as it has a greater risk of developing radiation-induced diseases including thyroid cancer, leukemia, breast cancer, and skin cancer. The increased risk is in part due to the longer life expectancy and higher radiosensitivity of children compared to adults [2, 5, 6]. In order to assess related radiation-induced risks accurately, it is recommended that organ-specific radiation doses are evaluated [7].

International standards dictate that all CT scanners provide a radiation dose report for each examination; this can be in terms of dose-length product (DLP) and volume CT dose index ($CTDI_{vol}$). $CTDI_{vol}$ offers a standardized way to compare different types of CT scanners' slice-by-slice radiation levels using a reference phantom. DLP, the product of scan length (cm) and $CTDI_{vol}$ (mGy), represents the overall irradiation energy to the reference phantom. Furthermore, $CTDI_{vol}$ is a CT exposure index that is determined from polymethyl methacrylate (PMMA) phantoms, which are available in two sizes, 32 cm and 16 cm [8]. These numbers correspond to the average adult abdominal and brain measurements respectively. The current $CTDI_{vol}$ values are based on adult measurements, thus, they do

not reflect the paediatric body size, which can vary from 1kg in neonates to 70 kg in adolescents. While defining the protocols of CT scans, it is possible to choose whether the $CTDI_{vol}$ to be computed is based on the 32 cm phantom or the 16 cm phantom, where a change in the process produces an artificial variation in the radiation dose [9]. Both DLP and $CTDI_{vol}$ are sensitive to variations in the CT scan parameters including tube current (mA), tube voltage (kVp), pitch, bowtie filters, and gantry rotation time (s). Nevertheless, they are independent of the size of the patient [10]. Consequently, DLP and $CTDI_{vol}$ do not provide an accurate estimate of the absorbed dose relative to patient size and do not distinguish between the smaller paediatric and the larger adult populations [3, 11, 12].

In order to improve $CTDI_{vol}$ based on the size of the patient, the American Association of Physicists in Medicine (AAPM) task group 204 recommends size-specific dose estimates (SSDE), which is computed from measured patient diameters and $CTDI_{vol}$ using conversion factors from look-up tables [13]. Employing the SSDE approach has overcome the downsides of $CTDI_{vol}$ and DLP. Moreover, this approach has helped in obtaining a more precise radiation dose in paediatrics [14]. This study aims to establish DRLs for peadiatric patients based on SSDE.

Methodology

This retrospective study attained the approval of the institutional review board (20180322). The data collection process was conducted in four hospitals performing paediatric CT in Jordan in the period between March and October 2018. The most common CT scans were selected which included four body regions that used iodinated contrast media (brain) or without contrast (chest; abdominopelvic; and chest, abdomen and pelvis). Four types of CT scanners were used in the participating hospitals. Radiation dose delivered could be adjusted automatically based on the noise index and weight of the patient. Table 1 below shows the main models used in each hospital and the followed protocol.

Table 1: Characteristics of the used CT scanners models in each hospital

Centre	Manufacture	Model	Protocol
I	Philips	16 slice	Brain: from base of skull to vertex C-spine: base of skull to under jugular notch Chest: from jugular notch to under costophrenic angle Abdomen: from diaphragm to symphysis pubis
II	Toshiba	16 slice	Brain: from base of skull to vertex C-spine: from mid head to sternum Chest: above shoulder to below lung base Abdomen: from diaphragm to below ischium
III	Siemens	512 slice	Brain: from base of skull to vertex C-spine: base of skull to jugular notch Chest: from jugular notch to costophrenic angle Abdomen: from diaphragm to symphysis pubis
IV	Philips	16 slice	Brain: from base of skull to vertex C-spine: base of skull to jugular notch Chest: From Thyroid Gland to diaphragm Abdomen: from diaphragm to symphysis pubis

