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# Comparison of 640-slice Aquilion ONE CT scanner's measured dosimetric parameters with ICRP dose reference levels for head, chest and abdominal CT examinations

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## Abstract

**Background:** Diagnostic reference levels (DRLs) are optimum range of values or diagnostic standard data for a particular procedure by which other imaging measurements must be compared for purposes of optimizing patient dose and radiation safety in medical imaging. This study aimed to compare measured dosimetric parameters of the latest 640-Slice Aquilion ONE CT scanner with established DRLs for adult and pediatric head, chest and abdominal examinations as a quality assurance test in order to recommend appropriate radiological safety solutions if differences existed.

**Methods:** A prospective and retrospective study design was applied in this work. Data of measured CT dosimetric parameters (patient administered doses) such as dose length product and CT dose index were generated for pediatric head, chest and abdominal examinations using the Aquilion ONE CT scanner. The generated database was compared with established international standard DRLs. SPSS version 16 software was used for data processing and analysis.

**Results:** The measured volume weighted CT dose index ( $CTDI_{vol}$ ) and dose length products (DLPs) were generally lower than the ICRP and other internationally recommended DRLs. In particular, the relative deviations from the DRLs were head ( $CTDI_{vol} = -57.5\%$ ,  $DLP = -33.8\%$ ,  $p$ -value = 0.001), chest ( $CTDI_{vol} = -94.3\%$ ,  $DLP = -86.6\%$ ,  $p$ -value = 0.002), and abdomen ( $CTDI_{vol} = -91.0\%$ ,  $DLP = -75.2\%$ ,  $p$ -value = 0.001) for pediatric examinations, and head ( $CTDI_{vol} = +5.5\%$ ,  $DLP = -4.0\%$ ,  $p$ -value = 0.001), chest ( $CTDI_{vol} = -80.3\%$ ,  $DLP = -56.6\%$ ,  $p$ -value = 0.001), abdomen ( $CTDI_{vol} = -6.8\%$ ,  $DLP = -54.7\%$ ,  $p$ -value = 0.001) for adult examinations respectively.

**Conclusion:** The  $CTDI_{vol}$  and DLP administered doses for both pediatric and adult examinations were lower than their respective DRLs except adult head examination where the measured  $CTDI_{vol}$  was 5.5 % higher than the standard reference dose. Optimization of practice is needed to reduce dose to head CT examinations when using 640-slice Aquilion ONE CT scanner.

**Keywords:** Computed tomography, Dose reference level (DRL), Dosimetric parameters, International standards

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### Background

Computed tomography (CT) is a useful imaging modality incorporating advanced technology to produce high resolution 3-D images [1, 2]. Due to the associated high radiation dose [3], dose optimization protocols are applied to examination-specific practices to ensure occupational and medical radiological safety and protection [2, 4] in accordance with ALARA and radiation protection principles.

Dose reference levels (DRLs) are established with CT imaging to obtain image quality consistent with the procedure and optimization of radiation as a result of the associated high radiation dose [5, 6]. They are classified as suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses, and also considered as investigational levels applied in the identification of unusually high radiation doses [6–9]. The importance of DRLs for assessing existing protocols, developing new and improved protocols, and as a dose optimization tool for promotion of good practices in CT imaging has been affirmed [10–18]. According to the Australian Radiation Protection and Nuclear Safety [19], DRLs provide a common dose metric for the comparison of DRLs between facilities, protocols and modalities, assess dose impacts of newly introduced protocols, and provide compliance with the relevant state and territory regulatory requirements.

In CT imaging, DRLs are set at all levels for each examination and each patient group i.e., adults and children of different sizes [15]. The practical dose quantities set up to monitor CT practice include weighted ( $CTDI_w$ ) and volume-weighted ( $CTDI_{vol}$ ) CT dose index ( $CTDI$ ), and dose-length product ( $DLP$ ) [20]. Accordingly, the importance of establishing facility-specific  $CTDI_{vol}$  and  $DLP$  values for each examination type and associated clinical indication [21] has been suggested. The Institute of Physics and Engineering in Medicine (IPEM) [22] has indicated that DRLs should be compared with relevant national DRLs (NDRLs) (if any), and values found higher than the NDRLs investigated and either justified as being clinically necessary or reduced through appropriate modifications in practice to improve occupational and patient protection.

