ORIGINAL ARTICLE

Institutional Diagnostic Reference Level for CT Thorax in a University Hospital

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ABSTRACT

Introduction: Pandemic of COVID-19 in 2020 has seen the rise of computed tomography (CT) thorax as the gold standard modality. CT exposes patients to the highest radiation; hence, routinely assessing dose optimisation is essential. This study conducted to establish a diagnostic reference level (DRL) for CT thorax in an institution and assess conformity to the established national standard. In this study, the values weighted CT dose index (CTDIw), CT Dose index volume (CTDIv) and dose length product (DLP) were collected and correlated to the patient's age, body mass index (BMI) and values were compared between genders. DRL in CTDIw and DLP were presented as 75th percentile as suggested by ICRP. **Materials and methods:** Patient data and dose related to CT thorax (N = 83) were collected retrospectively through system from December 2022 until May 2023. **Results:** The institution dose presented 12.93 mGy for CTDIvol, 7.63 mGy for CTDIw and 553 mGy.cm for DLP. DLP value in this study slightly higher by 21% and CTDIw were significantly lower by 64% compared with MOH Malaysia. There is significant correlation between CTDIw and DLP with BMI which suggesting that the higher the patient's BMI, the higher the CTDIw value. Subsequently, there is no significant different between genders (P > 0.05). **Conclusion:** The DRL value suggested for this institution are within the national and international level. The requisite for further dose optimisation for CT thorax according to the patient's demographics to reduce the feasible stochastic effects and application of ALARA concepts to the patients.

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Keywords: Body mass index, Effective dose, Weighted CT dose index, Diagnostic reference level, Dose length product

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INTRODUCTION

The utilisation of multi-detector computed tomography (MDCT) has increased globally due to recent advancements and its improved diagnostic capabilities (1). The rapid development of MDCT technology has significantly increased the use of and importance of CT applications. Most significantly in recent years, because of the global COVID-19 pandemic (2) computed tomography (CT) scanning has been identified as the main contributor to the total effective dose compared to other imaging modalities. Studies has shown that CT scans account for 49–68% of the total radiation exposure from diagnostic radiology procedures (3-5).

CT thorax is one of the preferred diagnostic tools to detect COVID-19 due to its ability to form a 3-D view of organs and its efficiency and accuracy in classifying images of infected patients (6). however, repetitive CT scan examination potentially leads to radiation-induced cancers . Therefore, it is crucial to reduce excessive variability in examination methods and limit exposure to medical imaging (7).

The International Commission on Radiation Protection (ICRP) has published suggestions for optimising, justifying, and limiting the radiation dose of CT imaging to prevent its advantages from outweighing the hazards. Implementation of diagnostic reference level (DRL) has been demonstrated to be a powerful tool for identifying unusually high patient doses from radiological examinations (7).

DRL was first introduced by the ICRP in 1991, with detailed recommendations on managing patient dose in CT in 2000 (8). Since then, DRL has been widely accepted by many professional and regulatory organizations as a criterion for radiation protection of patients and optimization of radiologic procedures

(9). DRL is typically set as the third quartile (i.e., 75th percentile) of dose distribution sampled from the actual practice data representing the upper thresholds of dose levels used for a patient of average body size (10). These levels are not absolute limits; however, they are not expected to be exceeded when good practice is applied. The DRL is established based on available survey data. The reference values must be defined in terms of reproducible dose metrics for each imaging modality.

CT exams determine DRL based on two technical factors: Computed Tomography Dose Index Volume ($CTDI_{vol}$) and Dose Length Product (DLP) (11). The $CTDI_{vol}$ is a measure of the average dose received each slice, whereas the DLP indicates the total energy absorbed across the whole length of the scan and is calculated by multiplying the $CTDI_{vol}$ by the scan length (12). There is currently a discussion about whether patient size, age, and weight or clinical indication should be utilised as a patient parameter for determining diagnostic reference levels (DRLs). According to J∆rvinen H. et al. (13), most surveys have utilised average-sized patients to establish diagnostic reference levels (DRLs). This is because the size of the patient is a crucial factor in determining the appropriate quantity of radiation needed to obtain satisfactory image quality for a particular imaging examination.

