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Diagnostic Reference Levels for Paediatric CT in Jordan

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Abstract

This study aimed to investigate the current status of Diagnostic Reference Levels (DRL) in paediatric CT across Jordan. The dose data for four main CT examinations (brain, chest, abdominopelvic, and Chest, Abdomen and Pelvis (CAP)) in hospitals and imaging centres (n = 4) were measured. The volume CT dose index ($CTDI_{vol}$) and Dose Length Product (DLP) values were compared within the different hospitals and age groups (<1 year, 1-4 years, 5-10 years and 11-18 years). DRL in Jordan were compared to international DRLs. The paediatric population consisted of 1,818 children; 61.4% of them were male. There were significant variations between the DRLs for each CT scanner with an up to four-fold difference in dose between hospitals. There were apparent significant differences between Jordan and other countries with the DLPs in Jordan being relatively high. However, for $CTDI_{vol}$, the values in Jordan were close to those of other countries. This study confirmed variations in the $CTDI_{vol}$ and DLP values of paediatric CT scans in Jordan. These variations were attributed to the different protocols and equipment used. There is a need to optimise paediatric CT examinations doses in Jordan.

Keywords: Radiation dose, Optimisation, $CTDI_{vol}$, DLP

1. Introduction

Over the past decade, there has been exponential growth in the number of computed tomography (CT) scanners, with more than 30,000 units installed world-wide with an annual growth of 18% [1]. CT has become more readily available, which has resulted in referring physicians requesting more scans at the cost of increased radiation dose to patients [2]. CT has significantly contributed to the collective dose of the general population and accounts for 98% of the man-made sources of radiation, and 24% of annual radiation exposure of the population [3]. Although non-ionising methods of imaging do exist, they are slower, more expensive and less available. Referring physicians are less inclined to refer patients for imaging requiring sedation such as Magnetic Resonance Imaging [4].

This increased use of CT results in a greater risk of radiation exposure in paediatric subjects compared with older patients; children have more proliferative cells than adults, young children are a highly sensitive subgroup [5]. Also, any damage to the DNA has a longer period over which it might be expressed compared to adults [6, 7]. In Jordan, there has

been limited data available on the dose from CT to the paediatric population, despite the fact that children are more radiosensitive than adults [8]. Given this lack of infromation on paediatric CT radiation doses and the limited analysis on the impact of procedural and technological parameters on dose, it is hypothesised that large variations in dose between similar procedures exists in Jordan [9].

Diagnostic Reference Levels (DRLs) are a method by which the dose level, estimated using the volume CT dose index ($CTDI_{vol}$) and the dose length product (DLP), are monitored periodically. The median value from a survey for a group of patients of a dose quantity for a standard procedure is not expected to exceed the DRL where good practice is applied, and an investigation should be carried out if it does. The use of DRL has successfully resulted in an approximately 50% reduction in paediatric radiation dose in the UK [10-16]. The aim of this study was to establish local DRL values in paediatric CT in Jordan and to compare them with regional and international benchmarks.

2. Materials and Methods

The institutional review board waived patient consent for this retrospective study. Data collection was performed between March and June 2018. All imaging centres that performed CT paediatric studies in Jordan were invited to participate in the study. The study included examinations of the brain scans without contrast and chest and abdominopelvic scans with contrast. All hospitals agreed to participate (n = 4). CT scanners included two Philips Brilliance 16-slice scanners (A and D), Canon Aquilion, 16-slice scanner (B) and a Siemens SOMATOM 512-slice scanner (C); each scanner had the automatically adjusted option.