Mathematically, the  $CTDI_{vol}$  quantifies CT scanner output for a specific scan protocol and is introduced to account for the pitch as

$$CTDI_{vol} = \frac{1}{p}CTDI_w = \frac{1}{3p}(CTDI_{100,center} + 2CTDI_{100,edge}) \quad (1)$$

for a multislice system, and as

$$CTDI_{vol} = \frac{1}{p}CTDI_w = \left(\frac{d}{1/w}\right)CTDI_w = \left(\frac{d}{1/n\lambda}\right)CTDI_w \quad (2)$$

in terms of the travel distance per gantry rotation ( $d$ ), nominal beam width ( $w$ ) and number ( $n$ ) of sections per scan. The corresponding  $DLP$  during the complete examination is computed [23] via

$$DLP = L(CTDI_{vol}) = \frac{L(CTDI_w)}{p} = \left(\frac{n\lambda}{I}\right)CTDI_w = \sum_i (nCTDI_w)i\lambda t \quad (3)$$

where  $L$  and  $I$  are scan length interval and interval of scan length respectively, and serial scan sequence ( $i$ ), number of slices ( $N$ ), radiographic exposure ( $C$ ), total acquisition time ( $t$ ), and tube current ( $i$ ) are other scan parameters.

Effective dose is the amount of energy deposited in the irradiated organ and used for evaluating radiation dose, [24] and comparison of stochastic effects. It is evaluated from relative radiation risk to each organ and dose to individual organs, taking into account the absorbed dose received by each irradiated organ and organ’s sensitivity [25]. Using the International Commission on Radiological Protection 103 tissue-weighting factors ( $w_T$ ) and organ dose estimate approach, the effective dose can be calculated via

$$E_D = \sum_z \left[ \sum_T w_T H_T \right] \quad (4)$$

where  $H_T$  is the corresponding absorbed dose to the specified tissue ( $T$ ) [26], derived from the European Commission guidelines and computed  $DLP$  values [27] as

$$E_D = {}^DkDLP = k(LCTDI_{vol}) = \left(\frac{kL}{p}\right)CTDI_w \quad (5)$$

where  $k$  is a data set of tissue-weighting coefficients derived from data sets restricted to the scanned anatomic region.

The 640 multislice scanning volume Aquilion ONE TSX-301A CT scanner was recently installed at the Korle Bu Teaching Hospital (KBTH). The scanner supports simultaneous data acquisition of 320 row detector slices of the whole body scanning using the Selectable Slice-thickness Multi-row Detector (SSMD). However, recent Toshiba-initiated [28] recalls of this scanner upon confirmation of a potential software problem which indicated incorrect setting of x-ray output conditions, and consequently presented reliability challenges of the scan

results have been reported by the US Food and Drugs Administration (FDA) [29].

Radiation doses associated with the operation of this CT scanner at KBTH have not been characterized by comparing measured doses with internationally accepted DRLs, ascertain any differences, validate measurements, and establish a relationship between the DRLs and measured doses. In particular, this is important for purposes of ensuring occupational and medical radiation safety and protection. The absence of such studies presents obvious challenges to safety. Hence in accordance with IPEM [22] indications of the importance for each CT facility to establish local DRLs (LDRLs) or typical  $CTDI_{vol}$  and  $DLP$  dose levels for each type of examination and associated clinical indication, this study was performed to measure dosimetric parameters for CT examinations of the head, chest and abdominal anatomic regions and compare with internationally accepted DRLs. Any observed differences could then be investigated and justified as being clinically necessary or reduced via approved methods such as appropriate changes in clinical practice in order to improve medical radiation protection. Consequently, practicing radiographers and radiologists at this facility will be enabled to adapt good practices to patient dose optimization with respect to the DRLs.