However, the document produced by MOH Malaysia in 2013 is uses $CTDI_w$ as a reference level. $CTDI_w$ is to quantify the average CTDI over a specific axial portion of a cylindrical phantom. This concept was introduced in 1995 but not typically used as a sole reference in the establishment of DRL due to limited representation. $CTDI_w$ only displays the dose index averaged over a specific length of the CT scan and does not account relationship between individual variations and dose present.

This institution has yet to establish a local DRL for CT thorax examinations which may lead to inconsistent imaging practices and potential overexposure. Additionally, the lack of a standardised reference level makes it challenging to optimise radiation doses across similar procedures within the institution. Therefore, this study seeks to fill this gap by proposing a tailored DRL to ensure doses delivered to patients for CT thorax are optimised to reduce the viable carcinogenic effect on radiosensitive organs such as the thyroid, breast, and lungs while ensuring the production of diagnostically acceptable images.

Establishing a local DRL also allows for updated dose management, aligning with local clinical needs and equipment performances (9). It is a crucial tool for optimising and managing radiation doses by identifying unreasonably high or low patient doses and providing guidelines for the average dose for the specific imaging procedure. Appropriate information on DRL must be assessed to ensure that current CT imaging practice adheres to the ALARA (as low as reasonably achievable) principle. Additionally, the DRL and $CTDI_{vol}$ obtained will be correlated to patients' age and BMI, and these findings can be used as a reference for radiographers in the future when selecting the scanning parameters for patients of different sizes and age groups.

MATERIALS AND METHODS

Study Design

The research design is a retrospective cohort study conducted at the Department of Radiology in a university hospital between January 2023 and August 2023. The radiation dose data were extracted from the PACS, which are, $CTDI_{vol}$, DLP , tube potential (kVp), and effective tube current (mAs). The study was approved by Research Ethical Committee of the Faculty of Health Sciences, UiTM Puncak Alam (FERC/FSK/MR/2023/00107) and adhered to the Declaration of Helsinki 1964. The study also received permission from the Department of Research, Innovation, and Industrial Linkages Hospital: 500-PJI (18/4/67).

Sample Size

Raosoft sample size calculator software is used to calculate the sample size for the actual population. The estimated population size of this study is 193 patients from December 2022 until May 2023 in the selected setting. The calculation was based on a 50% response distribution, 5% margin of error and 95% confidence interval. A sample size of 129 has been recommended as the minimum sample size. However, only a total of 83 patients' data were able to be collected. This includes patients who underwent CT thorax examination without contrast , regardless of gender and recorded body mass index (BMI) information, and those aged between 18 to 60 years old. Different BMI were collected due the relation of radiation penetrations to body tissue.

Data Collection

Patients' data (N=83) were retrieved from the Picture Archiving Communication System (PACS) via INFINITT Healthcare Version 3.0.11.5. The related radiation dose data for example $CTDI_{vol}$, DLP, kVp and mAs were extracted from the PACS. The data collection sheet was prepared using Microsoft Excel 2013, which includes patient demographic information, CT technical parameters and doses to facilitate data collection uniformly and assist in data analysis.

CT Dose Index Calculation

The $CTDI_{vol}$ and the DLP are important measurements used to assess the amount of radiation dose received during computed tomography CT scans. CTDI value reflects average dose within the scanned volume of tissue while DLP is an estimation of the total radiation dose which combines the $CTDI_{vol}$ with the scan length, giving a cumulative dose for the entire scan. It's measured in milligray-centimeters (mGy.cm). DLP helps estimate the overall radiation burden, which can be converted to an approximate effective dose by applying body-region-specific conversion factors. These measures are essential for maximising patient safety and guaranteeing the correct radiation dosage levels in CT imaging operations (14).

In this study, there are three measurement unit included. First, $CTDI_{vol}$ is particularly relevant for helical (spiral) CT scans, where the dose distribution can be more complex compared to traditional axial scans. Equation as below

$$CTDI_w \times \left(1 + \frac{z}{2 \text{ x pitch}} \right) \quad (11)$$

Where:
$CTDI_{vol}$: CTDI volume.
$CTDI_w$: CTDI weighted (measured using a standard CTDI phantom and dosimeter).
Z : distance along the z-axis (in cm) over which the dose is integrated.
pitch : pitch factor of the helical scan, defined as the table increment per rotation divided by the total collimation width.