Patient demographics

A total of 1,818 cases were randomly selected to include paediatric patients in four age categories [<1 year (n = 494), 1-4 years (n = 403), 5-10 years (n = 407), 11-18 years (n = 514)] and those age groups were consistent with the studies of Järvinen et al. (2011) and Roch and Aubert (2012) [15, 16]. Of the 1,818 patients, 1,117 were males (61.4%) while the number of female patients was 701 (38.6%) and the range of their ages ranged between 3 months to <18 years. The number of scans for each hospital was as follows: (hospital 1: 713; hospital 2: 246; hospital 3: 338 and hospital 4: 521). The number of CT scans varied also according to each exam 1,163 (brain), 219 (chest), 234 (abdominopelvic) and 202 (Chest, Abdomen and Pelvis). Only complete patient information examinations including the study date and age, clinical histories, and dose indexes diagnostic questions were included. The general examinations indications were compatible with previous studies [17, 18]. For the brain, trauma was selected and for the chest, malignancy detection was selected. The abdomen CT indications that were not included in Schrimpton et al. (2005) [17], were the routine scan malignancy detection indications including; abdominal mass, abdominal pain, or inflammation or infection. In the case of the brain CT examinations, those performed without contrast were only included in this study. The abdomen/pelvis and chest CT examinations were included irrespective of the use of intravenous contrast, while all post-contrast exams were only single phase where similar protocol was included.

Dose Estimate

The patient age (y); scan parameters including tube voltage (kVp), tube current (mA), and pitch (mm); and dose reports including $CTDI_{vol}$ (mGy), DLP (mGy.cm), and phantom size (16 cm or 32 cm) were extracted from the Picture Archiving and Communication System

(PACS) of each participating hospital. The CTDIvol (Equation 1) and DLP (Equation 2) can be calculated using the following equations [19, 20]:

$$CTDI_{vol}(mGy) = \frac{CTDI_w}{Pitch\ factor} \qquad (1)$$

$$DLP\ (mGy \cdot cm) = CTDI_{vol} \times Scan\ length \qquad (2)$$

Where $CTDI_w$ is the Weighted CT Dose Index and the pitch factor is the distance the table moves in the z axis divided by the slices number and each slice thickness.

The AAPM Report no. 204 was used to determine SSDE. The effective diameter was estimated as a function of patient age. Then, the appropriate conversion factor was obtained from the report. f_{size}^{xy} denotes the appropriate conversion factor for each body size, in which x is the phantom size and y is the method of estimating the body size for each age group: < 1 year, 1-4 years, 5-10 years and 11-18 years. Conversion factors based on the use of the 16 cm diameter PMMA phantom for $CTDI_{vol}$ (f_{size}^{16Age}) were used for brain CT studies, and conversion factors based on the use of the 32 cm diameter phantom (f_{size}^{32Age}) were used for the chest, abdominopelvic, and chest, abdomen and pelvis (CAP) CT studies.

SSDE for brain examinations was calculated using the following equation (Equation 3):

$$SSDE = f_{size}^{16Age}.\mathrm{CTDI_{vol}} \qquad (3)$$

Whereas SSDE for chest, abdominopelvic, and CAP examinations was calculated using the following equation (Equation 4):

$$SSDE = f_{size}^{32Age}.\mathrm{CTDI_{vol}} \qquad (4)$$

Data analysis

A descriptive statistical analysis of the DRL values was performed which included the minimum, the 25th percentile, median (50th percentile), the 75th percentile, and the maximum $CTDI_{vol}$, DLP, and SSDE values. For specific CT protocols, the DRL values were defined as the radiation dose distribution 75th percentile as calculated using $CTDI_{vol}$, DLP as well as SSDE. The statistical analysis was conducted through SPSS, IBM Corp. Version 20. (Armonk, NY).

Results

For the <1 year age group, the DRL values ($CTDI_{vol}$, DLP and SSDE) were as follows; the brain examination (47.88 mGy, 741.67 mGy.cm and 58.40 mGy), the chest examination (5.65 mGy, 124 mGy.cm and 13.91 mGy), abdominopelvic (12.65 mGy, 321.5 mGy.cm and 28.72 mGy) and the CAP examination (16.12 mGy, 507.72 mGy.cm and 38.04 mGy).

For the 1-4 years age group, the DRL values ($CTDI_{vol}$, DLP and SSDE) were as follows; the brain examination (54.79 mGy, 979.12 mGy.cm and 55.88 mGy), the chest

examination (7.37 mGy, 220.85 mGy.cm and 14.68 mGy), abdominopelvic (16.16 mGy, 424.72 mGy.cm and 32.68 mGy) and the CAP examination (16.13 mGy, 742.1 mGy.cm and 33.54 mGy).