## Methods

A retrospective and prospective design was adopted to obtain data from previous and current examinations at the time of the study. The population consisted of 350 pediatric and adult patients referred for CT examinations of the head, abdomen and chest regions at the study site. Data acquisition was made from automatically generated  $CTDI_{vol}$  and  $DLP$  values for each patient scan based on radiographer selected parameters of the 640 multislice Aquilion ONE CT TSX-301A scanner which stores parametric scan data. Automatic dose reduction was ensured by integration of Toshiba's Adaptive Iterative Dose Reduction 3D (AIDR 3D) iterative reconstruction technology into the imaging chain. Images (in 3-D) of the head, chest and abdomen body regions of referred patients were acquired in volume and helical format. The LDRLs ( $CTDI_{vol}$  and  $DLP$  values) were then established by retrieval of the stored data including the standardized DRLs on the CT scanner. In this study, the ICRP DRLs were chosen as the main reference by which the measured DRLs were compared and deviations determined. Comparisons with DRLs specified by the American College of Radiology, American Association of Physicists, European Commission, and those used in Sweden and the United Kingdom were also made.

Paired sample *T-test* was used to compare the DRLs and the patient measured doses for each examination. A two-tail statistical significance with a  $p < 0.05$  value was determined.

## Ethics

The Ethical and Protocol Review Committee of the University of Ghana School of Biomedical and Allied Health Sciences, and management of the Radiology Department of KBTH approved the study. For the prospective study, the consent of adult patients was directly sought while parental consent was obtained from parents/guardians of pediatric patients. For the retrospective study, consent to access patients' data for the study was also approved by the management of KBTH. Demographic and scan data of patients referred for head, abdomen and chest CT examinations at the study site during the study period were included in the study. These CT examinations were selected because they constitute the most common or frequently requested examinations at the Centre. Conversely, patients' data obtained before and after the study period were excluded from the study. Additionally, data obtained from CT examinations other than the head, chest and abdomen regions were excluded from the study.

## Results

The age and gender demographics of the participants are presented in Table 1. The ages of the pediatric patients ranged from less than 5 years to 10 years. The number of head CT scans performed for the 6–10 year group was marginally higher ( $n = 37$ , 51.4 %) than those in the less than 5 year group ( $n = 35$ , 48.6 %). The same frequencies ( $n = 2$ , 50 %) were however obtained for both pediatric age groups referred for chest and abdomen CT examinations. There were more pediatric CT head referrals ( $n = 72$ , 90 %) compared to 5 % ( $n = 4$ ) each for chest and abdomen CT examinations.

The age range of the adults was 18 years to 100 years. Referrals for CT head and chest examinations were higher among the 36–59 age group (head:  $n = 130$ , 46.8 %,  $n = 20$ , 43.5 %) compared to the 60–100 years (head:  $n = 79$ , 28.4 %; chest:  $n = 15$ , 32.6 %). The number of CT referrals for abdominal; examination was the same ( $n = 33$ , 38.4 %) for both age groups however. The least referrals for all three modalities was registered among the 18–35 year group (head:  $n = 69$ , 24.8 %; chest:  $n = 6$ , 13 %; abdomen:  $n = 20$ , 23.3 %).

