Establishment of diagnostic reference levels in computed tomography for select procedures in Pudhuchery, India

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ABSTRACT

Computed tomography (CT) scanner under operating conditions has become a major source of human exposure to diagnostic X-rays. In this context, weighed CT dose index ($CTDI_w$), volumetric CT dose index ($CTDI_v$), and dose length product (DLP) are important parameter to assess procedures in CT imaging as surrogate dose quantities for patient dose optimization. The current work aims to estimate the existing dose level of CT scanner for head, chest, and abdomen procedures in Pudhuchery in south India and establish dose reference level (DRL) for the region. The study was carried out for six CT scanners in six different radiology departments using 100 mm long pencil ionization chamber and polymethylmethacrylate (PMMA) phantom. From each CT scanner, data pertaining to patient and machine details were collected for 50 head, 50 chest, and 50 abdomen procedures performed over a period of 1 year. The experimental work was carried out using the machine operating parameters used during the procedures. Initially, dose received in the phantom at the center and periphery was measured by five point method. Using these values $CTDI_w$, $CTDI_v$, and DLP were calculated. The DRL is established based on the third quartile value of $CTDI_v$ and DLP which is 32 mGy and 925 mGy.cm for head, 12 mGy and 456 mGy.cm for chest, and 16 mGy and 482 mGy.cm for abdomen procedures. These values are well below European Commission Dose Reference Level (EC DRL) and comparable with the third quartile value reported for Tamil Nadu region in India. The present study is the first of its kind to determine the DRL for scanners operating in the Pudhuchery region. Similar studies in other regions of India are necessary in order to establish a National Dose Reference Level.

Key words: Computed tomography, $CTDI_w$, $CTDI_v$, dose length product, dose reference level , pencil ionization chamber, polymethylmethacrylate phantom

Introduction

Computed tomography (CT) was introduced in the early 1970s and soon became a very important tool in medical diagnosis. This modality has become a very strong and flexible examination that has replaced many radiologic techniques.[1,2] CT applications have improved with the introduction of helical and multidetector row arrangement.[3] However, CT is associated with relatively high radiation doses, causing concerns regarding the risk of carcinogenesis.[4,5] In addition, the current CT scanners have an extensive choice of exposure factors and employ techniques that can significantly influence the radiation dose given to the patient.[6] Following international basic safety standards for protection against ionizing radiation and safety of radiation sources becomes mandatory whenever a radiological examination has to be performed in the case of a valid clinical indication.[7,8] During CT examination for a specific clinical objective, a quality image should be recorded without unnecessary dose to the patients. All guidelines therefore, include reference doses that are described as diagnostic reference levels (DRL)[9] or guidance levels[10] which can be thought of as reasonable doses for various clinical procedures that meet the clinical objectives and also can be used for optimizing patient dose. DRL are usually defined for a collection of patient dose data at the 75th percentile point of the dose spread.[11] It means 75% of the dose data are below the DRL value. DRLs are intended to provide guidance on what is achievable with current good practice rather than optimum performance, and helps to identify unusually high radiation doses or exposure levels (as in the rest of the 25% of cases). Hence, regular

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patient dose monitoring and image quality assessment will lead to optimal doses and meaningful DRLs and reduction of unnecessary patient doses.[12] The dose parameters recommended in the guidelines are weighed CT dose index ($CTDI_w$) and volumetric CT dose index ($CTDI_v$) for a single section and dose length product (DLP) for the entire examination.[13] The purpose of our study is to establish nationwide "Diagnostic Reference Level" for CT scanners for select procedures viz., head, chest, and abdomen. The first step towards setting a national DRL is to arrive at regional DRL for which the entire nation has been divided into five zones namely south, north, east, west, and center. The south zone includes the state of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, and Pudhuchery which is a union territory. An attempt has been made in the year 2008 to determine the third quartile value for $CTDI_v$ for the CT scanners in Tamil Nadu and the values were reported as 557 and 551 mGy for thorax and abdomen procedures, respectively.[14] Since then no studies have been carried out in this line in India. The aim of the present study is to establish DRL for $CTDI_v$ and DLP for the CT scanners operating in Pudhuchery region.

