



Research Paper

# Diagnostic Reference Level in Computed Tomography: An Evaluation of CT-Protocol Dose Index in a Diagnostic Facility

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## Abstract

Recent surveys in large medical centers have found that Computed Tomography (CT) studies now often account for 25% of all examinations and 60 to 70% of the patient dose received from diagnostic radiology (IAEA, 2009). This has created a sense of urgency and the impetus for establishing Diagnostic Reference Level (DRL) and dose reduction strategies. This study presents the assessment and evaluation of patient radiation doses for common CT examinations and derivation of DRLs for common CT examinations. Computed Tomography Dose Index (CTDIvol) and Dose Length Product (DLP) of common CT examinations including: Abdomen, Abdominopelvis, Brain, C-Spine, Chest amongst others were measured using a calibrated GE CT scanner. Data were collected for 402 patients. The mean CTDIv (mGy) and DLP (mGy.cm) for all the protocols were 17.92 & 684.94, 17.09 & 744.56, 51.19 & 852.96, 20.08 & 423.92, 16.8 & 490.07 respectively. When compared with international standards, the great variation in dose distribution was attributed to CT technical parameters, clinical complexity of the patients and inadequate quality control program. There is a dire need to establish local DRL, which are corrective measures that are required in elimination of radiation that does not contribute to overall profile of the patients.

Key words: Computed Tomography, Computed Tomography Dose Index, Dose Length Product, Dose Reference Level.

## Introduction

Researchers have been showing considerable interest in assessing and determining diagnostic reference level (DRLs) for typical procedures using computed tomography (CT) scans across various tertiary health care centers and institutions to establish a local or national diagnostic reference level for dose optimization in CT procedures. In fact, government agencies, international organizations, institutions and researchers are so much involved in the subject that their efforts are now providing some solutions in eliminating unnecessary radiation exposure that does not contribute to overall benefit of the patients. The term diagnostic reference level or reference value sets

an investigation level to identify unusually high radiation doses or exposure levels for common diagnostic medical imaging procedures [1, 2]. Diagnostic reference levels (DRLs) are a practical tool to promote the assessment of existing protocols and appropriate development of new and improved protocols at each CT center by facilitating the comparison of doses from present practice. Diagnostic reference levels were first successfully implemented in relation to conventional X rays in the 1980s and subsequently developed for application to CT in the 1990s [3]. The establishment of reference levels in diagnostic medical imaging requires close cooperation and communication between the physicians who are

responsible for the clinical management of the patient and the medical physicist responsible for monitoring equipment, image quality and estimating patient dose (ACR guidelines). Although, Diagnostic Reference Levels for CT examinations have been previously established by some researchers and their studies focused on breast CT protocols and CT trunk examinations [4, 5].

There is now a widespread concern about the increase in CT doses. The United Nations Scientific Committee on the Effects of Atomic Radiation report on Medical Radiation Exposures stated that CT constituted only 5% of radiological examinations, but contributed about 34% of the collective dose in the UK [6]. CT contribution to the collective effective dose from medical exposures in 1999 was 40%, compared with 20% in 1990 [7]. CT accounts for about 11% of x-ray based medical procedures in the USA, but delivers over 67% of total dose associated with medical imaging procedures [8].

The worldwide sales of CT scanners has more than doubled since 1998, and is predicted to continue increasing at the same pace as shown in Figure 1. Like other imaging modalities using ionizing radiation, CT in recent years has experienced tremendous technological advances, developing from the first generation in the early 1970s through the seventh generation [9]. The trend of increasing use of CT scanning has been and is being documented by international organizations, national bodies and in individual studies. The overwhelming thrust of the data is that the number of installations, the frequency, type of examinations, and the dose per examination are all increasing throughout the world [10].

