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Establishment of CT Diagnostic Reference Level in Paediatric Population

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Abstract: Radiation risk estimated amongst paediatric populations are the concern issues of radiation protection in dealing with ionizing radiation sources. In 2010 according to United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) report that the Computed tomography (CT) scan contributed over 20% higher radiation dose in medical imaging. Diagnostic reference levels (DRL) were used as a tool in optimization of practice in minimization of radiation dose and additional with image noise as an index in diagnostic image quality in CT. The purpose of this study was to evaluate the radiation doses in paediatric CT examinations in establish local DRL. Data were retrospectively collected from one single institution for a period between January 2016 and December 2018. Patient demographic was collected from the CT console (PACS) and recorded in a standardized form.145 subjects were included in this study where subject's age was less than 15 years old and underwent for CT brain, CT thorax, and CT chest-abdomen-pelvis (CT CAP) examinations. The study was categorized into 3 groups (1-<5years), (5-<10 years) and (10-15 years) and was found that the highest effective dose were recorded in CT CAP, CT thorax and CT brain in age category 10-15 years were 11.7 mGy, 4.0 mGy and 2.9 mGy respectively. CT CAP shows higher DRL in term of DLP in oldest age groups compared to the study from Korea and Switzeland. Hence, justification and optimization due to the increase in the cancer occurrence in CT examination should be done regarding the report on the risk of CT exposure in children.

Keywords: CT diagnostic, CT scan, Pediatric population, Tomography, Radiation

Since 1972 computed tomography (CT) scan has been introduced, the utilization of CT scan was increased due to the capability of CT in producing high contrast sectional images. Consequently, estimated dose in CT scan of the children have been an area of interest it is because of the increased awareness of the radiation risk from CT procedures [1]. United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) reports that children are in high risk of developing carcinogenic effect because of the young age of exposure and increased tissue radiosensitivity in some of the organs. Furthermore, the risk of radiation-induced cancer development in children can develop after a long latency period [2].

Hence, justification should be done regarding the report on the risk of CT exposure in paediatric and optimisation of CT radiation dose delivered to the patient should be As Low As Reasonably Achievable, according to the ALARA principle. In order to manage the radiation dose to patient so that the dose is comensurate with the clinical purposes, Diagnostic reference level (DRL) are used as a tool in optimisation of CT radiation dose. The purpose of DRL to decrease the dose level without compromise image quality or patient care. DRLs are defined for paediatric patients with standard size, age or weight. However, a correlation of dose and patient size can usually be anticipated if protocols are adjusted to the patient (Yu et al., 2015). In fact, there are three key elements contribute to CT dose; scanner output radiation level, scan protocols and patient characteristics (Al Mahrooqi et al., 2015; Gao et al., 2017; Muhammad et al., 2019).

The value of 75th percentile of dose are used in DRL setting since introduced by the International Commission on Radialogical Protection (ICRP) in 1996. Usually, in CT examinations, the standardized CT dose quantities used as an index in established local, national or international DRL are involved volume CT dose (CTDIvol), dose-length product (DLP) and effective dose (E). Several studies have reported that DRL are delivered in several countries and may assistance to perform quality assurance and dose optimization in CT. Therefore, The purpose of this study was to evaluate the radiation doses in paediatric CT examinations in establish local DRL.

This study was conducted in the Department of Biomedical Imaging University Malaya Medical Center (UMMC). The design of the retrospective study has been approved by the ethics committee of the University Malaya Medical Center (UMMC). The demographic information of paediatric patients between January 2012 and December 2018 were obtained from the Picture Archiving Communication System (PACS) and, 1000 paediatric patients who underwent CT brain, CT thorax and CT thorax-abdomen-pelvis (TAP) examinations were surveyed. The subjects were 145 children (66 males, 51 females) ages 0 to 15 years old.

The information of pertinent CT acquisition parameter and radiation dose parameter for each CT examination including tube potential (kVp), tube current(mA), time (s), effective tube current (mAs), nominal collimation beam width (N*hcol), table feed, slice thickness, and scan ranges were extracted from the DICOM. While the radiation dose data were abstract from the displayed console in PACS including volume Computed Tomography Dose Index (CTDIvol), dose length product (DLP), total mAs and the number within the series for any contrast study other imaging sequence. CT thorax and CAP were performed on Somatom definition 64 multidetector CT(MDCT) scanner by utilizing automatic tube current modulation (CARE Dose4DTM; Siemens, Erlangen, Germany) while CT brain were performed on Philips Ingenuity Core 128.

In this study CT scan parameter data were obtained to calculate the CTDIvol, DLP and effective dose by Monte Carlo software known as CT-EXPO version 2.3.1, Germany) [3–5]. This software also provides calculation of organ dose and effective dose by using tissue weighting factor ICRP 103. The application was capable of reporting $CTDI_{vol}$ and DLP by specifying the scanner model, scanner manufacturer and scanning parameter as input. All the data of patient characteristic, scanning parameter, and calculated result were collected in a microsoft excel spreadsheet before analyzing using the Statistical Package for the Social Science (SPSS) software version 25. Therefore, in establishing of DRL mean and third quartile value of

$CTDI_{vol}$, DLP and E were calculated according to region and protocol use for each age group of children and compared with the establish national and local DRL from previous study.