2.1 Patient demographics

The collected paediatric CT scans were categorised into four paediatric age groups as recommended by [17, 18]: < 1 year, 1-4 years, 5-10 years and 11-18 years. The study population consisted of 1,818 paediatric patients, of which 61.4% were male. Incomplete patient information examinations (study date, age) with study descriptions, dose indexes, clinical histories and diagnostic questions were excluded. These were excluded to prevent overestimation of the radiation dose. The generic indications of the examinations were chosen to be compatible with previous surveys [19, 20]: trauma for brain and detection of malignancy for chest. The indication for the CT of the abdomen, which was not considered in previous studies [19], was detection of malignancy routine scan indications, such as abdominal pain, abdominal mass, infection or inflammation. For CT examinations of the brain, only those performed without contrast were included in the study. CT examinations of the chest and abdominopelvic were included whether they were performed with or without intravenous contrast, as all post-contrast examinations were single phase only and the same protocol was used. The numbers of patients in the age groups < 1 year, 1-4 years, 5-10 years and 11-18 years were 494, 403, 406 and 515, respectively. The numbers of patients who underwent brain, chest, abdominopelvic and CAP scans were 1,163, 219, 234 and 202, respectively. Table 1 shows the numbers of CT scans for each age group according to hospital and CT examination.

Table 1: Number of CT scans performed per age group, hospital, and examination.

	<1 year	**1-4 years**	**5-10 years**	**11-18 years**	**Total**
Hospital					
A*	195	146	147	225	713
B	39	74	58	75	246
C*	173	58	54	53	338
D	87	125	147	162	521
All	494	403	406	515	1,818
Examination					
Brain	308	301	242	312	1,163
Chest	91	48	38	42	219
Abdominopelvic	61	26	63	84	234
CAP	34	28	63	77	202
Total	494	403	406	515	1,818

* Academic paediatric hospitals

2.2 Procedures

The details for each examination were obtained and filled in protocol templates established elsewhere [9]. Information included the anatomical region scanned, start and end positions, beam slice thickness, collimation and pitch, exposure factors including kVp (kilovolt peak) and mAs (milliampere-seconds), the use of automated tube current modulation and the use of contrast agents. $CTDI_{vol}$ and DLP data were obtained from dose reports for each examination. The readings of the dose reports were checked by the Energy & Minerals Regulatory Commission (EMRC) inspectors in Jordan. The inspectors have checked the consistency and precision of the reports.

2.3 Data analysis

The range, 25^{th} percentile, median (50^{th} percentile), and 75^{th} percentile values for $CTDI_{vol}$ and DLP were calculated. DRL for specific CT protocols were defined as the 75^{th} percentiles of the radiation dose distribution as estimated using $CTDI_{vol}$ and DLP [9]. Stepwise regression was used to determine the protocol parameters that are associated with high dose and the level of contribution of each parameter [21]. Finally, the accuracy of dose indices provided by manufacturers was determined. All statistical analyses were

performed using Statistical Package for the Social Sciences (SPSS, IBM Corp. Version 22. Armonk, NY).

3. Results

DRL for $CTDI_{vol}$ and DLP per hospital and age group showed significant variations for all CT examination types. At each hospital, there was a significant variation between the dose in each CT examination type for the different age groups where the dose doubled and sometimes tripled ($p = 0.001$). Some results showed four-fold increases in the dose in some hospitals compared to others. For the $CTDI_{vol}$, the variations in the chest examinations between hospital B and the other hospitals were significant. The median of the $CTDI_{vol}$ values for the age groups (5-10) and (11-18) were 60.3 compared with values ranged between (2.7-12.7) for the other three hospitals for the same age groups. Within those high values, for the same age group and examinations, the mean CTDIvol in hospital B, the mean of the mAs values was 216.7 compared with 88.6, 72.7 and 186.3 for hospitals A, C and D respectively. Those variations were associated with the mAs values. The mean value of mAs in hospital B (216.7) compared with 88.6, 72.7 and 186.3 for the A, C and D respectively. For the DLP values, the differences were significant also in the chest examination in hospital B for the age group (<1) where that value was 552.6 compared with values from 68.4 - 87 for the same hospital. The mAs mean in hospital B was 218.125 compared with 105, 132.03 and 129.28 for hospitals A, C and D respectively (Table 2). DRL for $CTDI_{vol}$, and DLP per examination and age group represented by the 75^{th} percentile showed wide variation between and within age groups. It can be noted that there was a significant increase in the values in general with increasing age. Regarding the DLP values, the values increased dramatically with age for all types of scans, as shown in Table 3.