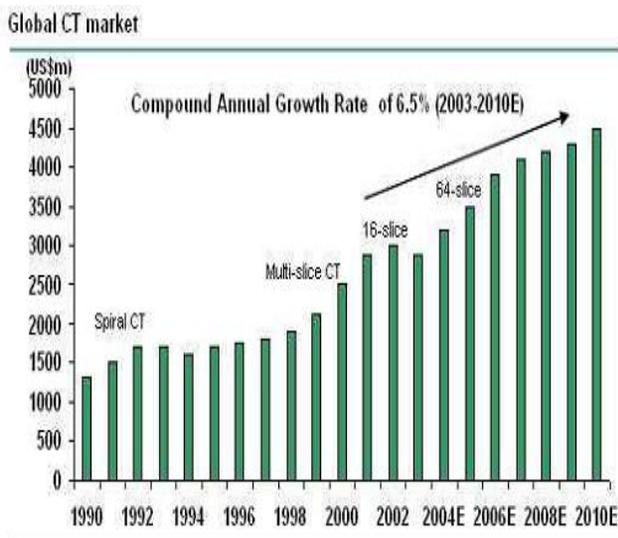


Figure 1. A schematic representation showing the worldwide CT sales.

## Methods

### CT Calibration

A computed tomography system (General Electric, Bright Speed Edge Select) was used for the study. The study was performed on the CT component of the system, which provides 8 slices per gantry rotation. Computed tomography head (16-cm diameter) and body (32-cm diameter) PMMA dosimetry phantoms were used in the study to mimic an adult head and body respectively. Calibrated 100 mm long pencil ion chamber connected to UNIDOS E electrometer (PTW Freiburg, Germany) was used in taking charge measurements. Thermometer and barometer were used in recording the room temperature and pressure respectively. Measurements were taken by setting up the head and body phantoms in succession. The head phantom was first setup on the CT couch and centered at the isocentre of the scanner with the long axis of the phantom aligned with the z-axis of the scanner. Scout view and single 1 mm slice image of the phantom was acquired for alignment purposes. The ion chamber was placed in the center of the phantom and a scout view image used to select the volume or slice to be imaged. Dosimeter readout was set to zero, and exposure in axial mode at brain CT scan technique (120 kV, 200 mAs) was used for the head phantom study. Charges (in nano-coulombs) were measured in the central and peripheral holes by changing the ion chamber position from one hole to the other. After taking head phantom measurements, the procedure was repeated on the body phantom. Pelvic CT scan techniques (120 kV, 250 mAs) were set for the body phantom measurements. All the measurements were taken at temperature of 22°C and pressure of 837 hPa (Table I). Electrometer readings were taken in charge mode, corrected for temperature and pressure, and converted into exposure.  $CTDI_{100}$ ,  $CTDI_w$  and  $CTDI_{vol}$  were estimated using equations (1) and (2) respectively. The estimated values were compared with console displayed doses ( $CTDI_{vol}$ ) for the two examinations.

$$CTDI_w = \frac{1}{3} \cdot CTDI_{100;c} + \frac{2}{3} \cdot CTDI_{100;p} \quad (1)$$

$$CTDI_{100} = CTDI_{vol} = \frac{CTDI_w}{Pf} \quad (2)$$

### Patient Data

The demographic information that were included in the study are: (i) age, no restrictions were applied to the patient's age; (ii) genders, male and female inclusive; (iii) examination type, body region indicating Abdomen, Abdominopelvis, Brain, Cervical Spine, Chest, Chest

Abdomen, Chest Abdominopelvis, Face, Lumbosacral Spine, Neck, Pelvis and Urogram CT procedures were included in the study.

### Scan Parameters

The exposure parameters are tube current time product (mAs) and kV. Other information recorded are: slice thickness, pitch, scan length, number of slices, scan mode, and field of view (FOV), automatic exposure control (AEC) and contrast phase.

### Dose Parameters

Dose index parameters such as volumetric computed tomography dose index (CTDIvol) and dose length product (DLP) were recorded. The scans were based on the pre-installed protocols. No patient name was recorded.

### Sample Size

A sample size of 402 participants was used in the study. These were obtained through the selection of 402 participants (male and female) that underwent CT examinations of the Abdomen, Abdominopelvis, Brain, Cervical Spine, Chest, Chest Abdomen, Chest Abdominopelvis, Face, Lumbosacral Spine, Neck, Pelvis and Urogram in the center of study using a purposive method of sampling [11].