While for $CTDI_w$ measurements are typically taken at multiple positions along the longitudinal axis of the CTDI phantom, and the average CTDI value is calculated to obtain the $CTDI_w$. The equation as below

$$CTDI_w \times \frac{1}{n} \sum_{i}^{n} = 1 \ CTDI_I \quad (11)$$

Where:
$CTDI_w$: the CTDI weighted.
ɳ : the number of measurements (usually along the longitudinal axis of the phantom).
$CTDI_I$: the CTDI value measured at each position ii along the phantom.

Lastly DLP is obtained by multiplying the average dose measured at each point by the total length of the scanned volume. The integrated dose measurements over the entire length of the scan are summed together to calculate the DLP.

$$\sum_{i}^{n} = 1 \ D\iota \text{ x } L\iota \quad (11)$$

Where:
DLP: the dose length product.
n : the number of dose measurements taken along the length of the scan.
Dι : the average dose measured at each point.
Lι : the length of the scan at point

The calculated DLP value is typically displayed on the CT scanner console and included in the scan report. It provides clinicians and medical physicists with important information about the radiation dose delivered to the patient during the CT scan.

Data Analysis

Data was analysed and interpreted using the Statistical Package for the Social Sciences (SPSS) version 28.0 (IBM Corporation, Armonk, NY, USA) and Microsoft Excel 2013. The study variables are summarised and reported using descriptive statistical analysis and expressed as mean (± standard deviation). Statistical significance is set at alpha <0.05. The dosage distribution at 75th percentiles was computed and compared to the DRL by Ministry of Health Malaysia using percentage difference. The Spearman correlation coefficient was used to assess the correlation between radiation doses with patients' BMI and age. As for the comparison of dose values between males and females, a non-parametric Mann-Whitney U test was conducted. All statistical tests are set at a confidence interval of 95%. Then, the 75th percentile value of procedures was compared with the established DRL.

RESULTS

Demographic characteristic

Table I showed a total of 47 (56.6%) female and 36 (43.4%) male patients with the mean age were included in this study. Patients' BMI in this study was divided into four groups. This study was chosen international BMI guidelines owing to broader comparability across diverse population in other countries. The highest percentage was in normal (between 18.5 – 24.9) BMI groups, which contributed 59% in this study. A total of 60 patients from age groups more than 45 years contributed 72.3%.

Table I: Demographic Data of CT thorax patients

	Frequency	Percentage
Demographics	n = 83	
Gender		
Male	36	43.3
Female	43	56.6
BMI groups		
Underweight	6	7.2
Normal	49	59.0
Overweight	19	22.9
Obese	9	10.9
Age groups		
18 - 30	8	9.6
31 - 45	15	18.1
>45	60	72.3

Comparison of DRL at Institutional, National and International level

The suggested measurement to measure diagnostic CT scans set up by MOH Malaysia for CT thorax is CTDI$_w$ and DRL and the derived quantity is effective dose, E in mSv. The guidelines outlines in this document are based on 75th percentile (third quartile) recommended by ICRP. Based on Table II, the institution dose presented is CTDI$_w$ is 7.63 mGy and DLP is 533 mGy.cm.

Table II: Mean and percentiles for CT Thorax

Statistics	DLP (mGy.cm)	CTDIv (mGy)	CTDIw (mGy)
Mean	377.59	9.57	5.74
25th percentile	233	5.85	3.5
50th percentile	359	9.33	5.6
75th percentile	533	12.93	7.63

According to Table III DLP value in this study marginly elevated 21% than value suggested by MOH (Table III). Among international values, Switzerland reported the lowest DLP at 250 mGy·cm, while Japan recorded the highest at 510 mGy·cm. The calculated CTDI$_w$ notably lower than national reference standard, showing a total difference by 64%. Meanwhile, the CTDI$_{vol}$ measured in this study was 12.93mGy which in between with lowest and highest international values. Singapore reported the lowest CTDI$_{vol}$ at 7 mGy, while Thailand recorded the highest value at 18 mGy.

