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Estimation of diagnostic reference levels for children computed tomography: A study in Tehran, Iran

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ABSTRACT

Background: The Diagnostic reference levels (DRLs) play a critical role in the optimization of radiation dose especially, in some conditions like pediatrics. They are useful indicators by which the radiologists can be aware of delivered excess radiation doses to the patients, and take corrective actions if necessary. In order to meet some requirements for establishing the national computed tomography DRLs tables, much studies are needed all around the country. ***Materials and Methods***: All active computed tomography (CT) scanners in public and private centers in Tehran were identified and checked for quality assurance and control certification. Eleven centers were chosen to be studied according to CT examination frequencies. Weighted CT dose index (CTDIw) and dose length product (DLP) for head, sinus, chest and abdomen/ pelvis scans of children were obtained from scanner's operator consoles and classified into four groups based on their ages (A; <1 year, B; 1-5 years, C; 5-10 years and D; 10-15 years). The 3rd quartiles of CTDIw were considered as DRLs and compared with the reported European Union (EU) and United Kingdom (UK) ones. ***Results:*** DRLs for head, sinus, chest and abdomen/pelvis scans were found to be 86.76, 31.33, 6.33, 7.65 mGy; 43.38, 31.33, 6.33, 7.65 mGy; 43, 31.33, 6.33, 7.65 mGy and 44.53, 31.33, 6.33, 7.65 mGy in the four groups (A-D) respectively. They are lower than the reported DRLs in EU and UK. ***Conclusion:*** There are variations in the radiation dose between the CT centers and identical scanners indicating the necessity for dose optimization. The data reported in this study can be remarkably useful in this concern.

Keywords: *Computed tomography, diagnostic reference levels, children, Tehran, Iran.*

INTRODUCTION

Computed tomography (CT) serves as a gold standard modality for detection and management of many different diseases. As a life -saving approach, CT has a great role in pediatric medicine. Recent reports have indicated a rise in CT imaging for pediatric diseases. According to some studies, about 5 to 9 million CT imaging are performed annually on children in the United States [1, 2]. Also, the improvement of CT hardware and software technologies, have resulted in more interest among pediatricians to prescribe CT scans [3].

It has been reported that almost one half of the total medical radiation exposure is due to CT imaging [4]. A considerable amount of literature has been published on CT radiation dose assessment, reduction, and protection. Regarding pediatric cases, there are unique

considerations for the radiation exposure concerns including: more radiosensitivity, longer life expectancy, and smaller body size (more radiation absorption). In the light of that, there is more risk for developing the radiation-related cancer in children compared with adults exposed to identical CT scan [5, 6].

The CT radiation dose pertains to several factors including the type of scanner, the filtration, the scan time, the body thickness; moreover to the exposure parameters and imaging protocols. In order to lessen the variations in dose assessment and also to optimize the radiation protection, The International Commission on Radiological Protection (ICRP) in 1997 had introduced the criteria called Diagnostic Reference Levels (DRLs) [7], in the goal of reducing the excessive radiation exposure by setting given thresholds.

Recently, several studies on CT DRLs have been conducted in different countries, and some of which have been updated subsequently [8-10]. In addition, a considerable amount of data was reported on pediatric computed tomography DRLs worldwide. Vassileva et al. conducted an international study on pediatric CT DRLs in four age levels groups including, 1-year, 1–5 y, 5–10 y and 10 –15 y. They established the international DRLs at rounded 75th percentile values of the distribution of median values from all CT facilities. Their Results showed that DRLs for CTDIvol is similar to the reference values from other published reports, with some differences for chest and abdomen CT scans. Higher variations were observed between DLP values, based on a survey of whole multi-phase exams [11]. Bibbo *et al.*, estimated the CT DRLs of pediatric examinations at a dedicated Australian pediatric hospital. Based on their results, the 75th percentile DRLs were found to be acceptable when compared with those published by the Australian National Radiation Dose Register and other two national children's hospitals, and also with the National Reference Doses for the UK. The 95th percentiles of CTDIvol for the various CT examinations were found to be acceptable values for the CT scanner Dose-Check notification [12]. Fukushima *et al* established the DRLs of CT in Japan using dose–length product (DLPs). In their study, DRLs were defined as the 25th and 75th percentiles of DLPs and that of the head CT of pediatric patients tended to be higher than the data reported from the EU or other countries [13]. Janbabanezhad-Toori *et al.* have reported a pediatric dose assessment in common CT examinations for the purpose of establishing the regional DRLs in Mazandaran state, a northern province in Iran [14]. In their study, different values of DLPs were reported as the regional DRLs for brain, sinus, chest, abdomen and pelvic CT examinations.