The 402 participants were selected based on the recommendation made by the European Commission, which says a minimum of 10 participants shall be recruited for each body part under examination [12]. The age limit and patient weight were not put into consideration because the data were collected retrospectively.

## Results and Discussion

Table I presents the various results obtained at different plurality positions as well as the mean values for CTDIw and CTDIvol. The CTDIvol shows a tolerance level of  $\pm 20$  (50.66) with a 6.03% deviation from the mean, indicating that it is within the acceptable limits recommended by the IAEA. Once the CT scanner general parameters were ascertained, its validation for accurate dose measurement was certified.

The descriptive analysis was employed to summarize the data for this study. It is used to give a description of the data by determining the measures of location (max value, min value, mean, median, first-quartile and third-Quartile). The results for the comparison of 3rd quartile values of dose parameters of this study with other established values in literature are presented below in the figures below (Figures 2-15).

The mean CTDIv for different CT protocol were determined by using the third quartile value for the range of CTDIv for both male and female patients. For example, the mean CTDIv for brain is 51.19 mGy (Figure 7) while that of Chest is 16.8 mGy (Figure 11). Also, the mean DLP for different CT protocol were determined by using the 3rd quartile value for the range of DLP for both male and female patients. For example, the mean DLP for brain is 852.96 mGy.cm (Figure 8) while that of chest is 490.07 mGy.cm (Figure 12).

The estimated effective dose were gotten from the normalized k value for each organs multiplied by the mean DLP of the organs. The estimated dose revealed female patients received more radiation doses than male patients did.

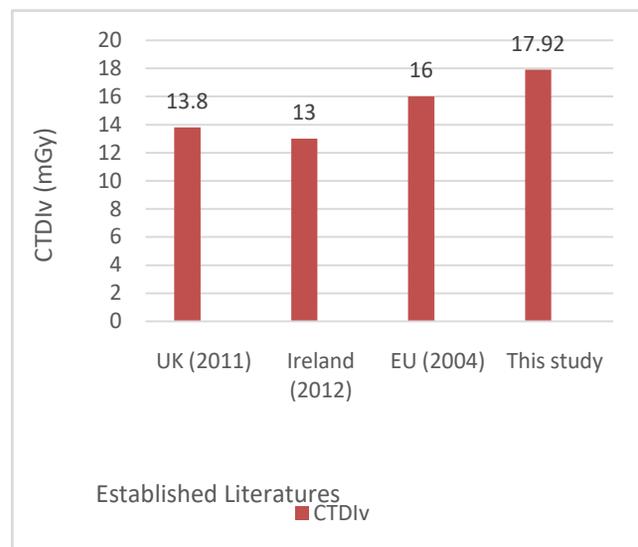


Figure 2. CTDIv (abdomen) for other established work compared with this study.

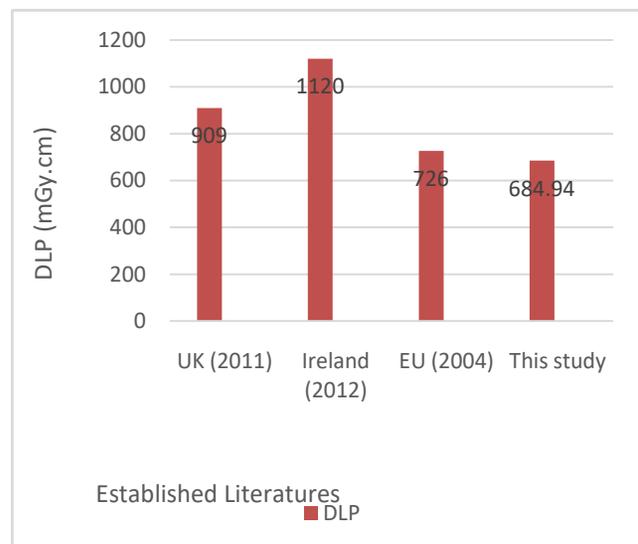


Figure 3. DLP (abdomen) for other established work compared with this study.