Table III: National and International dose values

Study	CTDI$_v$ (mGy)	CTDI$_w$	DLP (mGy.cm)
This study, 2023	12.93	7.63	533
Malaysia, 2013		21.3	420
Switzerland, 2019	7		250
Germany, 2016	10		350
France, 2018	10		350
USA, 2017	12		443
United Kingdom,2022	8.5		290
Australia,2021	10		390
Thailand, 2022	18		417
Japan, 2020	13		510
Singapore, 2022	7		295

Correlation of Radiation Doses with Patients' Age and BMI

Spearman correlation was chosen to assess the correlation of radiation dose (DLP, CTDI$_w$ and CTDI$_{vol}$) with the patient's BMI and age. Table IV showed a significant positive and strong linear correlation between CTDI$_{vol}$, CTDI$_w$ and BMI (rs= 0.803, P = <0.001), suggesting that the higher the patient's BMI, the higher the CTDI$_w$ value, leading to more significant radiation dose received by patients. Contrarily, CTDI$_w$ and age variables have a negative and weak correlation with rs = -0.076 and the P value of 0.495.

Table IV :Correlation between dose values and Patients' BMI and age (N=83)

Variables	BMI	Age
DLP	0.577[a]	-0.172[a]
	<0.001[b]	0.119[b]
CTDI$_w$	0.803[a]	-0.076[a]
	<0.001[b]	0.495[b]
CTDI$_v$	0.803[a]	-0.076[a]
	<0.001[b]	0.495[b]

[a] Spearman correlation coefficient, r$_s$

[b] P-value

Meanwhile, the strength of association between patients' BMI and DLP is moderate at 0.577, and it is significant as the P value is less than 0.05 (<0.001). Consequently, the null hyphothesis is rejected indicating a significant association between DLP and patients' BMI. Furthermore, an insignificant negative correlation was observed between DLP and patients' age (rs = -0.172, P = 0.119), suggesting an inverse relationship between the two variables.

Table V shows mean, minimum and maximum radiation dose output for all four BMI groups. The prevalence of trends associated with BMI demonstrates a progressive escalation from underweight to obese classifications. These observed trends indicate that a rise in BMI correlates with a heightened quantity of radiation exposure experienced by patients.

Table V: Mean, Minimum and Maximum of dose received according to BMI

	BMI	Mean	Minimum	Maximum
DLP	Underweight	159.75	115.70	195.00
	Normal weight	336.80	131.50	599.00
	Overweight	477.24	307.00	893.00
	Obese	534.51	367.00	709.40
CTDI$_w$	Underweight	1.317	0.20	2.88
	Normal weight	4.627	1.50	8.20
	Overweight	7.901	4.96	10.61
	Obese	10.21	7.76	14.19
CTDI$_v$	Underweight	2.193	0.30	4.80
	Normal weight	7.710	2.56	13.66
	Overweight	13.17	8.26	17.68
	Obese	17.02	12.93	23.65

In summary, patients' BMIs are significantly and strongly correlated with CTDI$_w$ (rs=0.803) and CTDI$_{vol}$ (rs=0.803) and moderately with DLP (rs=0.577) suggesting that obese patients receive larger doses of ionising radiation compared to those that are underweight. For age, there are negative and weak correlation exits for all the components tested.

Comparison of Radiation Doses Between Patients' Genders

An Independent t-test, a parametric test, were used for

$CTDI_w$ and $CTDI_{vol}$ variable, while a non-parametric, Mann-Whitney U test was carried out for DLP to assess the difference in the dose values between male and female patients.

The mean difference between $CTDI_w$ received by male and female patients are not statistically significant (p=0.51, 95% CI -0.74,1.76) similarly to the mean difference between $CTDI_{vol}$ received by male and female patients are not statistically significant (p=0.85, 95% CI -1.23,2.94). Thus, the null hypothesis failed to be rejected (Table VI).