Table 4 lists a comparison between the results of this study and previous studies regarding the paediatric CT DRL to compare the dose between Jordan and other countries. The table shows that there are apparent differences between Jordan and the other countries, especially in that the DLP values were higher for Jordan. However, with regards to $CTDI_{vol}$, the values in Jordan were close to those of other countries. No other studies have been found on paediatric CAP CT scans; therefore, we were are not able to compare the Jordanian case with other countries.

Table (2): Comparison between the $CTDI_{vol}$ and DLP median and 75th percentile values in the four hospitals.

CT protocol	Values	Age group	$CTDI_{vol}$					DLP				
			Hospital A* (713)	Hospital B (246)	Hospital* C (338)	Hospital D (521)	p-value	Hospital A* (713)	Hospital B (246)	Hospital C* (338)	Hospital D (521)	p-value
Brain	Median	<1	47.8 (164)	58.8 (17)	27.7 (75)	38.16 (52)	0.001	661.8 (164)	767.4 (17)	395 (75)	723.7 (52)	0.001
		1-4	54.7 (127)	58.8 (53)	38.1 (32)	38.2 (89)		879.9 (127)	838.6 (53)	646.5 (32)	863.7 (89)	
		5-10	65.0 (120)	58.8 (29)	41.1 (21)	38.2 (73)		1090.5 (120)	921.3 (29)	709.6 (21)	902 (73)	
		11-18	52.1 (171)	58.8 (44)	39.3 (28)	50.9 (68)		1020.8 (171)	978 (44)	619.5 (28)	1177.4 (68)	
		p-value	0.001	0.001	0.001	0.001		0.001	0.025	0.001	0.001	
	75th percentile	<1	47.88 (164)	58.8 (17)	31.1 (75)	38.8 (52)	0.001	735.725 (164)	869.5 (17)	487.4 (75)	900.0 (52)	0.001
		1-4	59.9 (127)	58.8 (53)	43.9 (32)	50.9 (89)		984.5 (127)	921.3 (53)	863.2 (32)	1100.3 (89)	
		5-10	65.0 (120)	58.8 (29)	42.9 (21)	50.9 (73)		1155.6 (120)	987.4 (29)	805.9 (21)	1126.8 (73)	
		11-18	60.7 (171)	60.3 (44)	43.9 (28)	50.9 (68)		1270.8 (171)	1019.9(44)	812.5 (28)	1238.2 (68)	
		p-value	0.001	0.001	0.001	0.001		0.001	0.025	0.001	0.001	
Chest	Median	<1	2.4 (13)	3.4 (8)	5.6 (63)	5.6 (7)	0.001	68.4 (13)	552.6 (8)	87 (63)	86 (7)	0.001
		1-4	4.4 (11)	5.05 (6)	5.6 (17)	7.5 (14)		82.9 (11)	178.7 (6)	104.3 (17)	218.5 (14)	