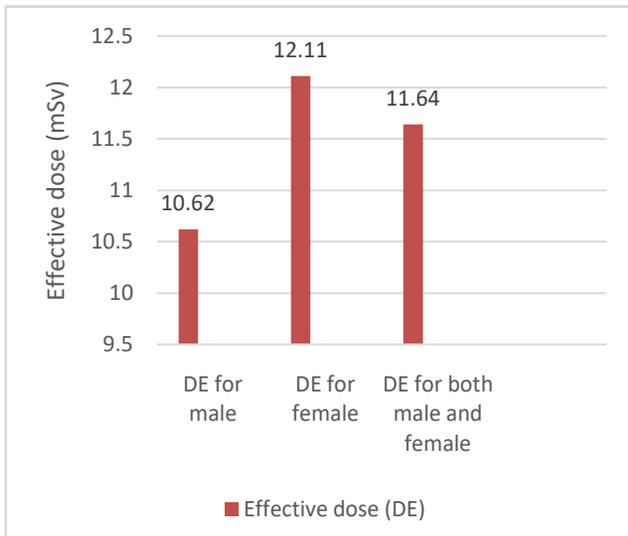


Figure 4. Effective dose (abdomen) for male, female and both male and female patients in this study.

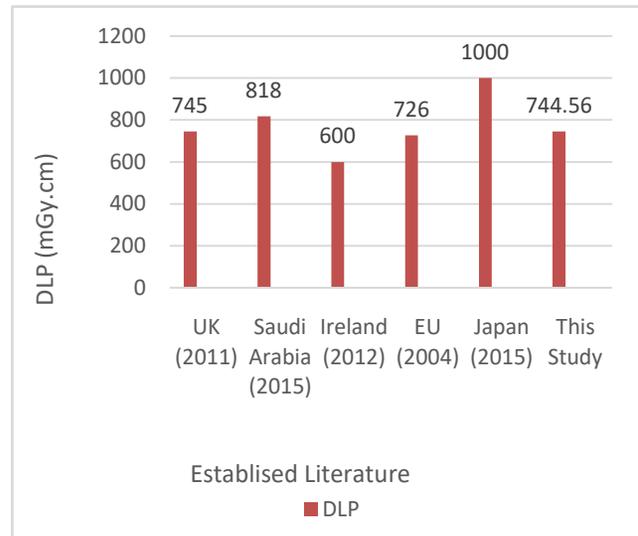


Figure 6. DLP (abdominopelvis) for other established work compared with this study.

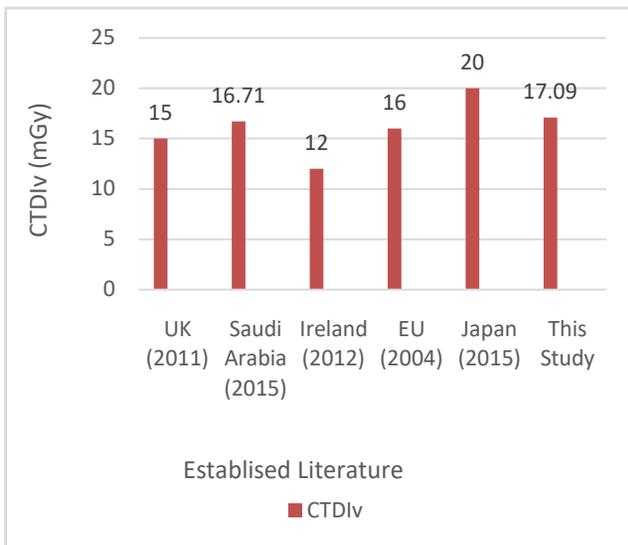


Figure 5. CTDIV (abdominopelvis) for other established work compared with this study.