Table VI: Comparison of dose value ($CTDI_w$ and $CTDI_v$) according to gender

Variable	Male (N=36) Mean (SD)	Female (N=47) Mean (SD)	Mean diff. (95% CI)	t-stats (df)	P value
$CTDI_w$	6.03 (2.40)	5.52 (3.14)	0.51 (-0.74, 1.76)	0.81 (81)	0.417
$CTDI_v$	10.06 (4.00)	9.21 (5.22)	0.85 (-1.23, 2.94)	0.81 (81)	0.418

Although for DLP, Table VII shows that there is no significant difference in DLP value between male (Median=352.4, N=36) and female (Median=379.0, N=47) patients undergoing CT thorax, and gender has little to no effect on the determinant of the DLP value (Z=-0.427, P=0.669, r=0.047). Hence, the null hypothesis is supported.

Table VII: Comparison of DLP received according to gender

Variable	Male (*N*=36) Median (IQR)	Female (*N*=47) Median (IQR)	Z statistic[a]	*P* value[a]	r[b]
DLP	352.4 (193.23)	379.0 (374.30)	- 0.427	0.669	0.047

[a] Mann-Whitney *U* test
[b] effect size

However, the difference in the radiation dose received in showed no significant difference (P > 0.05) in either $CTDI_w$, DLP, or E. The effect sizes are also small (r < 0.05) for all dose metrics, indicating that genders have an unjustifiable effect on the exposures received.

DISCUSSION

Comparison of DRL at institutional, national, and international

The implementation of DRL has been demonstrated to reduce the overall radiation dose and range of radiation doses received by patients undergoing single-phase CECT thorax procedures. Upon obtaining the required data, the DRL values ($CTDI_w$ and DLP) were compared with the established DRL. The $CTDI_w$ calculated was significantly smaller than the established values. This substantially reduces the risk to the patient, as the dose is related to the stochastic radiation effect on the irradiated organs, which in this procedure involves the thyroid, lungs, and glandular breast tissues (15,16). This corresponds to previous literature, which showed the established local DRL were lower than previously published national values (17). According to ICRP, if the institutional value is lower than established value, imaging techniques should always be reviewed for potential reduction in their levels of dose without compromising the clinical purpose of the examination.

Most of research done are used $CTDI_{vol}$ rather than $CTDI_w$ to established DRL because $CTDI_{vol}$ considers the radiation dose distribution across the entire volume of the scanned while $CTDI_w$ only focus on limited length along the z-axis. $CTDI_{vol}$ is particularly relevant for helical (spiral) CT scans, where the dose distribution can be more complex compared to traditional axial scans. In helical scans, the table moves continuously while the X-ray tube rotates, resulting in a varying dose distribution along the z-axis. $CTDI_{vol}$ accounts for this variation and provides a more accurate representation of the total dose. The national guidelines provided by Malaysia government were initially implemented in 2013. However, the necessary preparations had to be initiated several years prior and during the process which limited utilisation of helical scan equipment at institutions and hospitals. According to Vacy et al., (18) national and regional DRLs should be revised at regular intervals of 3–5 years or more frequently when substantial changes in technology, new imaging protocols, or improved post-processing of images have occurred.

Implementation of high-pitch protocol with iterative reconstruction (IR) allowed a reduction in dose in thoracic scans with a further reduction observed after the introduction of advance detector. This might be a reason why institutional $CTDI_w$ is significantly lower than national DRL.

Correlation of Radiation Doses with Patients' Age and BMI

Patients' ages are negatively and weakly associated with all dose metrics (rs < 0.39). Despite the weak correlation, the negative association signifies that younger patients receive higher doses than older patients, which aligns with findings from a study by Perchik et al. (19). This study's sample population was exclusively comprised of adult patients aged 18 to 60 years. Hence, the association between age and dose is insignificant as tube current modulation techniques adapt the radiation dose to the patient's size rather than the age (20). Previous studies have only reported a linear correlation between DLP and patient age for the paediatric population, whereby their sizes are notably different for each age group (20).