For the 5-10 years age group, the DRL values ($CTDI_{vol}$, DLP and SSDE) were as follows; the brain examination (65.03 mGy, 1129.94 mGy.cm and 55.92 mGy), the chest examination (12.57 mGy, 383.9 mGy.cm and 22.45 mGy), abdominopelvic (12.34 mGy, 450.75 mGy.cm and 22.23 mGy) and the CAP examination (13.46 mGy, 748.85 mGy.cm and 25.69 mGy).

Finally for the 11-18 years age group, the DRL values ($CTDI_{vol}$, DLP and SSDE) were as follows; the brain examination (60.7 mGy, 1207.9 mGy.cm and 41.81 mGy), the chest examination (12.94 mGy, 496.2 mGy.cm and 20.49 mGy), abdominopelvic (16.13 mGy, 803.07 mGy.cm and 23.06 mGy) and the CAP examination (16.13 mGy, 1101.5 mGy.cm and 23.85 mGy). These DRL values and the descriptive statistics for the four examinations for each age group can be seen in Table 2.

Table 2: Scan parameters and dose estimates for all CT examinations for the four age groups

Examination	Age group (years)	n	kVp (n)	mAs [median (range)]	Pitch [median (range)]	$CTDI_{vol}$ (mGy)			DLP (mGy.cm)			SSDE (mGy)		
						Median	75th	Range	Median	75th	Range	Median	75th	Range
Brain	<1	308	100, 120	280 (10-450)	0.67 (0.2-1.7)	47.87	47.88	2.78-77.04	644.82	741.67	4.8-6702.3	54.09	58.40	3.39-93.98
	1-4	301	100, 120	320 (37-530)	0.67 (0.2-1)	51.7	54.79	3.06-77.05	874.98	979.12	27.9-1659.5	53.14	55.88	3.09-80.90
	5-10	243	100, 120	350 (40-459)	0.67 (0.2-1)	58.8	65.03	2.6-77.05	1038.44	1129.94	25.2-1484.65	52.92	55.92	2.23-71.64
	11-18	311	100, 120	274 (47-992)	0.687 (0.2-1.2)	52.1	60.7	2.8-275	1019.1	1207.9	12.6-2795.2	36.90	41.81	1.70-189.75
	All	**1,163**	**100, 120**	**287 (10-992)**	**0.67 (0.20-1.70)**	**50.9**	**58.8**	**2.6-275**	**875.0**	**1100.3**	**4.8-6702.3**	**50.3**	**55.92**	**1.7-189.75**
Chest	<1	91	90, 100, 120	145 (13-320)	0.937 (0.5-1.2)	5.63	5.65	0.93-79	86.1	124	15-730.3	13.90	13.91	2.29-195.13