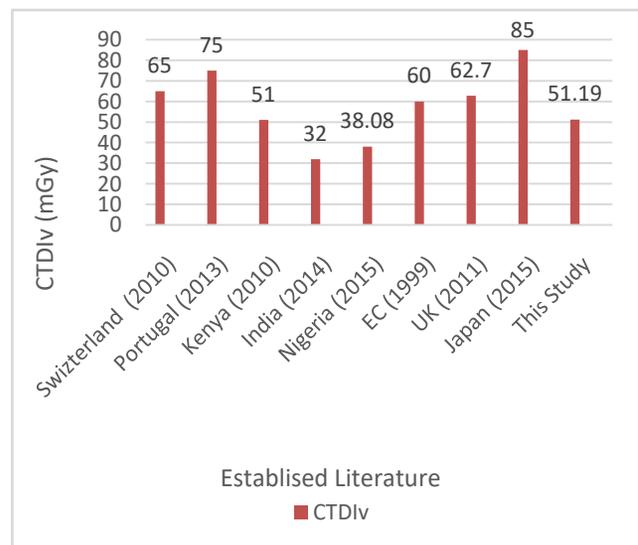


Figure 7. CTDIV (brain) for other established work compared with this study.

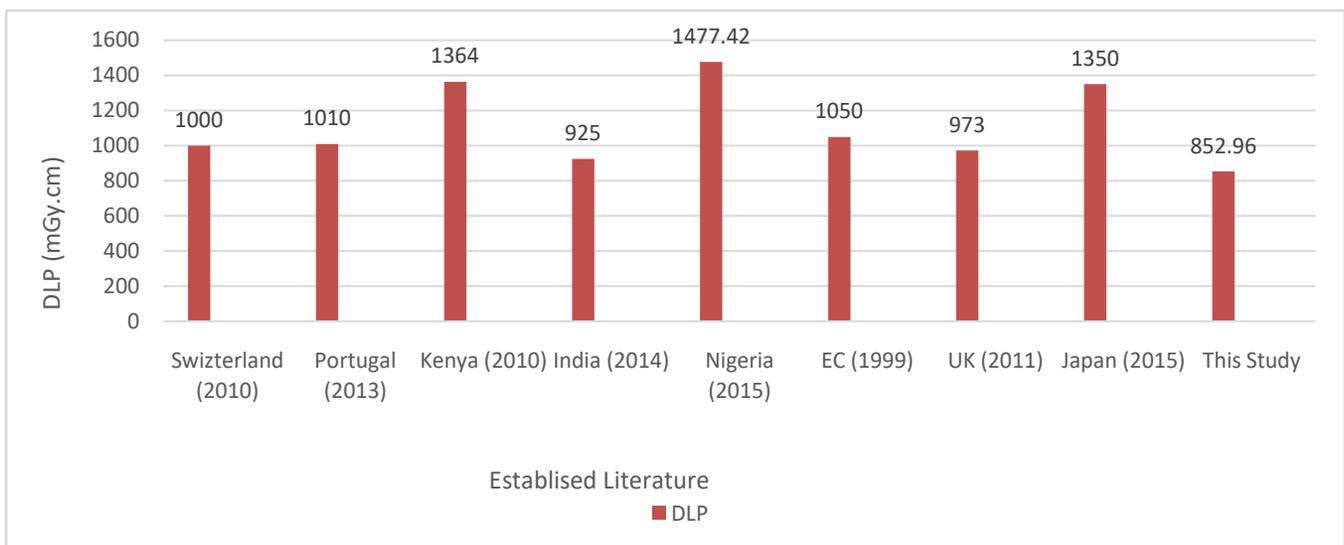


Figure 8. DLP (brain) for other established work compared with this study.