More male pediatric CT head ( $n = 42$ , 58.3 %) and abdominal ( $n = 3$ , 75 %) examinations were studied compared to 41.7 % ( $n = 30$ ) and 25 % ( $n = 1$ ) for females. On the contrary, more ( $n = 3$ , 75 %) pediatric chest examinations were registered for females than for males ( $n = 1$ ,

**Table 1** Age and gender demographics

Patient category	Demographic variable	Type of CT examination					
		Head		Chest		Abdomen	
		No.	Percent,%	No.	Percent,%	No.	Percent,%
<i>Age demographics</i>							
Pediatrics	≤5 years	35	48.6	2	50.0	2	50.0
	6-10 years	37	51.4	2	50.0	2	50.0
	Total	72	100.0	4	100.0	4	100.0
Adults	18-35 years	69	24.8	6	13.0	20	23.3
	36-59 years	130	46.8	20	43.5	33	38.4
	60-100 years	79	28.4	15	32.6	33	38.4
	Total	278	100.0	41	100.0	86	100.0
<i>Gender demographics</i>							
Pediatrics	Male	42	58.3	1	25.0	3	75.0
	Female	30	41.7	3	75.0	1	25.0
	Total	72	100.0	4	100.0	4	100.0
Adults	Male	150	54	26	63.4	42	48.8
	Female	128	46	15	36.6	44	51.2
	Total	278	100.0	41	100.0	86	100.0

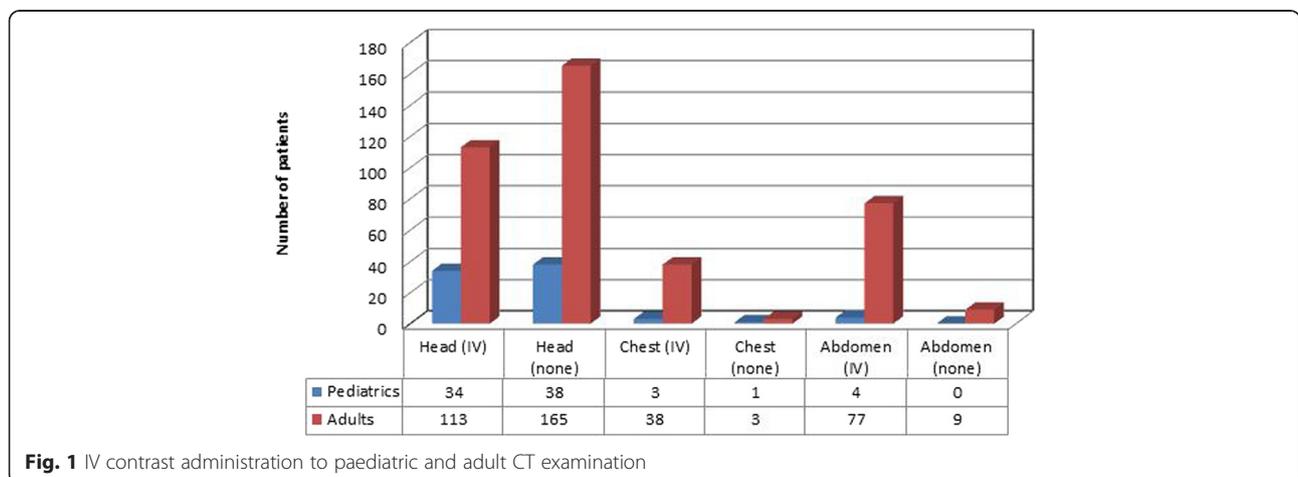
Source: field data, (2014)

25 %). The tally of the adult CT scan reports showed more males for head ( $n = 150, 54\%$ ) and chest ( $n = 26, 56.5\%$ ) scans compared to 46 % ( $n = 128$ ) and 32.6 % ( $n = 15$ ) for females respectively. More females ( $n = 44, 51.2\%$ ) however, registered for abdominal scans than males ( $n = 42, 48.8\%$ ).