	1-4	48	90, 100, 120	77.5 (10-221)	1.2 (0.5-1.2)	4.7	7.37	1.77-32.91	104.66	220.85	11.3- 849.5	9.45	14.68	3.78- 67.79
	5-10	38	90, 100, 120	110 (27-379)	1.2 (0.5-1.2)	5.41	12.57	1.83-65.03	252	383.9	55.4-1147.3	9.62	22.45	3.36-117.7
	11-18	42	120	199 (46-399)	1.01 (0.5-1.2)	12.89	12.94	1.8-71.43	262.65	496.2	51.5-577.7	17.65	20.49	2.46-109.28
	All	**219**	**90, 100, 120**	**145 (10-399)**	**0.86 (0.50-1.20)**	**5.6**	**9.7**	**0.93-79**	**114.4**	**256.85**	**11.3-1147.3**	**10.2**	**17.72**	**2.29-195.13**
Abdominopelvic	<1	61	90, 100, 120	126 (69-320)	0.8 (0.5-1.2)	6.94	12.65	2.73-60.33	145.8	321.5	35.5-849.5	15.41	28.72	6.23-138.75
	1-4	26	90, 100, 120	150 (30-450)	0.93 (0.5-1.2)	9.7	16.16	0.87-204	294.2	424.72	14.2-2008.42	18.86	32.68	1.72-420.24
	5-10	63	90, 100, 120	150 (37-250)	1 (0.5-1.2)	9.7	12.34	2.6-47.8	336.5	450.75	65.5-926.5	17.848	22.23	4.628-91.298
	11-18	84	100, 120	200 (37-339)	1 (0.5-1.2)	13.12	16.13	3.9-60.11	612.5	803.07	8.17-1185.9	19.11	23.06	4.68-95.57
	All	**234**	**90, 100, 120**	**163 (30-450)**	**0.70(0.50-1.20)**	**9.7**	**16.13**	**0.87-204**	**343.4**	**613.1**	**8.17-2008.4**	**15.2**	**23.41**	**1.72-420.24**
CAP	<1	34	90, 100, 120	150 (17-320)	1.2 (0.5-1.5)	9.7	16.12	1.21-77.14	248.48	507.72	40-1399	23.13	38.04	2.78-166.62
	1-4	28	90, 120	237 (40-320)	1.2 (0.5-1.2)	12.25	16.13	2.75-60.33	530.06	742.1	83.5-831.3	24.77	33.54	5.44-129.10
	5-10	63	90, 100, 120	180 (54-365)	1.2 (0.67-1.2)	9.7	13.46	1.64-970	524	748.85	44.6-1195.5	18.52	25.69	3.01-1784.8
	11-18	77	90, 100, 120	249 (10-610)	1.2 (0.6-1.2)	16.12	16.13	2.8-970	876.3	1101.5	106-1807	21.29	23.85	3.6-1600.5
	All	**202**	**90, 100, 120**	**199 (10-610)**	**0.93(0.50-1.50)**	**12.9**	**16.12**	**1.2-970**	**530.1**	**817.3**	**40.0-1807.0**	**18.1**	**28.69**	**2.78-1784.8**