A total of 145 paediatric patients data who underwent CT brain, CT thorax, and CT CAP examinations were collected in this study. The characteristics of patients in this study were summarized in Table 1. The patients were divided into 3 age groups (1-,5 years), (5- <10years) and (10 – 12 years). The ranges value of body mass index (BMI) in this study from 13.88 to 25.34 kgm^{-2}.

The radiation dose from CT mostly depends on CT acquisition parameters such as tube potential (kVp), tube current (mAs), pitch, slice thickness, nominal beam width, and scan ranges. Table 2 shows the CT parameter in this study. It observed that the acquisition parameter used in CT brain, CT thorax, and CT CAP between three age groups are varied. The tube current is found to be widely depends on patients habitus. The details of mean and third quartile value of radiation dose in term of $CTDI_{vol}$, DLP, and E are presented in Table 3. From this data we can see that CT brain has the highest value in mean $CTDI_{vol}$ in three age groups with 24.8 ± 8.2 mGy, 25.4 ± 9.7 mGy and 41.8 ± 14.4 mGy respectively. The lowest mean value of CTDIvol was found in CT thorax with 4.6 ± 2.6 mGy, 6.6 ± 3.4 mGy, and 8.0 ± 5.0 mGy respectively. These variations maybe due to non-optimised imaging protocol and CT acquisition parameter in term of tube current in CT brain were higher compared with CT thorax and CT CAP examinations.

However, the results of effective dose are were higher in CT CAP in three age groups compared with CT thorax and CT brain. The proposed local DRL are compared with others study from establish local DRL in Switzerland and Korea as indicated in Table 4. It observed that the third-quartile values of CTDIvol and DLP in CT CAP were higher compared to study from Switzerland and Korea. DRL can be used as an advisory document by regional, national and local authorized body [6].

Table 1: Patient characteristic distribution of CT brain, thorax and CAP by sex and age group

CT Protocol	Parameters					
	Age (years)	Sex	N	Weight (kg)*	Height (cm)*	BMI (kg m^{-2})*
CT Brain	1-<5	M	13	10.00 ±4.00	76.55 ±17.22	16.76 ±3.46
		F	9	7.57 ±2.43	65.98 ±10.45	17.19 ±3.03
	5-<10	M	12	20.37 ±4.42	118.09 ±10.89	14.62 ± 2.62
		F	2	15.70 ±0.43	105.50 ±3.54	13.88 ±1.29
	10-15	M	7	37.30 ±17.96	155.50 ±16.26	14.90 ± 4.29
		F	5	57.60 ±0.00	147.00 ±0.00	26.66 ± 0.00
CT Thorax	1-<5	M	45	9.67 ±1.80	117.67±2.50	13.95 ±6.29
		F	47	10.53 ±3.85	85.62 ±20.51	14.36 ±1.95
	5-<10	M	19	23.93 ±5.68	108.38 ±12.55	21.09 ± 7.82
		F	20	21.63 ±5.97	120.95 ±16.23	14.57 ±2.15
	10-15	M	45	39.70 ±00.00	130.00±00.00	23.49 ± 00.00
		F	45	35.12 ±12.35	149.58 ±9.33	15.38 ± 04.24
CT CAP	1-<5	M	49	14.52 ±6.29	95.61 ±13.84	14.82 ±3.41
		F	39	10.35 ±1.56	82.44 ±8.31	12.52 ±0.84
	5-<10	M	28	16.60 ±2.19	108.38 ±3.86	15.32 ± 2.02
		F	48	20.12 ±11.13	114.69 ±10.00	17.10 ±6.90
	10-15	M	53	34.10 ±5.75	136.37 ±20.06	25.34 ± 5.56
		F	35	28.35 ±14.38	129.58 ±12.41	21.28 ± 9.28

*(mean ±SD)
M = Male, F = Female, N = Number

Table 2: CT paediatric examination parameters

Parameters	CT Protocol								
	CT Brain			CT Thorax			CT CAP		
Age (years)	1-<5	5-<10	10-15	1-<5	5-<10	10-15	1-<5	5-<10	10-15
Tube Voltage (kVp)	100	100-120	100-120	80	100-120	120	100	100-120	120
Tube current (mAs)*	286.5 ±35.9 (423-220)	185.50 ±20.5 (380-114)	233.33 ±24.8 (80-430)	76.80 ±34.2 (10-261)	110.81 ±54.5 (35-225)	145.28 ±52.0 (20-360	76.80 ±34.2 (28-177)	110.81 ±54.5 (35-272)	145.28 ±52.0 (53-287)
Scan Range	14.42 ±1.6	14.53 ±4.8	15.03 ±4.7	16.98 ±15.2	18.81 ±5.4	25.01 ±5.2	31.49 ±1.6	40.77 ±4.6	52.25 ±10.5
Pitch	0.4-0.64	0.4-0.64	0.4-0.64	1-1.4	1-1.4	1-1.4	1.4	1.2-1.4	1.2-1.4
Slice thickness (mm)	3	3	3	3-5	0.8-5	3-5	3	3-5	3
Collimation	40x0.6	40x0.6	40x0.6	64x0.6	64x0.6	64x0.6	64x0.6	64x0.6	64x0.6
Table feed	11-16	11-16	11-16	26.9	26.9	26.9	26.9	26.9	26.9