**Administration of Intravenous Contrast Media**

Intravenous (IV) contrast media was administered to some of the patients (Fig. 1). All (100 %) the abdominal CT referrals for pediatric patients were administered with IV contrast media while administrations for chest

and head referrals were 75 % ( $n = 3$ ) and 52.8 % ( $n = 38$ ) were respectively. Overall, 51.3 % ( $n = 41$ ) of pediatrics received IV contrast administration. The clinical histories associated with these examinations were mainly hydrocephalus, seizures, and trauma. Similarly, 40.7 % ( $n = 61$ ) of adult head CT referral cases received IV contrast media. As observed for the pediatric patients, higher rates of IV contrast administrations were recorded for adult CT referrals for chest ( $n = 38, 92.7\%$ ) and abdomen ( $n = 77, 89.5\%$ ). The registered clinical histories for the adult referrals were cerebrovascular accident (CVA), intracranial space occupying lesion



**Fig. 1** IV contrast administration to paediatric and adult CT examination

(ICSOL) and trauma (head CT), cancer of the lung and pulmonary TB (chest CT), and abdominal pains (abdomen CT).

**Dosimetry**

**Head, chest and abdominal examinations**

The results of the measured doses compared with the ICRP DRLs for CT head, chest and abdominal scans are presented in Table 2. The means of the measured  $CTDI_{vol}$  values for pediatric and adult doses were  $23.87 \pm 10.18$  mGy and  $63.29 \pm 8.94$  mGy respectively. Comparatively, the measured doses were lower than the ICRP DRL value of  $56.11 \pm 12.843$  for pediatrics, and higher than 60.00 mGy for adult the ICRP DRL. Statistically, a  $p$ -value of  $0.001 < 0.005$  with a 0.95 confidence interval was estimated which established a significant difference between the measured doses and the DRLs. The measured  $DLP$  doses for pediatric and adult CT head scans were  $406.59 \pm 71.121$  mGy, and  $1008.26 \pm 266.730$  mGy. Comparatively, the measured  $DLPs$  were lower than the ICRP DRLs and calculated  $p$ -values ( $<0.005$ ) established significant differences between them. Relative deviations of the measured values (LDRL) from the reference (DRL) values were calculated via eqn. (6)

$$Rel. dev. = \left( \frac{LDRL - DRL_{ref}}{DRL_{ref}} \right) \times 100\% \quad (6)$$

The measured chest  $CTDI_{vol}$  values (pediatrics:  $1.70 \pm 10.18$  mGy; adults:  $5.92 \pm 3.14$  mGy) were very significantly lower than the ICRP DRLs ( $30.00 \pm 0.00$  mGy) for both pediatrics and adults with calculated  $p$ -values of 0.001- 0.002 ( $<0.005$  at 0.95 confidence interval). Similarly, the measured  $DLPs$  (pediatrics:  $67.20 \pm 69.54$  mGy; adults:  $282.14 \pm 159.12$  mGy) were very significantly lower than the ICRP DRLs (pediatrics:  $500.00 \pm 115.470$ ; adults:  $650 \pm 0.00$  mGy). The estimated  $p$ -value was  $0.001 < 0.005$ .

The same trend was observed for the abdominal CT examinations for both categories of patients. These results indicated the measured dosimetric parameters were

much lower compared to the ICRP DRLs. In particular, the relative deviations of the measured  $CTDI_{vol}$  and  $DLPs$  from the ICRP DRLs were 91.0 % ( $2.70 \pm 1.16$  mGy vs.  $30.00 \pm 5.77$  mGy) and 75.2 % ( $144.50 \pm 93.57$  vs.  $375.00 \pm 144.34$  mGy) respectively for pediatrics, and 80.6 % ( $6.79 \pm 3.02$  vs.  $35.00 \pm 0.00$  mGy) and 54.7 % ( $353.48 \pm 178.394$  mGy vs.  $780.00 \pm 0.00$  mGy) for adults respectively. For both categories of patients, an estimated  $p$ -value of  $0.001 < 0.005$  was statistically established a significant difference the measured and standard DRLs.