The differences between the brain DRLs of the four participating hospitals for the paediatric brain CT examination were also reported (Table 3). The differences between the $CTDI_{vol}$ and SSDE values between the four hospitals were not significant except for hospital (III) where the values for the <1 year age group were nearly half (27.72 mGy and 33.5 mGy) when compared with the CTDIvol and SSDE values in hospital (II), which reached (58.8 mGy and 64.09 mGy). For the same age group, the DLP value for hospital (III) was also approximately halved compared with the other three hospitals.

Table 3: Dose estimates for the four age groups between the hospitals.

Exam	Dose Index	Age	Hospital I		Hospital II		Hospital III		Hospital IV	
			n	Median (IQR)	n	Median (IQR)	n	Median (IQR)	n	Median (IQR)
Brain	$CTDI_{vol}$ (mGy)	<1	164	47.87 (47.87-47.87)	17	58.8 (58.8-58.8)	75	27.72 (25.42-30.99)	52	38.16 (31.82-38.45)
		1-4	127	54.79 (54.79-59.92)	53	58.8 (30.4-58.8)	32	38.18 (34.52-43.33)	89	38.2 (38.16-50.93)
		5-10	119	65.03 (59.93-65.03)	29	58.8 (53.7-58.8)	21	41.06 (37.66-42.37)	73	38.2 (38.16-50.93)
		11-18	172	57.2 (52.1-60.7)	44	58.8 (58.8-60.31)	28	39.33 (34.14-43.94)	68	50.93 (50.93-50.93)
	DLP (mGy.cm)	<1	164	661.89 (601.67-735.7)	17	767.4 (348.1-869.45)	75	395 (336-487.4)	52	727.6 (647.9-899.97)
		1-4	127	879.96 (874.89-984.51)	53	838.6 (435.2-921.3)	32	646.5 (498.5-863.15)	89	863.7 (787.8-1100.3)
		5-10	119	1090.58 (1035.07-1155.61)	29	921.3 (576.2-987.4)	21	709.6 (602.05-805.9)	73	902 (712.75-1126.8)
		11-18	172	1123.03 (1007-1270.75)	44	978 (612.2-1019.87)	28	619.55 (412.42-812.52)	68	1177.4 (1090.7-1238.2)
	SSDE (mGy)	<1	164	58.38 (54.1-58.4)	17	64.09 (64.09-66.44)	75	33.5 (30.9-36.23)	52	42.43 (37.54-46.77)
		1-4	127	55.73 (55.33-57.52)	53	54.68 (31.92-59.38)	32	36.89 (33.92-44.78)	89	38.58 (35.52-49.4)
		5-10	119	55.92 (53.97-55.92)	29	50.56 (47.43-52.92)	21	35.53 (33.29-36.95)	73	35.52 (31.7-43.79)
		11-18	172	10.16 (7.55-10.51)	44	42.63 (38.8-47.04)	28	26.2 (22.74-30.76)	68	35.14 (33.23-36.16)
Chest	$CTDI_{vol}$ (mGy)	<1	11	4.42 (3.06-4.42)	8	30.4 (30.4-38.1)	63	5.63 (5.63-5.64)	7	5.63 (5.63-7.76)
		1-4	11	4.42 (4.42-4.42)	6	5.05 (4.9-5.21)	17	5.63 (2.97-7.34)	14	7.56 (2.38-9.7)
		5-10	9	4.78 (3.75-4.99)	9	60.31 (56.8-60.31)	9	2.7 (2.33-4.78)	12	9.7 (4.5-12.57)
		11-18	8	5.19 (2.64-5.19)	8	60.31 (60-71.43)	8	4.07 (3.4-5.97)	18	12.91 (12.89-12.94)
	DLP (mGy.cm)	<1	11	49.68 (47.54-71.865)	8	552.6 (479.3-591.45)	63	87 (77-118)	7	86 (78.5-177.7)
		1-4	11	82.92 (82.39-96.2)	6	178.75 (115.11-377.52)	17	104.3 (49.2-200.05)	14	218.5 (51.3-258.62)
		5-10	9	114.42 (96.5-117.92)	9	611.1 (305.25-669.4)	9	67.3 (60.55-137.75)	12	316.4 (142.65-380.02)
		11-18	8	138.88 (73.93-166.9)	8	449.4 (256.4-523.1)	8	108.8 (89.07-199.97)	18	462.1 (302.77-541.77)