Radiation doses in $CTDI_w$, $CTDI_{vol}$ and DLP were assessed to see the strength of association with patients' BMI and age. Patients' BMIs are significantly and strongly correlated with $CTDI_w$ and CTDI vol (rs=0.803), moderately with DLP (rs=0.577), suggesting that obese patients receive larger doses of ionising radiation compared to those that are underweight. This finding is consistent with the result from previous research by Deevband et al. (21), which showed that increased BMI results in increased radiation dose to the patients. This poses a risk to the patient, as radiation dose is related to the stochastic radiation effect on the irradiated organs, which in this procedure involves the thyroid, lungs, and glandular breast tissues (22,23). Patients with android obesity, whereby fats accumulate across the thoracic and abdominal regions, are at higher risk of inducing stochastic effects, consequently due to increased exposure during CT thorax (24). This corresponds to previous literature by Mohammadbeigi et al. (22), which established local DRLs were lower than published national values where adults were confined to a representative standard patient size that falls under the overweight category (17). However, the samples included in this study mostly fall under normal weight category by more than 50%, which is attributed to the lower DLP value obtained.

Comparison of Radiation Doses Between Patients' Genders

It is expected that male patients obtain higher doses than female patients. A study by McLaughlin PD et al. (25) indicated that female patients had a significantly higher composition of adipose tissue than males, which is the strongest predictor of DLP. The greater total adipose volume, the greater the value of DLP.

However, in this study, different genders showed no significant difference ($P > 0.05$) in the radiation dose obtained, either $CTDI_w$, CTDI vol and DLP. The effect sizes are also small ($r < 0.3$) for all dose metrics, indicating that genders have an unjustifiable effect on the exposures received. Despite this, a researcher suggested that considerations must still be taken when setting the parameters for male or female patients (9). Lower exposures should be imposed on female patients as there is an additional carcinogenic radiosensitive organ which is the breast, being exposed during CT thorax compared to males (23). The principles of radiological protection, including parameter settings optimisation for CT thorax protocol and reassessment of justification, should be further emphasised (23).

Considering those principles of radiological protection, including parameter settings optimisation for CT thorax protocol and reassessment of justification should be further emphasised (26). Breast radiation equivalent doses can also be reduced by up to 17% by organ-based tube current modulation and up to 19% by lowering the tube potential (23).

Limitations of this study include a larger sample size is required to accurately analyse the CT dose metrics as automatic exposure control systems produce variations of these dose values boost (27). A large sample size is needed for data with high variable outcomes to estimate the effect size precisely (28). This small sample size attributed to the fact that this institution only began its operation officially two years ago; hence, a relatively smaller number of patients were received during this short period. The sample of patients also showed most of the patients aged over 45 and suggested future research to make sure that the age population is about the same for all three groups.

Limitations

A more substantial sample size is essential to conduct a thorough analysis of the CT dose metrics, as the implementation of automatic exposure control systems generates fluctuations in the dose values. Furthermore, they indicated that a sizable sample size is requisite for datasets exhibiting high variability in outcomes to accurately estimate the effect size. The cumulative sample size acquired for this investigation is merely 83, which is significantly smaller in comparison to the requisite size and may adversely affect the reliability of the findings. Apart from that the comparison between CT technology is not available as most of the research conducted are not mentioning about that. Thus, we know that technology is a crucial factor in influenced the radiation dose received by patients.

CONCLUSION

DRL should be regarded as a method that is adapting to stay abreast of technological advancements and clinical progress. Patient size plays an important role in the determination of the amount of radiation required to achieve adequate image quality for a given procedure. This study has revealed several approaches to establishing national DRL for CT for example use of $CTDI_w$ for DRL by MOH Malaysia. Whereas there is general agreement in being compliant with ICRP to use CTDI vol and DLP as technical parameters indicating dose. The range of DRL proposed for this institution were around 12.93 mGy for $CTDI_{vol}$, 7.63 mGy for $CTDI_w$ and 553 mGy cm for DLP. The utilisation of institution DRL as a means of ongoing quality enhancement facilitates the establishment of a culture of dose reduction. This is achieved by providing guidance to radiographers, radiologist and medical physicists to encourage them to adopt a new approach in any examination involves ionising radiation. Ultimately, this guideline aims to attain a high standard of quality and safety in the field of medical imaging.

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