		5-10	4.7 (8)	60.3 (9)	2.7 (9)	9.7 (12)		114.4 (8)	611.1 (9)	67.3 (9)	316.4 (12)	
		11-18	5.1 (8)	60.3 (8)	4.1 (8)	12.9 (18)		138.8 (8)	449.4 (8)	108.8 (8)	462.1 (18)	
		p-value	0.330	0.003	0.625	0.005		0.448	0.067	0.111	0.001	
	75th percentile	<1	2.62 (13)	5.9 (8)	5.7 (63)	7.8 (7)	0.001	81.0 (13)	591.5 (8)	118.0 (63)	177.7 (7)	0.001
		4-1	4.4 (11)	11.6 (6)	7.3 (17)	9.7 (14)		96.2 (11)	377.5 (6)	200.1 (17)	258.6 (14)	
		5-10	5.2 (8)	60.3 (9)	5.2 (9)	12.6 (12)		131.3 (8)	669.4 (9)	137.8 (9)	380.0 (12)	
		11-18	5.2 (8)	71.4 (8)	6.7 (8)	12.9 (18)		166.9 (8)	523.1 (8)	200.0 (8)	541.8 (18)	
		p-value	0.330	0.003	0.625	0.005		0.448	0.067	0.111	0.001	
Abdomino pelvic	Median	<1	3.1 (11)	3.4 (7)	5.6 (25)	9.6 (18)	0.001	67.2 (11)	567.9 (7)	82.2 (25)	247.3 (18)	0.001
		1-4	6 (5)	4.5 (8)	7.3 (5)	12.2 (8)		375.8 (5)	186.6 (8)	286.2 (5)	416.7 (8)	
		5-10	5.1 (8)	4.5 (12)	7.3 (13)	9.7 (30)		154.1 (8)	184.9 (12)	299.8 (13)	364.6 (30)	
		11-18	11.4 (19)	5.8 (15)	12.8 (9)	16.1 (41)		588.6 (19)	247.3 (15)	591 (9)	767 (41)	
		p-value	0.025	0.001	0.001	0.001		0.003	0.001	0.001	0.001	
	75th percenti	<1	3.1 (11)	6.3 (7)	7.4 (25)	12.9 (18)	0.001	68.9 (11)	610.5 (7)	202.3 (25)	338.5(18)	0.001
		1-4	6.23 (5)	4.7 (8)	10.0 (5)	16.2 (8)		132.5 (5)	204.0 (8)	339.5 (5)	499.0 (8)	
		5-10	18.8 (8)	4.9 (12)	9.7 (13)	16.1 (30)		306.6 (8)	283.2 (12)	377.3 (13)	575.8 (30)	
		11-18	15.5 (19)	7.4 (15)	16.1 (9)	16.1 (41)		696.0 (19)	342.5 (15)	788.0 (9)	851.5 (41)	
		p-value	0.025	0.001	0.001	0.001		0.003	0.001	0.001	0.001	
CAP	Median	<1	3.1 (7)	6.0 (7)	5.6 (10)	16.1 (10)	0.001	60.4 (7)	450.1 (7)	134.7 (10)	541.2 (10)	0.001
		1-4	4.7 (3)	6.0 (7)	5.0 (4)	16.1 (14)		125.8 (3)	340.2 (7)	160.2 (4)	752.4 (14)	
		5-10	4.7 (12)	4.9 (8)	9.7 (11)	12.8 (32)		178.6 (12)	198.7 (8)	524 (11)	724.3 (32)	
		11-18	5.1 (26)	7.1 (8)	15.5 (8)	16.1 (35)		520.1 (26)	355.3 (8)	875.2 (8)	950.1 (35)	
		p-value	0.122	0.001	0.007	0.302		0.018	0.080	0.001	0.001	