	SSDE (mGy)	<1	11	10.17 (7.42-10.17)	8	68.23 (67.48-85.89)	63	13.9 (12.99-13.9)	7	13.9 (13.65-16.91)
		1-4	11	8.79 (7.56-8.87)	6	9.72 (9.39-10.22)	17	10.75 (5.04-14.07)	14	14.72 (5.21-17.89)
		5-10	9	8.8 (6.68-8.84)	9	110.97 (11.62-110.97)	9	4.8 (4.45-8.17)	12	17.84 (9.98-21.29)
		11-18	8	8.4 (6.57-8.56)	8	89.03 (82.51-106.6)	8	6.14 (5.4-8.09)	18	18.5 (17.67-20.14)
Abdominopelvis	$CTDI_{vol}$ (mGy)	<1	11	3.06 (2.75-3.06)	7	30.48 (30.44-45.5)	25	5.63 (4.21-7.34)	18	9.68 (5.44-12.91)
		1-4	5	8.03 (3.66-47.87)	8	4.5 (4.5-74.04)	5	7.34 (7.34-7.34)	8	12.25 (9.7-16.16)
		5-10	7	4.78 (3.66-5.19)	12	4.55 (4.5-4.9)	13	7.37 (7.34-9.7)	30	9.7 (9.7-16.13)
		11-18	19	11.3 (6.27-15.48)	15	5.8 (4.9-7.05)	9	12.89 (12.65-16.12)	41	16.13 (12.94-16.13)
	DLP (mGy.cm)	<1	11	67.28 (60.95-68.94)	7	567.9 (479.3-610.5)	25	82.2 (4.85-202.25)	18	247.3 (134.47-338.5)
		1-4	5	375.85 (99.1-1324.24)	8	186.6 (186.6-204)	5	286.2 (134.25-339.45)	8	388.5 (323.37-499)
		5-10	7	148.06 (124.8-160.04)	12	184.9 (157-283.17)	13	299.82 (272.65-409.15)	30	364.6 (332.92-575.77)
		11-18	19	588.6 (273.01-696)	15	247.3 (221.3-342.5)	9	591 (421-788)	41	767 (589-851.45)
	SSDE (mGy)	<1	11	6.79 (6.64-7.49)	7	68.27 (67.84-103.51)	25	13.9 (9.68-18.12)	18	22.27 (14.57-28.47)
		1-4	5	15.33 (7.24-102.44)	8	9.27 (9.27-154.36)	5	14.53 (14.01-15.12)	8	23.8 (20.37-31.43)
		5-10	7	9.13 (6.26-9.24)	12	8.37 (8.21-8.49)	13	13.56 (13.45-18.52)	30	18.52 (17.84-27.58)
		11-18	19	15.96 (9.71-18.72)	15	8.87 (6.94-10.45)	9	19.07 (17.65-22.08)	41	22.09 (20.49-24.67)
Chest-Abdomen-Pelvis	$CTDI_{vol}$ (mGy)	<1	7	3.06 (2.75-4.42)	7	60.33 (60.33-60.33)	10	5.63 (5.63-7.36)	10	16.12 (9.7-16.12)
		1-4	3	4.78 (3.06-4.78)	7	7.5 (5-60.33)	4	5.03 (2.75-7.9)	14	16.12 (12.57-16.45)
		5-10	12	4.78 (4.78-8.03)	8	4.9 (4.5-5)	11	9.7 (5.63-14.5)	32	12.89 (10.17-16.12)
		11-18	26	10.19 (3.06-19.4)	8	7.05 (6.025-9.975)	8	15.56 (12.2-16.12)	35	16.12 (16.12-16.13)
	DLP (mGy.cm)	<1	7	60.45 (46.62-110.01)	7	450.1 (230.56-552.1)	10	134.75 (74.52-225.75)	10	541.27 (342.45-574.12)
		1-4	3	125.87 (87.9-138.78)	7	340.22 (210.2-530.22)	4	160.2 (84.47-458.75)	14	752.4 (565.6-808.42)
		5-10	12	178.63 (161.69-353.01)	8	198.75 (147.3-360.95)	11	524 (300.7-768.2)	32	724.3 (528.37-828.4)
		11-18	26	520.12 (129.7-1012.6)	8	355.35 (288.1-472.45)	8	875.2 (462.55-1075.75)	35	950.1 (741.1-1183)
	SSDE (mGy)	<1	7	7.03 (6.7-9.72)	7	138.75 (134.53-143.58)	10	13.65 (13.39-17.52)	10	36.43 (25.63-37.07)
		1-4	3	9.12 (7.83-9.29)	7	14.32 (9.57-124.27)	4	10.54 (5.44-16.36)	14	31.91 (27.89-34.17)
		5-10	12	9.12 (8.75-14.59)	8	8.72 (8.38-9.02)	11	18.52 (10.35-26.2)	32	23.73 (21.18-28.69)
		11-18	26	14.85 (4.37-58.47)	8	10.32 (9.03-13.06)	8	21.28 (16.49-21.6)	35	22.08 (21.27-23.86)