In Tehran province, the capital of the Islamic Republic of Iran, there is a large number of medical centers; equipped with CT scanners; and to the best of our knowledge, there are no published reports concerning the CT DRLs for pediatric. Therefore, we aimed in this study to establish the DRLs for pediatrics CT scans based on a the four age level groups classification, in Tehran state.

MATERIALS AND METHODS

CT scanners and data collection

This work was conducted as a prospective descriptive cross-sectional study with ethical considerations in Tehran, Iran. All ethics issues were passed through the ethics committee of Tehran University of Medical Sciences. In this study, all active computed tomography (CT) scanners in the public and private centers in Tehran province were identified and checked for the quality assurance and control certification. The Required data were obtained from Iran's Atomic Energy Organization. Eleven centers were chosen to be investigated according to CT examination frequencies. For each scanner, the factors including: the Manufacturer, model, year of installation, number of detector rows, the presence or absence of automatic exposure control (AEC) and also the presence or absence of the CTDI display were recorded. Moreover, the examination protocols such as the slice thickness, exposure parameters (mAs, KVp), scan length and pitch factor for patients undergoing CT imaging were obtained and

recorded. The Patient's demographic information was also collected.

CT dose quantities and validation

Two quantities including the dose length product (DLP) in mGy·cm and the volumetric CT dose Index (CTDIv) in mGy were provided by current scanners and displayed on the control console. DRLs can be established based on $CTDI_W$ or DLP. The most frequent CT examinations like; head, sinus, chest and abdomen/pelvis scans of children were considered for obtaining the quantities from scanner's operator consoles, and then they were classified according to the four age groups of patients as follow: A; <1 year, B; 1-5 years, C; 5-10 years and D; 10-15 years.

From each group, all data pertaining to these procedures performed over a period of 1 year were collected. To ensure the accuracy and precision of the quantities displayed on the console, we performed standard CT dosimetry based on the protocol recommended by the European Commission [15]. For this reason, we used two head and body phantoms made of Poltmthylmethacrylate (PMMA) with 16 and 32 cm in diameter, respectively to calculate the $CTDI_W$ and DLP. These cylindrical phantoms had four holes at 90° intervals on the periphery and one in the center to insert radiation dosimeter. All dose measurements were performed using a 100 mm long pencil ionization chamber (Barracuda; Rti Electronics Ab, Sweden) corrected for the changes in the environmental temperature and pressure conditions. In each center, the phantoms were scanned with the same parameters as daily routine protocols. Peripheral (p) and central (c) CTDI were measured and then weighted CT dose index (CTDIw), CTDIv, and DLP were calculated by the following equations (1, 2 and 3):

$$CTDI_w = 1/3\ (CTDI_c) + 2/3\ (CTDI_p) \quad (1)$$

$$CTDI_v = CTDI_w/pitch \quad (2)$$

$$DLP = CTDI_v \times \text{scan length} \quad (3)$$

The calculated $CTDI_v$ and $CTDI_v$ displayed on the control console were compared to ensure that the difference between the two values was not significant and not exceed the limitss recommended by relevant regulatory bodies such as Iran's Atomic Energy Organization.

Statistical analysis

The collected data were analyzed using SPSS v. 19.0 (PASW, Chicago, IL). $CTDI_W$ was expressed in the order of mean, min and max values. 3rd quartiles of $CTDI_w$ were considered as local DRLs and compared with the reported ones by European Union (EU) and United Kingdom (UK).