Materials and Methods

CT scanners

This study was carried out using six CT scanners out of 10 machines operating in Pudhuchery region. Before initiating measurements in hospitals, a questionnaire was prepared to collect data regarding the CTs' protocols and clinical practices adopted by the hospital in Pudhuchery region. This data helped to record the CT dose index values for different scanning protocols adopted by the various departments. Table 1 summarizes the make and model of CT scanners used in this study.

Dose Measurement system

In-site CT dose measurements were carried out using a calibrated 100 mm pencil ionization chamber (DCT10 RS, S/N 1636) [Figure 1a] with Solidose electrometer 400 (S/N 4253) [Figure 1b], from RTI Electronics, Sweden. The electrometer was calibrated to read the dose in phantom directly.

Phantom

The average patient was simulated by dedicated cylindrical polymethylmethacrylate (PMMA) phantom.

Table 1: Details of CT units

Make	*Model*	*Number of units*	*No. of slice*
Hitachi	Pratico	1	Single
Siemens	Somatom sprit	3	2
Philips	Brilliance MDCT	1	6
Siemens	Somatom sensation	1	64

CT: Computed tomography, MDCT: Multidetector CT

The diameter and length of head-equivalent phantom was 16 and 15 cm, respectively. This was nested into another phantom with dimension 32 cm outer diameter, 16 cm inner diameter, and 15 cm length to use as a body equivalent phantom [Figure 2]. Each cylindrical phantom contains four holes (13 mm diameter) on the periphery at 90° intervals and one at the center. During measurements the unused holes were plugged using PMMA pegs [Figure 2].

Experimental technique

The most common procedures performed in most of the radiology departments' viz., adult head, chest, and abdomen were selected for the study. The head scan procedure was carried out with and without contrast in machines other than Hitachi (Pratico), whereas chest and abdomen scan procedures were carried without contrast in all the machines. From each machine the data pertaining to 50 head, 50 chest, and 50 abdomen procedures (a total of 150 × 6 = 900 procedures) performed over a period of 1 year have been collected. The data included information

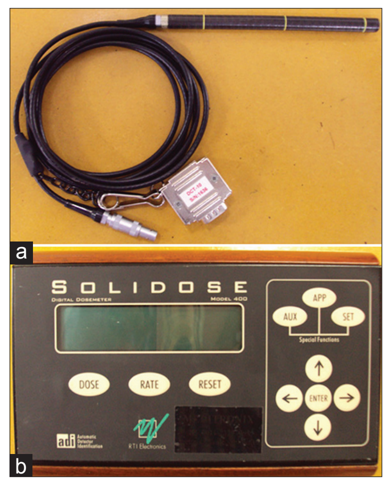

Figure 1: Dose measurement system (a) Pencil ion chamber (b) Electrometer

Figure 2: Computed tomography dose index head and body phantom with the pencil ion chamber inserted in the center hole of head phantom and the other holes plugged with polymethylmethacrylate pegs

related to patients such as patient height, weight, sex, age, and lateral diameter and machine operating parameters such as tube voltage and tube current-time product, pitch, scan time, slice thickness, and average scan length used for the purpose of obtaining good quality images. This data abstraction has been done as per 'Nationwide Evaluation of X-ray Trends' (NEXT) protocol.[15] The data related to the machine operating parameters for the scanners under study is presented in Table 2.

The dosimetry technique was based on the methods proposed by European Guidelines.[9] Before dose measurements were carried out, quality assurance (QA) was performed for each machine and was compared with the CT dose indices displayed on the control console to ensure that the output of the machines were fairly constant for the past 1 year because the data were collected during this period. After QA, each scanner's CTDI values were normalized using standard protocol involving tube potential of 80, 100, and 120 kV, tube current-time product of 100 mAs and 5 mm slice thickness. Then, the phantom was placed in the couch and as per Food and Drug Administration (FDA)'s recommendation the ion chamber was inserted into holes in the phantom such that its center matched with the isocenter of the phantom so as to read the dose received throughout the length of the phantom. The temperature and pressure correction for the chamber were applied at different locations of CT scanner under the prevailing conditions. Thus, the dose received by the phantom at the center ($CTDI_{100,\ c}$) and periphery ($CTDI_{100,\ p}$) was measured using the pencil ion chamber connected to a solidose electrometer for the machine operating parameters presented in Table 2.