The differences between the DRLs of the four participating hospitals for the paediatric chest CT examination are reported in Table 3. The differences between the DRL values between the hospitals were not significant except for hospital (II) where some of the values were two to five folds larger compared with the other three hospitals. For example, the $CTDI_{vol}$ values for the age group (11-18 years) were (5.19, 4.07 mGy and 12.91 mGy) for hospitals (I, III and IV) respectively while the CTDIvol value for the hospital (II) was (60.31 mGy). Similar observations were made for the DLP and SSDE values except for the age group (1-4 years) where the differences were not significant.

Regarding the abdominopelvic CT examinations, the associated DRL values that were reported in the four hospitals as seen in Table 3 showed wide differences between four hospitals. For example, for the age group (1-4 years) the CTDIvol value double between the hospital (I; 8.03 mGy) and hospital (IV; 12.25 mGy), and for the age group (<1 year) reached four-folds larger between the hospital (I; 3.06 mGy) and hospital (IV; 12.25 mGy). However, the widest variation was found for the age group (1-4 years) in hospital (II) where the CTDIvol value was 30.48 mGy compared with (3.06 mGy, 5.63 mGy, and 9.68 mGy) for the other hospitals with similar variations noted in the SSDE values.

The reported DRL values for the CAP CT examination for paediatric patients between the four participating hospitals are presented in Table 3. As can be noticed, the differences in the DRL values varied extensively between the four hospitals. In particular, for the age groups (<1 and 1-4 years), the differences between the $CTDI_{vol}$ and SSDE values in hospital (IV) were four times higher than the CTDIvol and SSDE values in hospital (I). The same values in hospital (IV) were double the CTDIvol and SSDE values reported in hospital (III). However, the highest variations in the DRL values recorded were in the hospital (II) where the recorded values exceeded the other three hospitals' values tenfold.

Although there are few studies that compared the SSDE values of paediatric CT scans, we undertook to compare the Jordanian values with SSDE values in other countries. The Jordanian $CTDI_{vol}$ values related to the CT examination are generally higher compared with USA; however, these values are not highly accurate since the comparison was between the median and mean of Jordan and USA respectively in addition, the USA study had no age categorization and the values were general.

For the chest examination, it was possible to compare the SSDE and $CTDI_{vol}$ values with other countries. It can be observed that the Jordanian SSDE values for the chest examination are higher than the values of the other countries. The SSDE values for both the CAP and Abdomen and Pelvis examinations were also higher in Jordan in comparison with the other countries. Depending on the age group, the Jordanian SSDE values for these examinations were double, triple, and four-folds larger as shown in Table 4.

Table 4: Comparison of DRLs between the current study (Jordan) and other studies (other countries)

CT Protocol	Current study		South Korean [21]		USA [7]		Turkey [22]	
	$CTDI_{vol}$ (mGy)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	SSDE (mGy)
Brain								
<1 year	47.87	54.09						
1-4 years	51.0	53.14						
5-10 years	58.8	52.92	NA	NA	45.3*	NA	NA	NA
11-18 year	52.1	36.90						
Chest								
<1 year	4.7	13.9	4.0	4.0			-	-
1-4 years	5.41	9.45	5.3	5.3	5.5*	8.7*	4.93	10.5
5-10 years	12.94	9.62	7.2	6.1			7.83	14.8
11-18 year	9.7	17.65	11.4	8.9			11.7	19.7
Abdominopelvic								
<1 year	6.94	15.41	5.6	6.1				-
1-4 years	9.7	18.86	6.7	6.8	8.4*	12.7*	4.93	10.5
5-10 years	9.7	17.84	10.1	9.0			7.83	14.4
11-18 year	13.12	19.11	13.1	10.5			11.7	18.9
CAP								
<1 year	9.7	23.13					-	-
1-4 years	12.25	24.77	NA	NA	6.4*	10.1*	4.93	10.5
5-10 years	9.7	18.52					7.83	14.6
11-18 year	16.12	21.29					11.7	19.2

*** The sample was treated as a single group**

Discussion

Due to the increased use of CT scans, dose optimization is one of the major issues facing Radiology. CT scans are considered to be the main contributor to the medical radiation dose [23, 24]. Currently, optimization of CT dose for paediatric patients is more challenging than in adult patients, due to several reasons: 1. children have greater radiosensitive characteristics compared with adults [25]. 2. Children have a longer life expectancy compared to their adult counterparts, which allows the potential radiation effects to become occult [3], and 3. the large variations in the composition and size of the children's bodies (percentages of muscle, fat as well as bone) amongst every age group and through different paediatric age groups (0 to 18 years) [26-28].

There are several clinical centres that are implementing weight-based and age-specific CT scanning protocols, and the influence of these on the reduction of the dose has been documented [26, 29,30]. Ultimately, these weight-based and age-specific protocols vary from centre to centre, which makes the full implementation of these protocols challenging for busy radiology departments [26-33]. As such, there is a lack of standardization for the existing pediatric scanning protocols. Whilst the common age group for pediatric patients

as reported by the related studies (0-15) has wide size variations, they are examined using a similar protocol [18, 34, 35].