75th percentile	<1	4.4 (7)	6.0 (7)	8.7 (10)	16.1 (10)		110.0 (7)	552.1 (7)	225.8 (10)	574.1 (10)	
	1-4	4.78 (3)	6.0 (7)	9.1 (4)	16.5 (14)		125.87 (3)	530.2 (7)	458.8 (4)	808.4 (14)	
	5-10	8.0 (12)	5.2 (8)	16.1 (11)	16.1 (32)	0.001	353.0 (12)	361.0 (8)	768.2 (11)	828.4 (32)	0.027
	11-18	5.21 (26)	10.3 (8)	16.1 (8)	16.1 (35)		1012.6 (26)	472.5 (8)	1075.8(8)	1183.0 (35)	
	p-value	0.122	0.001	0.007	0.302		0.018	0.080	0.001	0.001	

* Academic paediatric hospitals

Table 3: Dose level statistics for $CTDI_{vol}$ and DLP per examination and age group.

CT protocol	$CTDI_{vol}$				DLP				DLP/Pitch			
	25^{th}	Median	75^{th}	Range	25^{th}	Median	75^{th}	Range	25^{th}	Median	75^{th}	Range
Brain												
<1 year	31.8	47.1	47.8	2.7-77.0	512.1	644.8	743.7	28.2-1391.4	638.6	788	876.3	8.7-946.3
1-4 years	38.2	51.0	54.7	3.0-77.0	774.5	874.9	981.8	27.9-1659.5	518.4	685.4	839.1	40.6-928.5
5-10years	41.3	58.8	65.0	2.6-77.0	850.9	1038.4	1129.5	32.9-1484.6	247.3	484.7	839.4	24.8-933.9
11-18 years	50.9	52.1	60.7	2.8-77.0	790.3	1097.5	1207.9	32.9-2540.2	283.5	442.7	700.2	12.4-821
p-value			0.001				0.001					
Chest												
<1 year	5.6	5.6	5.6	0.9-79.0	76.0	86.1	124.0	15.0-730.0	71.7	143.6	199.7	27.2-933.8
1-4 years	3.0	4.7	7.3	1.7-32.9	65.2	104.6	222.1	11.3-849.5	54.9	123.7	210	20.5-516.9
5-10years	3.0	5.4	12.9	1.8-65.0	88.4	252.0	416.4	55.4-1147.3	81.1	170.7	292.6	46.1-874.9
11-18 years	5.1	12.8	12.9	1.8-71.4	119.0	262.6	496.4	51.5-577.7	181.6	335.6	498.7	50.6-658.1
p-value			0.002				0.001					
Abdominopelvic												
<1 year	3.4	6.9	12.6	2.7-60.3	60.5	145.8	325.1	35.5-849.5	84	106.6	326.9	44.3-676.3
1-4 years	4.5	9.7	19.8	0.8-90.6	186.6	294.2	408.7	14.2-2008.4	167.5	211.9	376.2	17.7-786.7
5-10years	5.1	9.7	12.8	2.6-47.8	219.5	336.5	460.5	65.5-926.5	230.9	323.5	521.8	67.6-912.8
11-18 years	9.2	12.9	16.1	3.9-60.1	388.6	612.5	807.0	8.17-1185.9	322.9	589.8	767	13.6-945.0
p-value			0.002				0.001					
Chest, Abdomen and Pelvis												
<1 year	4.7	9.7	16.1	1.2-77.1	86.4	248.4	526.8	40.0-1399	73.5	184.6	509.1	33.3-900.2
1-4 years	4.9	12.2	16.1	2.7-60.3	215.9	530.0	762.7	83.5-831.3	189.4	404	786.9	69.5-861
5-10years	5.3	9.7	12.9	1.6-50.9	230.0	524.0	759.0	44.6-1195.5	246.7	459.5	702.3	37.1-906.4
11-18 years	7.7	7.7	16.1	2.8-60.7	373.4	373.4	808.8	64.9-1807.0	285.2	460.6	755.2	90.6-936
p-value			0.018				0.001					

Table 4: Comparison between paediatric CT DRLs in Jordan and other international paediatric CT DRLs.

		Age	South Korea[22]	Germany [23]	Turkey [24]	Switzerland [20]	UK [25]	Kenya [26]	Current study
$CTDI_{vol}$	Brain	<1	39.1	33.6	31	20	30	-	47.8
		1-4	41.7	49.0	33.4	30	45	-	54.7
		5-10	44.1	58.0	40.3	40	50	-	65.0
		11-18	55.3	64.5	51.3	60	65	-	60.7
	Chest	<1	5.7	6.9	13.6	5	12	6	5.6
		1-4	6.8	8.4	13.5	8	13	6.5	7.37

		5-10	9.3	11.9	13.5	10	20	10	12.9
		11-18	13.8	16.0	11.5	12	14	-	12.9
	Abdomin opelvic	<1	7.5	6.8		-		-	12.6
		1-4	8.9	8.3		-		-	19.8
		5-10	12.4	13.7		-		-	12.8
		11-18	16.6	20.2		-		-	16.1
DLP	Brain	<1	545	393		270	270		743.7
		1-4	508	611		420	470		981.8
		5-10	792	711		560	620		1129.5
		11-18	947	920		1000	930		1207.9
	Chest	<1	53	93		110	200	6	124.0
		1-4	121	137		200	230	6.5	222.1
		5-10	160	257		220	370	10	416.4
		11-18	473	488		460	580	-	496.4
	Abdomin opelvic	<1	196	164		-	170	-	325.1
		1-4	338	261		-	250	-	408.7
		5-10	513	477		-	500	-	460.5
		11-18	780	804		-	560	-	807.0

The results of the stepwise regression for all the parameters used in the different protocols (kVp, mAs, field of view (FOV), filter, patient protection, pitch, mode of scan, number of slices and slice thickness) are shown in Table 5. The parameters used in protocols that are associated with high dose and the level of contribution of each of the included factors (kVp, mAs, pitch, slices thickness, and number of slices) are listed for both $CTDL_{vol}$ and DLP. It was found that, mAs, pitch, slice thickness and kVp were factors associated with $CTDL_{vol,}$ while mAs, kVp and slice thickness were associated with DLP. However, FOV, filter, patient protection, mode of scan and number of slices were not correlated significantly with either $CTDL_{vol}$ nor DLP.

