ORIGINAL ARTICLE

Diagnostic Reference Level of Radiation Dose and Image Quality of Adult CT Abdominal Examination Based on Body-mass Index (BMI) in a Tertiary Hospital in Malaysia

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ABSTRACT

Introduction: Computed tomography (CT) ionising radiation may raise the risk of deterministic consequences and cancer development to the patient. Objective of this study is to determine the updated local DRL of adult CT abdominal examinations using a noise index to indicate the image quality. **Materials and methods:** A retrospective analysis was conducted on 200 adult patients who underwent CT abdominal examinations between January 2021 and December 2022 and categorised into three body mass index (BMI) groups; group 1, underweight (<18.5), group 2, overweight (≥25.0) and group 3, obese (≥30.0) and statistically compared the radiation dose exposure. The noise magnitude was quantitatively calculated by measuring the standard deviation of the circular region of interest (ROI) at five different locations around the abdominal area. The volume-weighted CT dose index (CTDIvol), the dose-length product (DLP), and the effective dose (E) were computed for each BMI group, and DRLs were established with a 50th percentile set. **Results:** The highest radiation dose for CTDIvol, DLP and E was in group 3 (obese) with mean 15.44 ± 5.43, 769.78 ± 253.25 and 15.37 ± 4.74 respectively. Both DRL and noise reference levels between BMI groups have differed significantly with p-value < 0.05 and <0.70. **Conclusion:** Patients with varying BMIs had significantly variable radiation doses and noise intensities, necessitating the adjustment of some parameters to satisfy the clinical requirement.
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INTRODUCTION

Computed tomography (CT) can contribute up to 75% of the effective dose administered to the general public in developed countries, and its share is increasing rapidly over time. To help diagnose patients and obtain useful information about diseases, CT has become essential in clinical practice. However, individuals may experience adverse consequences from extremely high radiation exposure, which raises the risk of cancer. Ionising radiation, which can damage DNA and induce mutations and chromosomal abnormalities. An estimated 72 million CT operations were carried out in the US in 2007; these treatments led to 29,000 radiation-induced malignancies, solid tumors, and leukemia, with CT procedures making up 2.0% of all malignant tumors at the moment (1).

Several optimization strategies have been introduced to protect patients from the various aspects that impact radiation dose (6 - 9) In keeping with the as low as reasonably achievable (ALARA) principle, recent technological developments and innovations have contributed to a notable reduction in radiation dosage exposure. The optimization procedures must yield high-quality images to guarantee that physicians can accurately diagnose patients and develop a successful treatment plan. Recently, an automated method for determining the degree of noise in CT pictures was developed to aid the ongoing enhancement of CT protocols (10). They introduce the idea of global noise level which characterizes the most prevalent noise level in homogeneous tissue regions. To be more precise, the global noise level provides a dependable, automated method for determining CT noise levels in quality control projects. Combining the global noise level with additional automated characterizations of imaging performance may offer a good platform for standardizing and optimizing the CT process. Ensuring that optimization is implemented to maintain image quality at the appropriate radiation dose is beneficial. One of the most promising methods for attenuating a patient's radiation dose is automatic tube current modulation (ATCM). It is possible to optimise the CT dose for the abdominal regions of the patient by varying the tube current along their Z-axis (11). It has been acknowledged that the recently established optimised technique, which includes tube potential adaptation with dual-energy imaging protocol or monoenergetic algorithm, and current modulation along the X and Y-axes, greatly reduces the CT dose (11, 12). In the meantime, the US-made General Electric CT scanner manually sets the noise index (NI) according to the patient's body size (13). Alternatively, the ATCM could decrease radiation exposure for small patients or increase it for large patients to provide a constant image quality of the patient. As a result, the radiologists' worry about getting images that the ATCM system would accept for diagnosis has mainly been allayed (14 - 16).