RESULTS

There are fifty-five active CT centers in Tehran. Eleven centers equipped with spiral CT scanners which provide the criteria for this study. Table 1 shows the specifications of CT centers including: the manufacturer, model, year of installation, number of detector rows, the presence or absence of automatic exposure control (AEC) and CTDI display.

The Results of the experimental phantom dosimetry are shown in figure 1. The measured $CTDI_w$ had a range of 12-28 and 5-15 mGy for head and body phantoms, respectively. There were no significant differences between these quantities and those reported by scanner consoles, and they were in the acceptable range recommended by Iran's Atomic Energy Organization.

Table 2 shows in details the results of $CTDI_w$ quantity for the 4-age groups. The 3rd quartiles of $CTDI_w$ as DRLs along with the mean, min and max values were determined. In table 3, we can see the results of DLPs and DRLs compared with the UK and EU values.

DISCUSSION

The study results revealed the wide ranges of CT procedures that performed currently in Tehran province among which the head, sinus, chest and abdomen/pelvis were the most frequent scans. Also, there were many special pediatric

hospitals equipped with new CT systems. On the other hand, new advancements in hardware and software technologies of CT have resulted in more interest among pediatricians to prescribe CT scan [3]. The Scan parameters such as kVp, mA, scan time, pitch factor, sections thickness have influence on the absorbed dose [16, 17]. This can lead to expanding the range of radiation dose even for a specific CT scan procedure.

Table 1. The Characteristics of CT scan centers.

Center	Center issue	Center location	CT Company	CT Model	Number of slice	CT Country builder	Year of installation	Number of detector rows	AEC presence	CTDI presence
A	General	South	GE Medical Systems	Bright Speed	8	USA	2007	8	Y	Y
B	Private	Center	Neu Soft	Spiral Neuviz Dual	16	China	2009	2	N	Y
C	General	West	Siemens	Emotion	16	Germany	2009	16	Y	Y
D	General	West	GE Medical Systems	Lightspeed	4	USA	2008	4	Y	Y
E	Private	North	GE Medical Systems	Bright Speed Elite	16	USA	2008	16	Y	Y
F	Private	East	GE Medical Systems	Lightspeed Plus	4	USA	2009	4	Y	Y
G	Private	West	Siemens	Somatom Sensation	16	Germany	2010	16	Y	Y
H	Private	Center	GE Medical Systems	Hispeed Dual	16	USA	2008	16	Y	Y
I	General	North	Siemens	Somatom Sensation	4	Germany	2012	4	Y	Y
J	Private	East	Siemens	Somatom Sensation	4	Germany	2004	4	Y	Y
K	General	North	Siemens	Somatom Sensation	16	Germany	2009	16	Y	Y

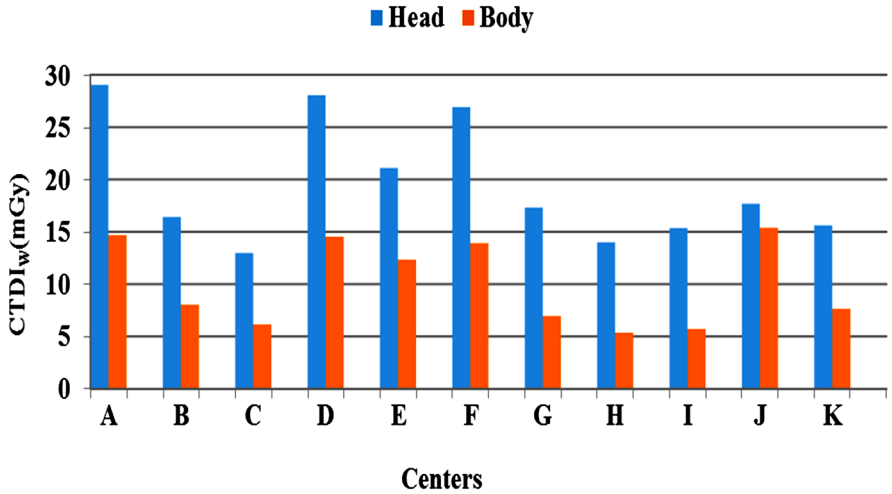

Figure 1. The CTDIw distribution among various CT scan centers.