Table 5: Predictive associated parameters of $CTDI_{vol}$ and DLP.

		R-square	p-value
$CTDL_{vol}$	mAs	0.490	0.001
	Pitch	-0.517	0.001
	Slice thickness	0.538	0.001
	kVp	0.553	0.001
DLP	mAs	0.526	0.001
	kVp	0.560	0.001
	Slice thickness	0.572	0.001

* (-) sign indicates the inverse relation

For $CTDI_{vol}$, the following equation was used

CTDI= -38.03+ 0.138A - 16.468B+1.720 C+0.407D

where A is mAs, B is the pitch, C is the slice thickness and D is kVp.

The the following equation was used to determine the most accurately predictive factors for DLP.

DLP = -1135.141+2.598 A +9.383 B + 27.155 D

where A is mAs, B is kVp, and C is the slice thickness.

It can be noted that the pitch has an inverse effect on $CTDI_{vol}$ values unlike mAs, slice thickness and kVp, while mAs, kVp and slice thickness have a positive effect on the dose in the DLP values.

4. Discussion

With the increasing potential of harm due to radiation doses during paediatric CT, establishing DRL continues to be an important mechanism for monitoring radiation doses and identifying overexposure. DRL have been reported as an effective method to reduce excessive radiation levels with some studies reporting up to a 50% dose reduction [27]. While implementing national DRL can be a challenge, it can decrease the radiation doses to which patients are exposed [28]. Since children are more affected by radiation doses than adults, general DRL establishment in CT scans for paediatric patients is a critical issue. Although several studies have tried to establish a generic DRL for paediatric CT scans in different countries, this is the first study to take place in Jordan, where no DRL for paediatric CT have existed previously.

The results of this study indicate that there are significant differences in dose used during paediatric CT scans between hospitals. This result may be attributed to the different protocols and technologies used by the different hospitals. The results showed also that the lowest dose was in the academic paediatric facilities compared with nonacademic paediatric or adult facilities for the different examinations where this result is consistent with [29] study, which stated that academic paediatric facilities use lower dose for all brain

and the majority of chest and abdominopelvic exams. The primary factors that could influence dose variation include the use of different technologies, as there were differences in the CT scanners used in the four hospitals involved in this study. This conclusion is based on a previous study, Smith-Bindman et al. [30] that claimed that multiphase scanning and institutional protocol choices are other factors that could result in dose variations. Moreover, automated tube current modulation (ATCM) could be another reason behind the dose variations between hospitals as ATCM greatly contributes to CT dose optimization by reducing the CT dose according to body size, shape, and attenuation without degrading image quality [31, 32]. In the current study, only centre C employs ATCM for paediatric patients and this is reflected in the lower median dose findings. Therefore, the use of CT scanners that has ATCM facilities is recommended.

At each hospital, there was a significant variation between the dose in each CT scan for the different age groups; the dose doubled and sometimes tripled with age. This result can be attributed to the radiographer's skill level and amount of experience, which may also have an impact on the amount of radiation dose given to patients [33, 34]. It was noted that there were differences in technique which could reflect a disparity in experience among radiographers [35]. Further training and study days are recommended to encourage proper use of the equipment and adequate collimation only to the region of interest as part of the radiation protection of the patient [36, 37].