In 1990, to facilitate more research for optimisation, the International Commission on Radiological Protection (ICRP) underlined the need to establish the diagnostic reference level (DRL) (17 - 19). The DRL acts as a benchmark for dose monitoring since it can show whether an exposure is deemed excessive compared to other medical facilities in the area. The CT dose length product (DLP) and CT dose index volume (CTDIvol) are the standard quantities to publish the DRL in CT examinations. However, a false understanding of the DRL has been frequently used in medical facilities. It has been erroneously believed that the DRL, independent of patient size and therapeutic indications, is the threshold dose (17, 20, 21). The World Health Organization (WHO), 2018 states that the Body Mass Index (BMI), a simple weight-to-height index, can be used to classify adults as underweight (<18.5), overweight (≥25.0), or obese (≥30.0). The unit of measurement is kg/m2, which is the weight in kilograms divided by the square of the height in meters. Poor optimization has impeded certain CT examinations, especially those involving obese and overweight patients. This has increased the amount of unnecessary radiation exposure by requiring repeat scans. The DRL is a useful clinical tool for groups of patients rather than individuals, and it should only be utilized as a guideline for examining radiation dose optimum levels (21).

The DRL is often set at the median values obtained from many representative centers, at the 75th percentile. It should be mentioned that the DRL values acquired heavily rely on the level of practice used at a particular test or organisation. Apart from the radiation exposure, image quality is an essential component that must be taken into account in each optimization procedure (22, 23).

Generally, smaller patients need less radiation exposure than larger patients to achieve a high-quality image. Integrating the size-dependent DRL with the image quality level is essential to give an optimal technique that works over a wide range of patient BMIs. Therefore, the purpose of this study was to evaluate the dose measures' median values, ranges, and reference ranges in addition to the image quality (noise magnitude) based on BMI and estimate relevant DRLs. The results are compared with CT abdominal procedures in other countries. To create an updated local DRL, this study evaluates image quality and radiation exposure among standard adult CT abdominal examinations.

MATERIALS AND METHODS

Medical Research and Ethics Committee (MREC) of the Ministry of Health Malaysia (MOH) approved this retrospective study without requiring patient consent (approval ID: NMRR-22-01459-7QM; date: September 13, 2022). The Picture Archiving Communication System (PACS) was used to gather data from the Radiology Department at Hospital Pulau Pinang (HPP) between January 2021 and December 2022. This study comprised only CT abdominal examinations performed on adult patients. Those who underwent more than one examination or whose information was insufficient were removed from the data. Three groups based on BMI were created from all of the subjects: underweight (<18.5), overweight (≥25.0), and obese (≥30.0). The patients comprised 200 (88 males and 112 females) who underwent CT abdomen. The guidelines in ICRP Publication 135 served as the foundation for this investigation, stipulating that a DRL in a particular patient category must involve a minimum of 30 individuals. The 128 Slices MDCT CT Scanner, manufactured by Siemens Sector Healthcare in Forchheim, Germany, was utilized for all examinations and OsiriX version 3.8 (Pixmeo SARL, Switzerland) DICOM software was utilised to reconstruct the images.

CT acquisition data collection

CT abdomen examination with media contrast was performed according to the hospital's protocol. Relevant scanning information, including tube voltage (kVp), effective tube current (mAs), rotation time (s), table feed (TF), slice thickness and pitch factor was retrieved via the hospital's Digital Imaging and Communications in Medicine (DICOM) system. Information about dosimetry such as CTDIvol, DLP, and effective dose was taken from the PACS. All CT abdomen examinations were performed using ATCM.

Radiation dose calculation software

The CTDIvol, DLP and effective dose values were evaluated using CT-EXPO software Version 2.3.1 (SASCRAD, Berlin, Germany). Using the tissue weighting factor published in Publication 103 by the ICRP, the tool was also used to calculate the effective dosage (ICRP, 2007). This gave a promising thorough evaluation of the radiation doses from scanner type, manufacturer, and scanning parameters, given by software.

Image quality evaluation

To represent the image quality indicator, the noise value was scientifically assessed using the Radiant DICOM Viewer programme (Medixant, Poznan, Poland). Noise measurement was conducted by positioning the same-sized circular regions of interest (ROI), or approximately 0.7 cm2 on the grey matter area around the abdomen region for CT abdomen images as captured in Figure 1. Standard deviation (SD) and all CT numbers were calculated in Hounsfield Units (HU). Noise in CT is commonly presented as standard deviation, σ and formulated as equation below :

$$SD\ (\sigma) = \sqrt{(\sum(x_{ip} - x_m)^2 / (t-1))}$$

where x_{ip} represents the single pixel value, x_m is the average of all the pixel values in the ROI and t is the total of t pixel amounts in the ROI.