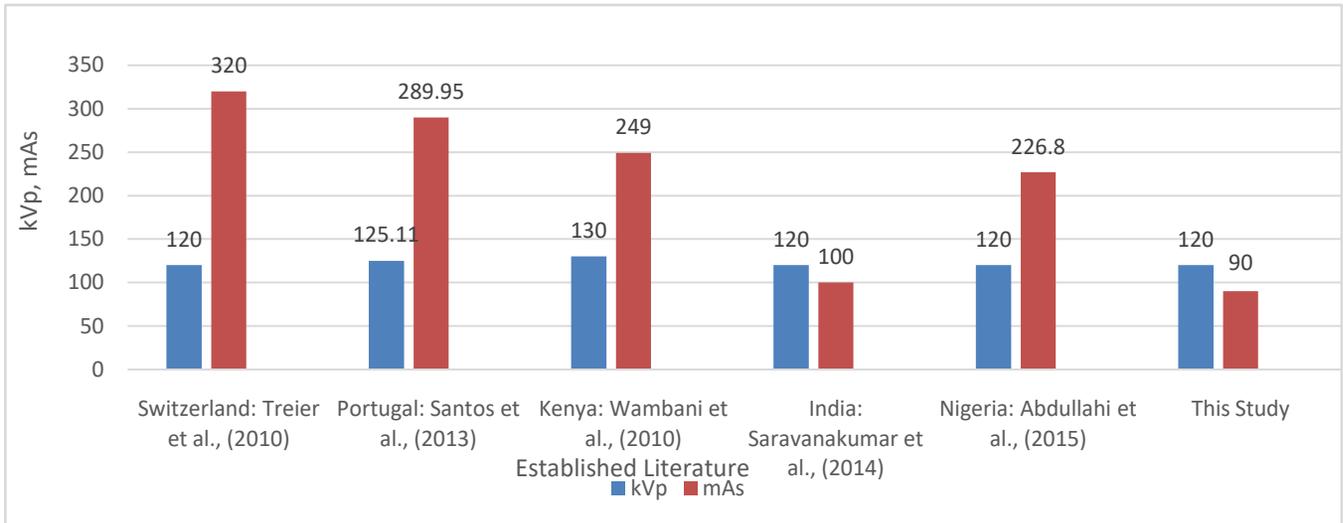


Figure 9. kVp and mAs (brain) of this study compared with other published literatures in other countries.

Table I. Table showing results for CT calibration procedure

ACQUISITION MODALITY							READING AT THE CENTER				
MODALITY	Sec	Kv	mA	Thickness (mm)	FOV (mm)	Matrix	Modality	Measurement 1	Measurement 2	Measurement 3	
Head Standard (S&S)	1	120	200	8	240 (S)	512	Head Standard (S&S)	27.4	28.3	29.6	
Body Standard (S&S)	0.5	120	250	32	400 (L)	512	READING AT POSITION 3 (3 O'CLOCK)				
READING AT POSITION 12 (12 O'CLOCK)							Modality	Measurement 1	Measurement 2	Measurement 3	
Modality	Measurement 1	Measurement 2	Measurement 3				Head Standard (S&S)	45.7	46.85	47.1	
Head Standard (S&S)	45.6	46.9	47.2				READING AT POSITION 6 (6 O'CLOCK)				
READING AT POSITION 9 (9 O'CLOCK)							Modality	Measurement 1	Measurement 2	Measurement 3	
Modality	Measurement 1	Measurement 2	Measurement 3				Head Standard (S&S)	45.6	46.9	47.2	
Head Standard (S&S)	45.7	46.9	47.1				CALCULATION FOR MEAN VALUES				
	CTDI <sub>w</sub>	nCTDI <sub>w</sub>					Calculation	Center (mean)	1/3 C	Periphery (mean)	2/3 P
Cranio Standard (S&S)	50.66	0.25					Cranio Standard	28.43	9.47	46.56	31.06
Therefore: CTDI <sub>vol</sub> = 50.65686 (Tolerance ± 20%)											

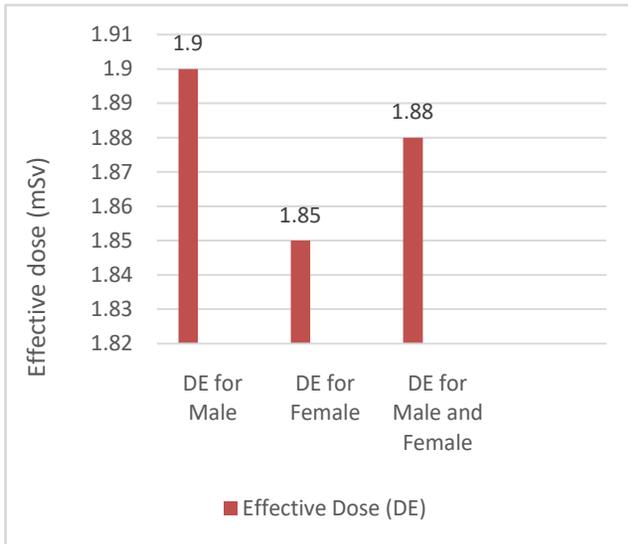


Figure 10. Effective dose (brain CT) for male, female, and both male and female patients.