Using the ICRP recommended tissue weighting coefficients, the computed effective doses from the  $CTDI_{vol}$ ,  $CTDI_w$  and  $DLPs$  for each measured  $DLP$  for the three body regions are shown in Table 3. The calculated effective doses for both categories of patients were lower than the ICRP recommended values. The least deviation of 4.0 % was registered for adult head CT effective dose (10.8 mGy) compared to the ICRP value (10.50 mGy), while the highest deviation (86.6 %) of effective dose (8.06 mGy) relative to the ICRP value (60.0 mGy) was observed for pediatric chest. Effective doses for abdominal CT examinations were lower in pediatrics (11.16 mGy, 75.2 % rel. deviation) than adults (42.42 mGy, 54.4 % rel. dev.).

**Discussion**

A study conducted to assess and compare doses a new 640-Slice Aquilion ONE CT scanner with established DRLs for adult and pediatric patients undergoing CT examinations of head, chest and abdominal regions was successfully realized. For both pediatric and adult patients, the lowest frequencies of CT referrals were recorded for chest ( $n = 45$ , 9.3 %) and ( $n = 90$ , 8.6 %) for abdomen examinations compared to over 72 % ( $n = 350$ ) for head CT examination. The findings are agreeable with the literature which indicates increasing numbers of head CT scans [4]. More adults presented for head CT scan than pediatrics as this procedure is usually not requested for pediatric patients unless it is very necessary. This is consistent with concerns about cancer risks from exposure to ionizing radiation arising from

**Table 2** ICRP DRLs and measured dosimetric parameters for pediatric and adult CT head, chest and abdominal scans

Body Region	Patient category	$CTDI_{vol} \pm s.d$ (mGy)			$DLP \pm s.d.$ (mGy/cm)			$p$ -value
		ICRP DRL	Measured	Rel. dev. %	ICRP DRL	Measured	Rel. dev. %	
Head	Pediatric	56.11	$23.87 \pm 10.18$	-57.5	614.58	$406.59 \pm 10.18$	-33.8	0.001
	Adult	60.00	$63.29 \pm 10.18$	5.5	1050.00	$1008.26 \pm 10.18$	-4.0	0.001
Chest	Pediatric	30.00	$1.70 \pm 10.18$	-94.3	500.00	$67.20 \pm 10.18$	-86.6	0.002
	Adult	30.00	$5.92 \pm 10.18$	-80.3	650.00	$282.14 \pm 10.18$	-56.6	0.001
Abdomen	Pediatric	30.00	$2.70 \pm 10.18$	-90.0	375.00	$93.00 \pm 10.18$	-75.2	0.001
	Adult	35.00	$6.79 \pm 10.18$	-80.6	780.00	$353.48 \pm 10.18$	-54.7	0.001

**Table 3** Effective dose

Body region	Patient category	Weighting factor $W_T$	Effective dose $E_D$ (mGy)		
			ICRP DRL	Measured	Rel. dev., %
Head	Pediatric	0.01	6.15	4.07	-33.8
	Adult	0.01	10.50	10.08	-4.0
Chest	Pediatric	0.12	60.00	8.06	-86.6
	Adult	0.12	78.00	33.86	-56.6
Abdomen	Pediatric	0.12	45.00	11.16	-75.2
	Adult	0.12	93.60	42.42	-54.4

Rel. dev. relative deviation from reference DRLs, s.d. standard deviation

increased use of CT in pediatrics. In particular, it has been reported that the increased use of CT in pediatrics, combined with the wide variability in radiation doses resulted in administration of higher doses to many children and that dose-reduction strategies targeted to the highest quartile of doses could dramatically reduce the number of radiation-induced cancers [30]. The observed lower pediatric referrals for head CT scan in this study is also confirmed by a study [31] which identified the lack of clinical significant findings associated with the vast majority of pediatric head CT scans and recommended reductions in the frequency of CT referrals as well as implementation of interdisciplinary measures in advocating for decreased and unnecessary CT imaging of pediatrics.

More males ( $n = 264$ , 54.4 %) CT examinations were studied compared to females ( $n = 221$ , 45.6 %) for all the three examinations. The higher male ratio could be attributed to the fact that many males suffered more trauma cases than females as evidenced via the noted clinical trauma histories in the various examinations.