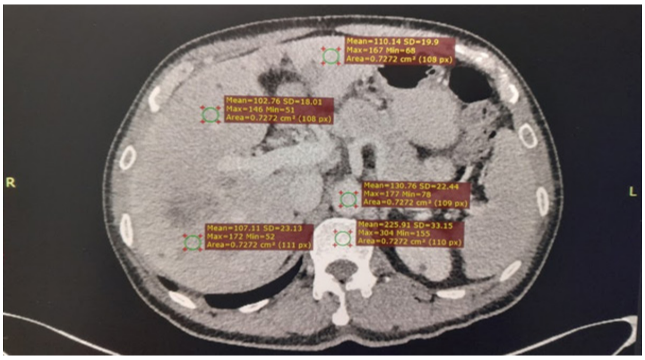

Figure 1: Placement of the circular Region Of Interest (ROI) for the noise magnitude (SD) calculation around the abdomen area.

Data analysis

The data were presented descriptively for each BMI group using the median, mean, range (min-max), and interquartile (IQ) values, according to the protocol followed. To compare with the established DRL from the other study, the 75th percentile was employed. For statistical analysis, all data were input using IBM SPSS Version 25.0 (IBM Corporation, Armonk, New York, USA). Significant variations in radiation doses and noise levels between age groups were identified when $p < 0.05$. The normality of the data distribution was assessed using the Kolmogorov-Smirnov test, and BMI group differences were ascertained using the Kruskal-Wallis H test.

RESULTS

The number of samples obtained was up to 200 adult patients, 44% (n=88) were male and 56% (n=112) were female who underwent CT abdomen examination. Table I displays the data on baseline characteristics including BMI and age according to gender in CT abdomen examination using standard CT abdomen protocol as stated in Table II. The mean age of the patients are 54 ± 15.48 and 53 ± 16; mean BMI 24.55 ± 6.10 and 23.54 ± 6.54 for male and female respectively. The relationship between CTDIvol with BMI in CT abdomen is shown in Figure 2.

Table I: Data on baseline characteristics based on gender

Baseline Characteristic	CT abdomen	
	Male	Female
No. of examination (*n*)	88	112
Body Mass Index (BMI) (kg/m)*	24.55 ± 6.10	23.54 ± 6.54
Age*	54 ± 15.48	53 ± 16

* (mean ± SD)

Table II: Data on the standard scanning acquisition of CT abdomen examinations.

Scanning Parameter	Values
Tube Voltage (kVp)	120
Tube current (mAs)	150
Rotation time	0.5
Range	150
D-FOV	400.4
Slice thickness	5
nHcol	0.5 x 32
Pitch factor	0.8

The scanning parameters shown in Table II are related to image noise and radiation dose received by the adult patients in CT abdomen protocols. The effective tube current (mAs) and tube potential (kVp) of the adult patients varied among BMI groups for CT abdomen examinations.

Figure 2: Correlation between CTDIvol (mGy) and Body Mass Index (BMI) group in adult CT abdomen examination.

The mean of CT abdomen radiation dose exposure measurements were listed in Table III. The highest radiation dose for all dose descriptors CTDIvol, DLP and E was in group 3 (obese) with mean 15.44 ± 5.43, 769.78 ± 253.25 and 15.37 ± 4.74 respectively. Patients in the G2 and G3 body size groups typically received high voltage and high tube current. Conversely, the majority of patients in the underweight category (G1) had the lowest exposure values.

Table III: Exposure dose distribution of CT abdomen examinations

Dose Descriptor / BMI Group	Group 1 (<18.5)	Group 2 (≥25.0)	Group 3 (≥30.0)
No. of examinations (n)	28	80	92
CTDIvol (mGy) *	9.08 ± 3.35	10.21 ± 6.81	15.44 ± 5.43
DLP (mGy.cm) *	366.41 ± 102.35	509.90 ± 217.51	769.78 ± 253.25
Effective Dose (mSv) *	7.37 ± 2.40	11.65 ± 5.02	15.37 ± 4.74

* (mean ± SD)

Table IV provides descriptive statistics for the noise magnitude in this study. Overall, the noise magnitude surrounding the abdomen area was in the range of 14.90 to 37.36 HU. The median and mean noise magnitudes respectively range from 22.16 to 24.11 HU and 24.58 to 25.51 HU.