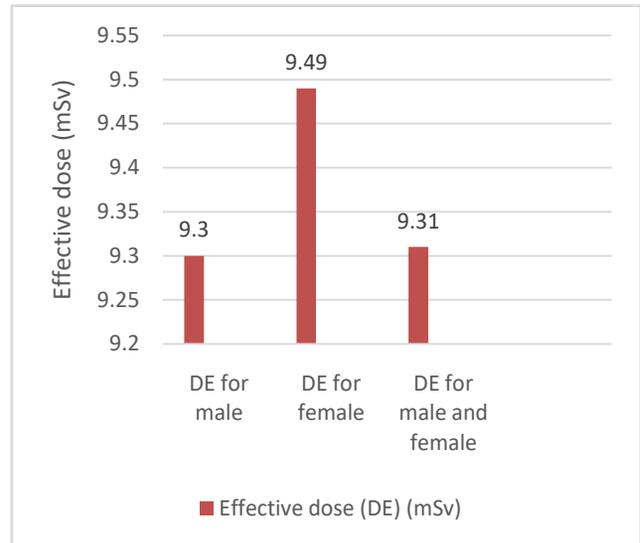


Figure 13. Effective dose (chest) for male, female and for both male and female patients.

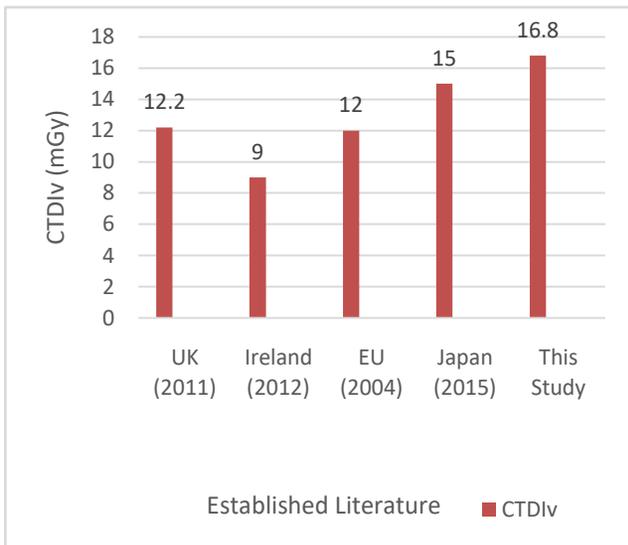


Figure 11. CTDIv (chest) for other established work compared with this study.

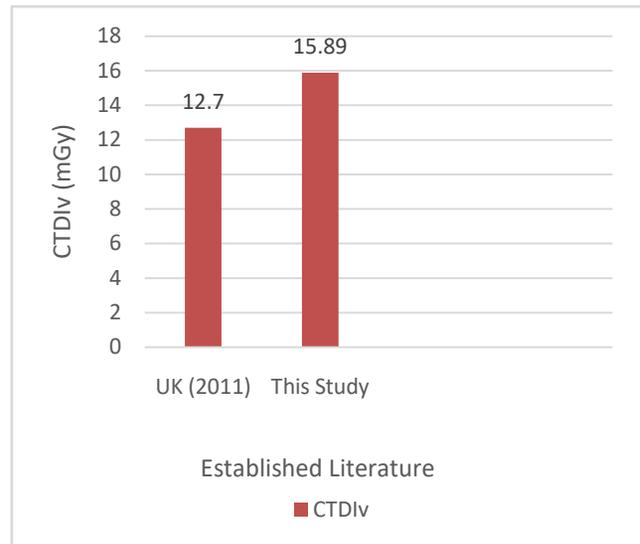


Figure 14. CTDIv (urogram) for other established work compared with this study.