Using these dose values, the other CT dose indices viz, $CTDI_w$, $CTDI_v$, and DLP were calculated using equation 1, 2 and 3.

$$CTDI_w = 1/3\ (CTDI_{100,\ c}) + 2/3\ (CTDI_{100,\ p}) \quad (1)$$

$$CTDI_v = CTDI_w/\text{pitch} \quad (2)$$

$$DLP = CTDI_v \times \text{scan length} \quad (3)$$

The $CTDI_v$ thus calculated was compared with the estimated $CTDI_v$ obtained from the control console and was ensured that the difference between the two values fell within the limit recommended by Atomic Energy Regulatory Board (AERB). To establish DRL the third quartile value of the calculated $CTDI_v$ and DLP has been determined for the dose pertaining to the exposure parameters involved during patient scanning that were routinely used in each center.

Table 2: Exposure parameters used for select procedures in CT examinations

Machine	*Make (model)*	*Study region*	*Tube voltage (kV)*	*Tube current-time product (mAs)*	*Pitch*	*Scan time (s)*	*Slice thickness (mm)*	*Mean scan length (cm)*
A	Siemens (Somatom sprit)	Head	120	160	1.00	18.00	6.00	28.50
		Chest	120	90	1.80	12.00	5.00	38.00
		Abdomen	120	95	1.80	18.00	5.00	40.00
B	Siemens (Somatom sensation)	Head	120	250	0.85	12.40	2.00	28.60
		Chest	120	225	1.00	6.83	5.00	29.00
		Abdomen	120	225	1.00	6.83	5.00	28.00
C	Siemens (Somatom sprit)	Head	130	160	1.00	18.00	6.00	26.28
		Chest	130	80	1.80	12.00	5.00	38.00
		Abdomen	130	60	1.80	18.00	5.00	29.00
D	Hitachi (Pratico)	Head	120	150	Axial	1.0*	5.00	31.50
		Chest	120	150	1.00	20.20	10.00	38.00
		Abdomen	120	180	1.00	28.10	10.00	41.47
E	Philips (Brilliance MDCT)	Head	120	200	0.656	29.80	4.50	21.50
		Chest	120	200	0.90	38.40	3.00	38.00
		Abdomen	120	200	0.90	38.40	3.00	25.00
F	Siemens (Somatom sprit)	Head	130	225	0.90	20.00	5.00	28.50
		Chest	130	100	1.80	15.00	5.00	40.00
		Abdomen	130	100	1.80	15.00	5.00	45.00