### Contrast examination

Intravenous contrast (IV) contrast media are administered in radiographic examinations to make the anatomy of interest more visible. The study showed that about 55.5 % of all the CT examinations were administered with contrast media (head: 30.3 %; chest: 8.5 % and 16.7 %) while all (100 %) the abdominal CT referrals were IV contrast media-administered for the pediatric examinations. The clinical histories associated with these examinations were mainly hydrocephalus, seizures, and trauma for pediatrics, while cerebrovascular accident, intracranial space occupying lesion (head CT), cancer of the lung and pulmonary tuberculosis (TB) (chest CT), and abdominal pains (abdomen CT) were registered for adults. These findings agree with the work of Wang and You [32], which revealed clinically important abnormalities such as history of malignancy, focal neurologic deficit in a study of clinical predictors of abnormal findings of head CT non-trauma patients. Contrary to these however, the prediction of abnormalities on head CT as

indications of increased risk of lumbar puncture-induced brain herniation history and physical examination findings has been queried [33].

### Dosimetry

The LDRL or measured mean weighted  $CTDI_{vol}$  value of  $63.29 \pm 8.94$  mGy for adult head CT examination was consistent with the ICRP [34] and European Commission [35] DRL values 60 mGy with a 5.5 % deviation. In another study [5], different DRLs were reportedly used by imaging sites which demonstrated abrupt transition at 60 mGy, with increasingly higher values in order to produce the desired image quality. A new  $CTDI_{vol}$  value of 75 mGy was therefore set for head CT examination [16]. Comparatively, the measured adult head  $CTDI_{vol}$  value of  $63.29 \pm 8.94$  mGy reported in this work is lower than the ACR-AAPM and EUR 16262 DRLs as well as the published NDRLs for the United Kingdom 2003 (65–100 mGy), Switzerland 2010 (65 mGy), and Sweden 2002 (75 mGy) respectively [36–38]. Generally, the relative deviations of the LDRLs were least with respect to the ACR values. Taking cognizance of the fact that the precise rationale of established DRLs is to provide a benchmark for comparison, and not to define a maximum or minimum dose limit as stated by the American College of Radiology [6], the measured LDRL, though higher by 5.5 % with respect to the ICRP DRL (60.0 mGy) is however 15.6 % lower than the ACR's new  $CTDI_{vol}$  value of 75 mGy for head CT. Since ACR's new values do not impact negatively on patient radiological safety but are suitable for higher image quality, then the measured LDRLs in this study is within limits of patient radiological safety and would thus not induce any biological damage to the adult patients undergoing head CT examinations using this CT scanner. On the basis of this, it is expected that dose optimization strategies, as well as audit and practice review for promoting improvements in patient medical protection will be required and implemented as recommended by the Institute of Physics and Engineering in Medicine [39].

The results of the study further showed that the  $CTDI_{vol}$  measured doses for pediatric head, as well as pediatric and adult chest and abdominal CT scans were much lower than the ICRP, ACR-AAPM and EUR DRLs. The relative deviations ranged from 57.5 % to 94.3 % in pediatrics, and 5.5 % to 80.6 % in adults. These results are in agreement with another study [4] which reported radiation doses from adult CT procedures 90 % below the  $CTDI_{vol}$  reference levels. In terms of patient safety, the administered or measured doses generally did not exceed internationally accepted and recommended DRLs. This means that patients were not inadvertently exposed to radiation. Also the findings of the study are suggestive the scanner was safely operated within its

operating limits and conditions (OLCs) to ensure patient and occupational safety.