Table IV: Noise magnitude measurements according to the BMI groups

Examination / BMI Group		CT Abdomen		
		G1	G2	G3
No. of examinations (n)		28	80	92
Noise Magnitude (HU)	Range	22.46–30.81	18.17–35.46	15.90–37.36
	Median	23.27	22.16	24.11
	Mean	25.51	24.58	24.96

G1 = <18.5; G2 = ≥25.0; G3 = ≥30.0

Table V shows the relationships between Diagnostic Reference Level (CTDIvol) and Noise Reference Level (HU) values for different BMI groups. The values ranged from 6.33 to 21.52 mGy and 23.78 to 24.96 HU for all data involved. Between different BMI groups, radiation dose ranged from 4.63 – 7.65 (G1), 6.23-11.60 (G2) and 13.72-25.36 (G3) while noise ranged from 20.39-28.28 (G1), 21.72-28.66 (G2) and 22.12-28.78 (G3). The local DRL is found significantly different within different BMI groups ($p<0.05$) while not significant for noise reference level ($p<0.70$).

Table V: Local DRL and noise reference level

BMI Group *	CT Abdomen		
	G1	G2	G3
No. of examinations (n)	28	80	92
DRL (mGy)	6.33	8.55	21.52
Diagnostic Reference Range (mGy)	4.63-7.65	6.23-11.60	13.72-25.36
Noise Reference Level (HU)	23.78	24.56	24.96
Noise Reference Range (HU)	20.39-28.28	21.72-28.66	22.12-28.78

*Median value

Table VI presents a comparison of the 75th percentile of the CTDIvol and DLP analysis with other local and international adult abdominal DRL examinations. Comparing the current study to the other studies, the CTDIvol and DLP were the lowest at 9 mGy and 450 mGy.cm, respectively (27, 34 - 38). DLP value was similar to Malaysian DRLs. Nigeria (2023) found the highest value for both CTDIvol and DLP followed by Sudan (2020), Uganda (2022), Australia (2020), Ireland (2014) and Malaysia (2013).

Table VI: Comparison of CT abdomen DRLs with other studies.

Established CT abdomen DRLs	Dose descriptor	
	CTDIvol (mGy)	DLP (mGy.cm)
This study	9	450
Malaysian DRLs (2013) [27]	12	450
Nigeria (2023) [35]	16	2723
Uganda (2022) [37]	12	1418
Sudan (2020) [36]	13	1331
Australia (2020) [38]	13	600
Ireland (2014) [34]	12	600

DISCUSSION

Dose survey data has been established by both developed and developing countries as a basis for creating their DRLs in medical imaging techniques. (21 - 23). This study proposed a unique method for determining the local DRL for an adult CT abdomen examination using noise magnitude as the measurement of image quality. A DRL could be a helpful instrument to ensure high-quality images and reduce the CT examination radiation doses (25 - 27). In May 2013, the Medical Radiation Exposure Report published by the Malaysian Ministry of Health established DRL for radiological procedures including CT scan procedures. However, because there is so little data and the DRL is so old, it is still incomplete, especially for adult patients (27). To narrow the gap, this study assessed the noise of image quality and radiation dose of adult CT abdomen from a single medical facility to create updated local DRLs for adult CT abdomen patients.

All of the dose descriptors (CTDIvol, DLP and E) in Table III significantly increased as a result of the use of ATCM in CT abdomen, as the patient's BMI increased. The radiation dose would increase with a larger tube potential because it would produce an X-ray beam with a higher frequency (28). X-rays were attenuated more severely while passing patient's bodies that have higher BMI. Thus, at a given level of X-ray exposure, the quantity of X-ray photons reaching the CT detector was reduced, amplifying image noise. So we can see from the noise magnitude measurements according to the

BMI groups in Table IV stated that the noise range more higher in the obese group 15.90–37.36 HU compared to the underweight and overweight groups. To maintain image quality in a large patient, more radiation exposure is necessary. The tube current (mAs) determines how much of an X-ray is produced.