*Tube rotation time. CT=Computed tomography, MDCT=Multidetector CT

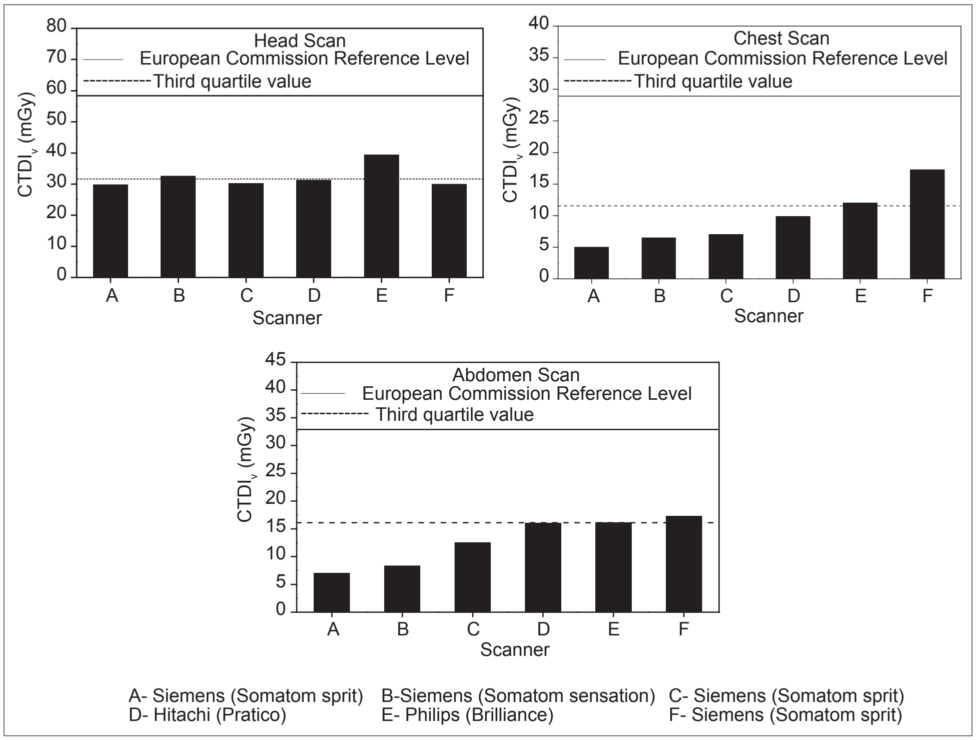

Figure 3: Comparison between calculated volumetric computed tomography dose index values for the different scanners, third quartile value, and the European Commission Reference level for head, chest, and abdomen scan

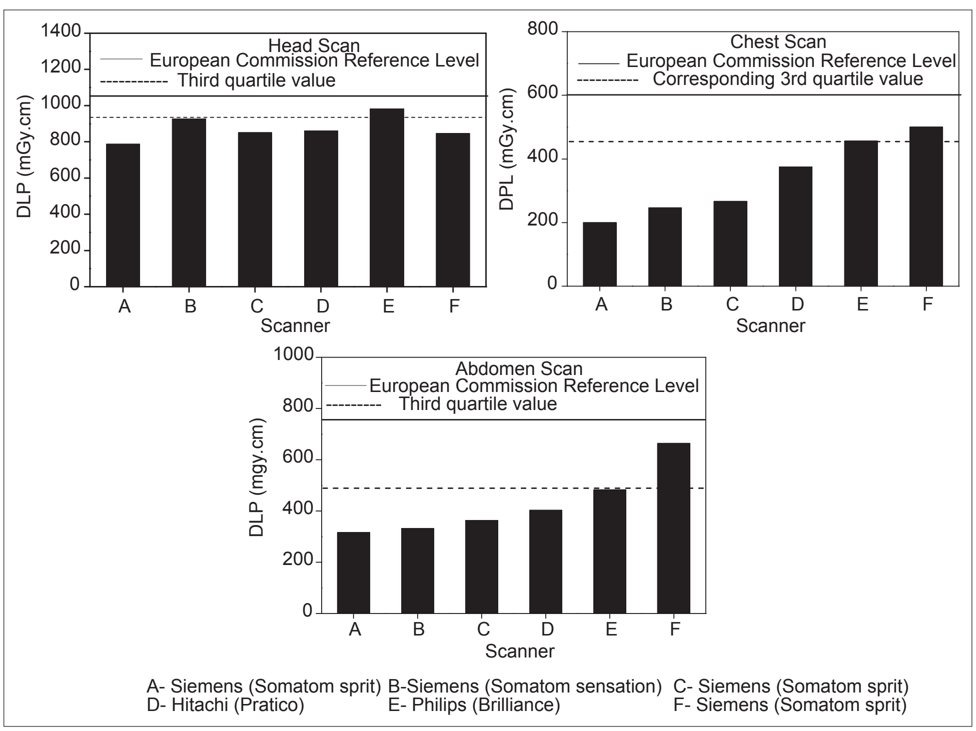

Figure 4: Comparison between calculated dose length product values for the different scanners, third quartile value, and the European Commission reference level for head, chest, and abdomen scan

Results and Discussion

The dose received by the head and body CTDI phantom at the center and periphery was measured using the pencil ionization chamber connected to solidose electrometer. Weighted CTDI, CTDI$_v$, and DLP have been calculated as per equations 1, 2, and 3. The values are presented in Table 3.

From Table 3, it can be seen that the difference between the estimated and calculated $CTDI_v$ is well within 40% which is the maximum tolerance level as per AERB standards.[16] As the mode of scanning for head region was axial in machine D (Hitachi (Pratico)) a least difference between the estimated and calculated $CTDI_v$ was observed. The mean, range, and third quartile values have been calculated for the $CTDI_v$ and DLP and are presented in Tables 4 and 5.