*(mean ±SD)

Table 3: Radiation dose measurement and DRL value (3rd quartile) in paediatric CT examinations

CT Procedure	Age (years)	This study		Switzerland 2008		South Korea 2015	
		$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
Brain	1-<5	30.2	475.7	30	420	41.7	508.0
	5-<10	30.9	523.2	40	560	44.1	792.0
	10-15	53.9	842.0	60	1000	55.3	947.0
Thorax	1-<5	5.4	97.1	8	200	3.4	60.5
	5-<10	7.8	163.2	10	220	4.6	80.0
	10-15	10.5	283.5	12	460	6.9	236.5
CAP	1-<5	5.7	204.0	9	300	4.4	169.0
	5-<10	10.6	419.4	13	380	6.2	256.0
	10-15	15.8	911.1	16	500	8.3	390.0

Table 4: Comparison of DRL to others study

CT Procedure	Age (years)	$CTDI_{vol}$		DLP		E	
		Mean ±SD	3rd Quartile	Mean ±SD	3rd Quartile	Mean ±SD	3rd Quartile
Brain	1-<5	24.8 ± 8.2	30.2	393.0 ± 156.4	475.7	1.6 ± 1.7	1.6
	5-<10	25.4 ± 9.7	30.9	428.9± 165.3	523.2	1.6 ± 1.2	1.9
	10-15	41.8 ± 14.4	53.9	679.3 ± 273.4	842.0	2.9 ± 1.6	3.6
Thorax	1-<5	4.6 ± 2.6	5.4	79.5 ± 54.8	97.1	1.6 ± 1.0	2.0
	5-<10	6.6 ± 3.4	7.8	135.3 ± 85.3	163.2	2.9 ± 2.1	3.4
	10-15	8.0 ± 5.0	10.5	207.7 ± 126.7	283.5	4.0 ± 2.6	5.3
CAP	1-<5	4.9 ± 2.0	5.7	164.1 ± 83.8	204.0	3.0 ± 1.6	3.8
	5-<10	8.2 ± 4.7	10.6	347.0 ± 214.6	419.4	6.8 ± 4.2	8.6
	10-15	13.1 ± 6.3	15.8	705.3 ± 348.3	911.1	11.7 ± 5.7	15.1

There are several limitations in this study. Firstly, the patient effective doses were calculated using the CT-EXPO calculator software by estimating organ equivalent dose base on mathematical phantom instead of being measured directly. Thus, uncertainties resulted from different body habitus and composition of each patient should be considered. Secondly, since our analysis was conducted on patient groups of single institutions, bias could have been introduced, even though the CT scans we obtained were from various hospitals throughout Malaysia.

In conclusion, in this study, radiation doses from paediatric CT examination have been present in term of $CTDI_{vol}$, DLP and E values. Local DRL are proposed particularly amongst paediatric as an optimization tool of CT parameter acquisition. Hence, justification and optimization due to the increase in the cancer occurrence in CT examination should be done regarding the report on the risk of CT exposure in children.

References

[1] D. L. Miglioretti, E. Johnson, A. Williams, R. T. Greenlee, S. Weinmann, L. I. Solberg, H. S. Feigelson, D. Roblin, M. J. Flynn, N. Vanneman, & R. Smith-Bindman, The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. *JAMA Pediatrics*, **167** (2013) 700–707. https://doi.org/10.1001/jamapediatrics.2013.311.

[2] D. J. Brenner & E. J. Hall, Computed Tomography — An Increasing Source of Radiation Exposure. *New England Journal of Medicine*, **357** (2007) 2277–2284. https://doi.org/10.1056/NEJMra072149.

[3] G. Brix, H. D. Nagel, G. Stamm, R. Veit, U. Lechel, J. Griebel, & M. Galanski, Radiation exposure in multi-slice versus single-slice spiral CT: Results of a nationwide survey. *European Radiology*, **13** (2003) 1979–1991. https://doi.org/10.1007/s00330-003-1883-y.

[4] M. Galanski, H. D. Nagel, & G. Stamm, Paediatric CT Exposure Practice in the Federal Republic of Germany: Results of a Nation-wide Survey in 2005 / 06. *Mhh*, (2005) 56. https://doi.org/10.1128/AEM.01911-09.

[5] G. Stamm & H. D. Nagel, CT-expo--a novel program for dose evaluation in CT. *RoFo: Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin*, **174** (2002) 1570–1576.

[6] R. Mbolatiana, A. Luc, R. M. Jeanne, R. Andraimbololona, R. Edmond, Z. J. L. Radaorolala, R. R. Dina, & R. T. Harimalala, Establishing Diagnostic Reference Level for Computed Tomography Examination in Madagascar. **1** (2015) 13–18. https://doi.org/10.11648/j.rst.20150102.11.