Table 2. The obtained DRL, mean, min and max of CTDIw in the present study.

Groups	CT examination		CTDIW			
			3rd-Quartile (DRL)	Mean	Min	Max
A	Brain	Base	45.66	37.64	17.01	90
		Cerebrum	41.10	42	17.01	145
	Sinus		31.33	22.13	2.30	46.30
	Chest		6.33	5.33	1.71	11.30
	Abdomen pelvis		7.65	8.62	1.74	34.80
B	Brain	Base	45.66	38.06	17.01	90
		Cerebrum	41.10	42.41	17.01	145
	Sinus		31.33	22.4	5.22	46.34
	Chest		6.33	5.39	2.4	11.30
	Abdomen pelvis		7.65	8.65	2.06	34.80
C	Brain	Base	44.9	38.31	18.20	90
		Cerebrum	41.10	44.23	18.20	145
	Sinus		31.33	22.13	22.44	5.70
	Chest		6.33	5.33	5.45	3.08
	Abdomen pelvis		7.65	8.62	8.79	3.60
D	Brain	Base	45.26	39.78	18.20	90
		Cerebrum	43.80	46.61	18.20	145
	Sinus		31.33	22.68	5.70	42.63
	Chest		6.33	5.55	3.17	11.30
	Abdomen pelvis		7.65	9	4.20	34.80

Table 3. Comparing DRL of this study by other relevant studies.

Groups	CT examination	This Study		European		UK	
		DLP	DRL	DLP	DRL	DLP	DRL
A	Head	334.80	43.38	300	40	270	30
	Sinus	158.81	31.33	--	--	--	--
	Chest	82.05	6.33	200	20	300	12
	Abdomen &pelvis	150.30	7.65	330	20	170	20
B	Head	334.80	43.38	600	60	470	45
	Sinus	158.81	31.33	--	--	--	--
	Chest	82.05	6.33	400	30	230	13
	Abdomen &pelvis	150.30	7.65	360	25	250	20
C	Head	350.13	43	750	70	620	50
	Sinus	158.81	31.33	--	--	--	--
	Chest	82.05	6.33	600	30	370	20
	Abdomen &pelvis	150.30	7.65	800	30	500	30
D	Head	380.19	44.53	750	70	930	65
	Sinus	162.38	31.33	--	--	--	--
	Chest	82.05	6.33	600	30	580	14
	Abdomen &pelvis	150.30	7.65	800	30	560	14

In regard to CT centers surveyed in our study, there were variations in the CTDIw values among all groups figure 2, which is in a good accordance with previous studies [18, 19]. This might be related to variations in the imaging protocols, the operator's knowledges and experiences, in addition to the various scanner models and also center's conditions.

Based on the scanner's model and design, some factors like the beam geometry, filtration,

the number and type of detector rows and the scattered radiation are important variables in determining the dose delivered to the patient. In our study, as shown in figure 1, the phantom study verified the dose variations among CT centers. Using dose optimization approaches was mandatory in this situation. The diagnostic reference levels play critical roles in radiation dose optimization. They are useful indicators by which radiology technicians can be aware of delivered radiation does to the patients and take corrective actions if necessary [19].

In regard to pediatric cases, the DRLs are more vital due to the more radiation sensitivity and the life expectancy. To the best of our knowledge, this is the first study on DRL measurement in Tehran, which may be interesting for local regulatory bodies. It was a good opportunity to collect the Iranian specific data regarding the CT DRLs for four–age levels.