As recommended in ICRP 135, this study presents the need for incorporating noise reference levels to determine the local DRL. A new concept for DRLs in an abdominal CT examination was first applied, according to a recent study by Ria et al., 2019. Larger patients had higher radiation exposure, but the ATCM system controlled the tube current, resulting in a generally stable trend in noise magnitude. ATCM automatically modifies the tube current by evaluating the image section's attenuation strength primarily using the localizer image. ATCM aids in radiation dose optimisation by modifying radiation exposure for each patient based on the strength of attenuation. Therefore, in patients of different sizes and BMI, the current CT abdomen techniques could result in a consistent image quality.

Diagnostic procedures are based on the foundation of CT optimization and justification based on radiation protection principles. To guarantee that CT examinations are safe to conduct, radiographers, radiologists, medical physicists, and CT scanner manufacturers have responsibilities. Recent research indicates that technological developments have enhanced CT scanner DRLs and decreased noise magnitude (20). Therefore, when the patient's radiation dose has significantly varied due to technological improvements, the establishment of CT scanner-dependent DRLs is relevant. Comparing newer CT scanner models to older versions, the iterative reconstruction algorithm may offer better image quality at a lower radiation dose (4, 29, 30). As a result, whenever medical facilities replace their older CT scanner models with the newest models available, the DRL needs to be regularly examined. Every DRL ought to be utilized exclusively with the precise CT scanner generation on which it was designed.

This study had the lowest CTDIvol and DLP values among comparable published studies, which can be attributed to some variables. The analysis only includes information from a single institution and one CT scanner model, a high-end model with 128 slices. Other research, meantime, used models of CT scanners and several institutions. Different radiation outputs and DRLs were created by several CT scanner models with differing acquisition techniques and technological breakthroughs. As shown in Table VI, this study's median CTDIvol and DLP values were compared to DRL data from research conducted in other countries (27, 34 - 38). The DLP value had been slightly lower than the other established reference. This difference might result from using a different CT scanner manufacturer, changing the CT scanning parameter settings and selecting between axial and helical acquisition scanning modes. Regardless of the type of CT scanner, this argument demonstrates the necessity of providing the CT scanner-dependent DRLs rather than compiling all the dose report data to create DRLs as a standard procedure.

Theoretically, pitch factor might be changed to control scanning; as pitch factor increased, patients' CTDIvol would decrease, but image quality would degrade (31, 32). But for high-end MDCT scanners, like second or third-generation dual-source CT scanners, a high temporal resolution ensures a respectable diagnostic performance even with a high pitch factor (33). A larger beam collimation range was intended to be covered by modern CT scanners with each revolution of the CT X-ray tube. By doing this, the patient's radiation exposure and scanning time would be shortened without sacrificing image quality. The patient's scan range and length were key determinants of the DLP's value; an increase in either would likewise raise the DLP.

This study was subject to certain limitations. Only one type of examination and population were used to limit this investigation. To build an all-inclusive set of DRLs, future research should aim to include other types of CT scan examinations and other groups of population in other institutions. Furthermore, this research only used the CT scanner from one manufacturer to calculate the DRL; so, it was not possible to account for the differences in performance between models made by different manufacturers or the developments in technology. This study only measures data at one study center, hence it cannot represent a trend in radiation dose exposure in other establishments with different CT abdomen procedures, CT abdomen practices, CT equipment, and scanning parameters. Only image noise parameters were assessed in image quality evaluations in this study. Future research should take into account other parameters as the indicator of image quality assessment and also include subjective image quality assessment. With all of these limitations, this study's findings could still be useful in optimizing radiation exposure in nearby facilities while waiting for more research on the creation of thorough DRLs by the local government.

CONCLUSION

The radiation dose and image noise were different among patients with different BMI and might be a requirement to establish DRLs for specific BMI groups. According to the ALARA principle, DRLs have been acknowledged as an important instrument for optimising the radiation dose to patients. The DRL levels that have been observed here are lower than those that have been documented in other countries. Therefore, the new data on noise reference level and the radiation dose from this study may serve as a useful guide for optimizing adult CT abdomen examination.

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