The application of DRL, in combination with staff education and awareness, has been demonstrated to be effective in dose optimisation in paediatric CT [38]. Paolicchi [39] demonstrated the role of radiological staff training for adult chest, abdominopelvic and whole body CT scans. This is a key issue in optimising CT protocols, and thus can significantly reduce radiation dose without affecting image quality. The results of a previous study [40] showed that the median values of CT dose index and dose-length product were significantly lower after training in all age groups. The 0 to 4-year-old group, reduced from 107 mGy and 1444 mGy·cm to 27 mGy and 338 mGy·cm; the 5 to 9-year-old group reduced from 68 mGy and 976 mGy·cm to 41 mGy and 483 mGy·cm and the 10 to 14-year-old group reduced from 107 mGy and 1480 mGy·cm to 51 mGy and 679 mGy·cm; ($p < 0.001$).

Although the current study was performed at dedicated paediatric centres where it is expected that health professionals are more aware to the needs of the paediatric population, it was found that there are apparent differences between Jordan and the other countries. The dose in Jordan was relatively high regarding the DLP values. This result indicates that, in Jordan, the main dosimetric aspects connected with the use of CT in paediatrics are still not fully optimised [41]. Optimisation programmes should be carried out on a regular basis, especially when new X-ray equipment or post-processing tools are installed.

Several reasons may lead to the different levels of DRL between countries including the equipment used and the condition and age of the equipment. Updated machines are manufactured now with the capacity to considerably minimise the radiation doses exposed to the patient. These machines have iterative reconstruction technology that has the ability to reconstruct equivalent CT images from small radiation doses [42]. As suggested by Sharma et al. [43], an additional cause for variations in radiation dose levels between the different countries may be attributed to the different training systems that radiographers undergo and the exposure parameters in their procedures. Zarb et al., [44] also highlighted that the protocols for CT scans are another factor for these variations in the countries. This may be a reflection of a suboptimal radiographic technique, because DLP is proportional to scan length [45].

High values of $CTDI_{vol}$ and DLP were attributed to the increase in mAs, kVp and number of slices, which were found to affect dose as well as non-accurate centering of patents withn the gantry. At fixed filtration and kVp, radiation dose is associated linearly to mAs, which means that by decreasing the mAs to half, dose will be decreased to half. However, image noise is proportional to $1/\sqrt{(mAs)}$. For instance, a 41% increase in image noise will result from halving the tube current-time product from 400 to 200 mAs, a 50% dose reduction [46].

Many studies have examined mAs modification as a way of decreasing the radiation dose. Results indicate that it is a straightforward and easy method of optimising the CT dose [47-49]. CT operators are not compelled technically to reduce the tube-current-time product (mAs). In the case of children, this may result in an unnecessary radiation dose. However, professionally and ethically, it is a major duty of the CT operator to take patient size into consideration. Selecting the appropriate mAs is the most important method of taking size into consideration [50, 51]. For brain CT imaging, the reduction of mAs from adults to newborns is about a factor of 2 to 2.5. Typically, for body CT imaging, an mAs reduction of a factor of 4 to 5 from adult techniques is suitable in newborns [52].

Moreover, radiation dose optimisation for patients will need the involvement of several professional bodies within Jordan. First, the responsible staff for maximising the general awareness of patient radiation exposure optimisation and protection will need more training and education. Second, rather than answering surveys, physicians should start to contact other CT departments in order to measure tube performance directly on site. Furthermore, radiologists need to play a role in determining disease- and patient-specific protocols that are adapted to the diagnosis required. Above

all, radiographers need to recognise that the adaptation of basic parameters for each patient is their duty; this can have significant impact on dose and thus the risk to the patient.

In this study, several limitations exist, including the absence of data on size, weight and exposure time. The comparative component of the present study was limited by a lack of international uniformity in age stratification for DRL data. This study recommends conducting prospective studies on the same subject in paediatric CT examinations to determine the actual characteristics of paediatric patients, such as employing weight-based protocols and observing patient centreing. It is also recommended for future work to conduct a meta-analysis on the variations between Jordan DRL and other countries in paediatric patients. Linking radiographers, equipment characteristics and image quality with variations in DRL values is recommended. The impact of dose variations on diagnosis and outcomes should be examined.

5. Conclusion

This study found variations in DRL values across different centres in Jordan and within the same centre. Variations in DRL values were also reported between Jordan and other countries. The variations in the DRL values were mainly linked to variations in mAs, pitch, slice thickness and kVp factors.

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