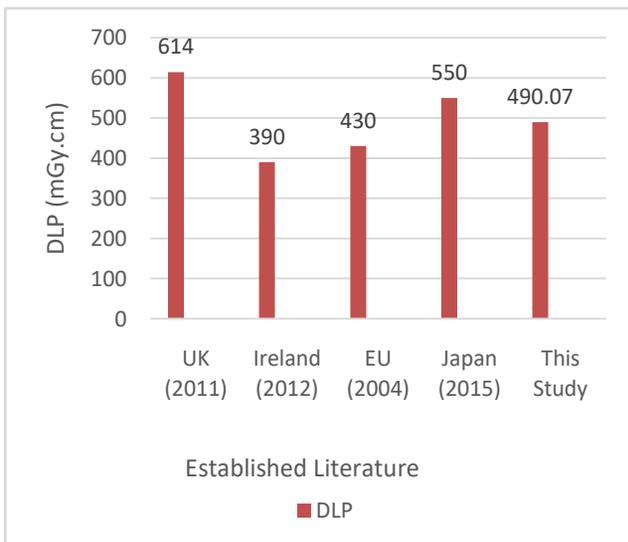


Figure 12. DLP (chest) for other established work compared with this study.

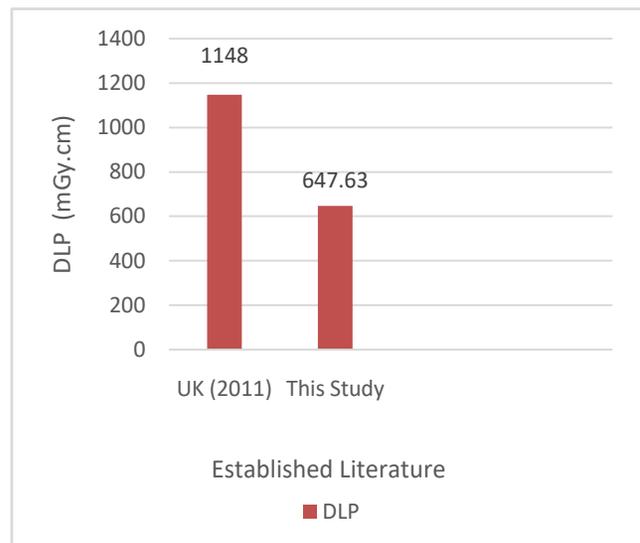


Figure 15. DLP (urogram) for other established work compared with this study.

## Conclusion

The study has established the local diagnostic reference levels (LDRLs) for various CT procedures. Even though, this study is not a general representative of CT practices within the country, it is an indication that a considerable optimization potential of CT practice through the standardization of imaging protocols is necessary in Nigerian hospitals. Compared with other imaging modalities using x-rays, radiation doses from CT are relatively high [13] and often approach or even exceed the values known to increase the probability of cancer formation [14]. Also, effective dose to some organs were calculated in this study and the study revealed that the effective dose to female patients were comparably higher to estimated dose to male patients. The high dose received by the patients in this study is attributed to variation in technical parameters, clinical procedures, radiographic technique, untimely quality control program and perhaps the condition of the CT machine.

## Recommendations

The following recommendations are proposed towards a better research:

- (i) Adequate education and training should be given to CT personnel especially radiographers on factors that affect patient dose, image quality, optimal selection of scanning parameters, and careful selection of the anatomical region to be scanned and the extent of the scan with and without contrast.
- (ii) A process of continuous audit to optimize CT scanning is recommended, which can guide CT centers in the appropriateness of their own scanning parameters and help avoid unnecessarily high doses being delivered.
- (iii) A National diagnostic reference level assessment is urgently required in identifying potentially unusual practice.

## Abbreviations

AEC: Automatic exposure control; DLP: Dose length product; DRL: Diagnostic reference level; FOV: Field of view.

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## Author Contributions

OAE, AMO, EJC and AMA contributed equally to this article. All authors gave their final approval.

## Competing Interests

The authors have declared that no competing interest exists.

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