Our results on DRLs, demonstrated that current CT dose levels were well below the European Union [20] and UK [21] proposed values. Although, their data return to many years ago and need to be updated. Albeit, they still the most suitable and available references for DRLs comparison. The main reason by which our measured DLP/DRLs were below the international values can be attributed to the improvements of CT technologies such as applying detectors with high efficiency, new reconstruction algorithms and automated tube current modulation (ATCM). Some Previous studies indicated that the ATCM can reduce the radiation dose up to 40%. [22, 23], which was available in all CT scanners included in our study. Concerning the more frequently used CT examinations included in our study, the low measured DRLs from these examinations are encouraging results.

Although DRLs are feasible measure for radiation dose optimization, there are newer criteria for more accurate dose estimation. Recently, the American Association of Physicists in Medicine (AAPM) has proposed "size-specific dose estimate" (SSDE) which takes into account patient the size, in order to optimize CTDIvol based on patient's physical dimensions [25]. Some studies have indicated that SSDE was more accurate and feasible criterion in CT scan dose estimation and optimization [26, 27]. Therefore, further studies taking into consideration SSDE criteria and a comparison with the results of this study is suggested.

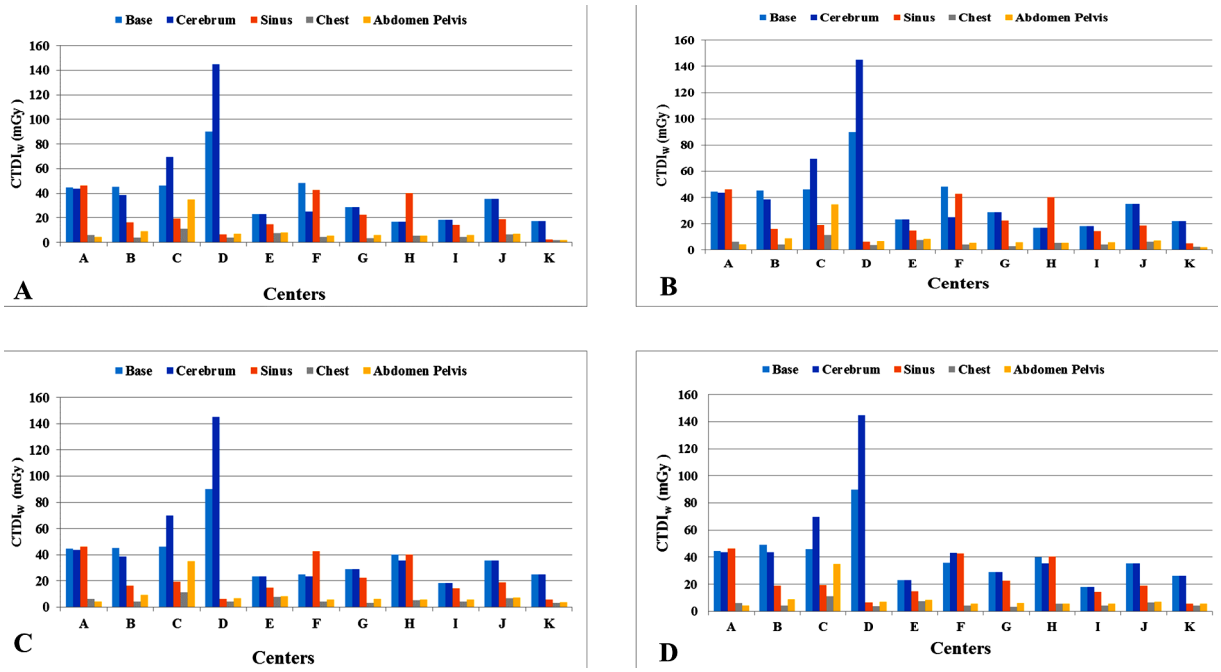

Figure 2. The CTDIw distribution based on different organs among various CT scan centers.

CONCLUSION

There are variations in dose between CT centers and identical scanners indicating the necessity for dose optimization. Our results can be applied to meet some requirements for the establishment of national computed tomography DRLs tables which in turn can help to prevent the children unnecessary radiation dose from CT scans.

***Conflicts of interest*:** *Declared none.*

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