In the current study, the DRLs for pediatric CT examinations were reported based on the SSDE in Jordan. The reported values were for four (brain, chest, abdominopelvic, and CAP) CT examinations. The values were also reported in each hospital for the four age groups (<1, 1-4, 5-10, and 11-18 years) to examine the differences between the hospitals. The results have shown that the DRL values for one hospital were double, triple, or even ten folds larger than the DRL values for another hospital.

The variations that have been reported in this study can be attributed to several factors. For instance, different kinds of CT scanners were surveyed. Change et al. (2011) demonstrated that different types of scanners deliver different dose levels for the same examination, we have shown that here too [36]. Furthermore, this study investigated the dose levels for four different age groups of different sizes and looked at the effects of automated tube current modulation (ATCM) on reducing the dose based on the characteristics of the patient [37]. Those hospitals using ATCM have lower dose levels. The variations between the mAs values contributed also to the variations between the different hospitals. Several studies have proven that using ATCM to correct mAs is the most effective method of optimizing for patient size and also avoids unnecessary radiation dose [38-40]. Rawashdeh et al. (2019) reported that the variations in the DRL values are linked to the variations in the different scan parameters including the mAs [41].

The variations between the age groups also could be attributed to several reasons including the scanner's manufacture type. Referring to the International Atomic Energy Agency (IAEA) survey of pediatric CT practices that was published in 2013 and included 40 countries [34], most of the clinical centers depend on provided pre-programmed scan protocols by the manufacturers. Moreover, the radiographer's training and used techniques could be another reason behind those variations.

Variations between hospitals can be attributed to variations in the scan protocols for every age group. Current results also demonstrated variations in the DRL values between Jordan and other countries. These variations can be attributed to a number of different factors. First, many countries now participate in DRL dose optimization programs but not all of them have their own established DRLs, rather they choose to adopt DRLs from countries like the EU or UK. Patient size is a critical factor in the variations in DRL values. For instance, DRLs are established in most countries for the average patient with a size of 70 kg [42]; the same patient with a size of 70 kg may have other body habitus compared with a taller person with the same weight. Ultimately, both of these patients would have different radiation dose requirements to achieve suitable imaging.

As pediatric CT DRLs are more accurately compared using SSDE the use of SSDE should expand and replace $CTDI_{vol}$ in the pediatric radiology field. In this study, the data showed some lower CTDIvol and SSDE values when compared with other countries' levels.

This is the first attempt to establish the DRLs for pediatric patients in Jordan while in the other countries such attempts were elaborated more where those kinds of studies are

updated every three years. The size of the pediatric patients is another reason behind those differences where the average size varied between countries. Recent studies report that patients in the same age category can have great variations in body composition and size caused by several factors including the obesity [15, 18, 26-35, 43-47].

Once established, DRLs can be used as a tool to drive dose optimization. The techniques for optimization are several. Hwang et al., (2015) stated that the radiation exposure from pediatric CT scans could be reduced with up-to-date techniques, and specific protocols for reducing radiation as well as "competent technicians and radiologists" [21]. It is possible that these reduction resources would be more obtainable in general or university hospitals than in private clinics or smaller hospitals. Moreover, employing ATCM facilities will help in optimizing the dose level without compromising the quality of the image.

Various strategies should be taken into account to reduce the SSDE in CT including developing child-specific imaging protocols that consider the body type and age of the patients, reducing CT scan frequency by justifying every exam, and utilising ultrasonic exams where appropriate, as well as omitting the contrast-enhanced CT. Encouraging the establishment of DRLs using SSDE will further encourage the development of imaging protocols appropriate to patient size. Appropriate protocols will lower the dose while preserving the diagnosis quality. To further reduce CT exposure techniques radiographers need to embrace lowering CT tube voltage [48-51], automatic exposure control [52-54], along with the successive approximation approach [55]. By incorporating SSDE in these techniques, optimized examinations designed for individual patients could become possible.

Conclusion

There were increases in $CTDI_{vol}$, DLP, and SSDE with ascending age groups. SSDE and age are closely matched to delivered radiation in pediatric CT; however, radiation dose levels remain high in Jordan. This work highlights the need for caution when administering radiation in the pediatric population. Standardizing protocols and accounting for patient size may contribute to reducing variations in SSDE within the different hospitals.

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