The findings of this study showed that all the measured mean *DLP* values for head, chest and abdomen CT examinations for both pediatrics and adults were lower than their respective ICRP DRLs. This is indicative that all administered doses were consistent with ALARA leading to dose optimization. It was reported [4] that the measured *DLP* exposures for adult CT procedures were below the *DLP* reference levels by 62 % and thus supports the findings of this study which recorded deviations in the range of 4.0 to 56.6 %. Generally, the deviations of the measured dosimetric parameters from the standard ICRP DRLs are consistent with published literature (Tsalafoutas et al., 2012 = 40). However, the degree of deviation depends on the type of CT scanner used, the imaging parameters and other physical operating conditions. In particular, the reported small deviations [40] were based on calculating patient effective dose via a comprehensive method in which 3 different CT scanners were used in 30 CT examinations of the chest, chest-abdomen-pelvis, and abdomen-pelvis regions. Statistically, *p*-values in the range of 0.001–0.002 < 0.005 with a 0.95 CI established significant differences between the measured dosimetric parameters and the ICRP reference doses.

Fundamentally, effective doses reflect the choice of scanning protocol (radiographic technique factors) such as such as mAs values, scan length, and pitch used in a given CT examination. In this study, the calculated effective doses from the measured *DLPs* were lower than the ICRP reference values, but higher than those reported elsewhere in the literature, particularly for adults. Effective computed doses of 1.3 mGy have been reported for head examinations [24], 5.4 mGy for chest examinations [41], and 9 mGy for abdominal examinations [42], using different approaches.

It has been reported that pediatric doses are currently lower than previously reported. Using dose reduction strategies, effective dose reductions from 9 mGy to 1.5 mGy for pediatrics weighing up to 10 kg for chest examinations and a corresponding reduction for abdominal CT examination from 7 mGy to 2 mGy have been indicated [42]. Comparatively the results of this study do not agree with this reported work [42]. The reasons for the differences could be attributed to the different imaging protocols and non-availability of useful diagnostic information at the time of the measurements. However, in accordance with dose optimization principles and medical radiation protection and safety principles, this study identifies with the fact that the increased radio-sensitivity of children and the increasing utilization of CT require significant dose reduction strategies for pediatrics without apparent loss of diagnostic information which is consistent with the literature [43].

## Conclusions

A comparative study of measured dosimetric parameters with ICRP and other internally recognized DRLs for pediatric head, chest and abdominal examinations has been done using the 640-Slice Aquilion ONE CT scanner facility in a tertiary referral hospital. The facility does not display any facility-specific DRLs on its monitors. Hence for purposes of this study, the well utilized and reliable ICRP 103 DRLs was used as the main reference DRLs. With the exception of *CTDI<sub>vol</sub>* values measured for adult head CT, all the measured values for head, chest and abdominal CT procedures, were generally consistent with the literature and lower than the standard ICRP, EUR 16262, ACR, AAPM and other NDRLs (Sweden, Switzerland, United Kingdom). Statistically, significant differences between the measured *CTDI<sub>vol</sub>* and *DLP* values, and the corresponding ICRP DRL values were established. The effective doses were lower in pediatrics than in adults which reflected the choice of scanning protocols adopted for the CT examinations.

In accordance with dose optimization, medical radiation protection and safety principles, this study identifies with the fact that the increased radio-sensitivity and increased utilization of CT require implementation or review of significant dose reduction strategies for optimization of practice using this scanner for CT head examinations. This has to be done without apparent loss of diagnostic information in accordance with ALARA.

## Abbreviations

ALARA, as low as reasonably achievable; CT, computed tomography; DRLs, diagnostic reference levels

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## Availability of data and materials

Data for this study has been duly presented in the text and tables of this manuscript.

## Authors' contributions

Authors SAS, BOB, WKA and RSB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

## Competing interest

The authors declare that they have no competing interests.

## Ethics approval and consent to participate

The Ethical and Protocol Review Committee of the University of Ghana School of Biomedical and Allied Health Sciences approved the study. For the prospective study, patients' consents were sought for this study. Parental consent was obtained from parents/guardians in cases where the participant was under 18 years. For the retrospective study, consent to access patients' data for the study was also approved by the management of the Radiology Department of KBTH. Therefore, the need for consent was waived by the IRB for the data collected retrospectively. These approvals included consents to publish this work.

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