From Table 4 it can be observed that the range of $CTDI_v$ values is almost the same for head, chest, and abdomen scan; whereas, Table 5 reveals the fact that the range of DL*P* values vary significantly for head, chest, and abdomen scan. To analyze this similarity and variation, the $CTDI_v$ and DL*P* values and their respective third quartile values are represented using a bar chart [Figures 3 and 4].

Figures 3 and 4 reveals the fact that the third quartile values of $CTDI_v$ and DLP for head, chest, and abdomen scans are well below the European Commission Reference Level. This is because, based on the average European adult patient size (density of the scan region) the machine operating parameters used by the scanners operating in those countries are on the higher side when compared to Indian conditions. Also, the third quartile value of $CTDI_v$ for abdomen scan is less than the one reported for Tamil Nadu (521 mGy).[14]

Table 3: The computed tomography dose indices of few scanners operating in Pudhuchery for select procedures

CT scanner						
Scan region	*A*	*B*	*C*	*D*	*E*	*F*
Calculated $CTDI^w$ (mGy)						
Head	32	26	30	31	26	27
Chest	12	17	13	10	11	09
Abdomen	15	17	23	16	15	13
Estimated $CTDI^v$ (mGy)						
Head	25	23	22	27	30	22
Chest	05	13	05	07	09	04
Abdomen	07	13	09	12	12	05
Calculated $CTDI^v$ (mGy)						
Head	32	30	30	31	39	29
Chest	06	17	07	10	12	05
Abdomen	08	17	12	16	16	07
Difference between estimated and calculated CTDIv (%)						
Head	23	25	27	14	25	25
Chest	28	26	22	27	25	21
Abdomen	21	26	26	28	27	25
Dose length product (mGy.cm)						
Head	925	863	786	982	846	847
Chest	246	500	266	374	456	199
Abdomen	332	482	363	664	403	316

CT: Computed tomography, CTDI: Computed tomography dose index

Figures 3 and 4 reveal the fact that the $CTDI_v$ and DL*P* value of machines A (Siemens (Somatom sprit)), B (Siemens (Somatom sensation)), and C (Siemens (Somatom sprit)) are low when compared to the other three for chest and abdomen scan. This may be due to a low scan time used in these machines when compared to machine D (Hitachi (Pratico)) and E (Philips (Brilliance Multidetector CT (MDCT))) and low tube voltage and current time product combination when compared to F (Siemens (Somatom sprit)). Due to these facts the radiation output from machines A, B, and C is less when compared to D, E, and F that has resulted in low dose level received by the phantoms and hence low $CTDI_v$ when compared to other machines.

It can be observed from Figures 3 and 4 that for head scan, the experimentally determined $CTDI_v$ and DLP for machine B (Siemens (Somatom sensation)) and E (Philips (Brilliance MDCT)) are above the third quartile values. This is ascribed to the machine operating parameters viz., low pitch value and slice thickness and fairly high scan length for machine B and low pitch value and longer scan time for machine E. Due to these factors the phantom has received higher doses which in turn resulted in a higher $CTDI_v$ and DLP. If these machine operating parameters are optimized than the dose indices could be brought down below the third quartile values and that would lead to a good scan practice.

Table 4: Mean, range, and third quartile values for volumetric CTDI for select procedures

Study region	*Volumetric CTDI (mGy)*		
	Mean	*Range, difference between highest and lowest value*	*Third quartile*
Head	32	10 (39-29)	32
Chest	10	12 (17-5)	12
Abdomen	13	10 (17-7)	16

CTDI: Computed tomography dose index

Table 5: Mean, range, and third quartile values for dose length product for select procedures

Study region	*DLP (mGy.cm)*		
	Mean	*Range, difference between highest and lowest value*	*Third quartile*
Head	875	196 (982-786)	925
Chest	340	301 (500-199)	456
Abdomen	427	348 (664-316)	482

DLP: Dose length product

As far as chest and abdomen scans are concerned, the dose indices values of machine F (Siemens (Somatom sprit)) are higher than the third quartile values. This is attributed to higher tube voltage, tube current time product, scan time, and mean scan length. These parameters when optimized would result in dose indices values below the third quartile values.

Conclusion

The paper presents the data that are an outcome of the preliminary survey and experiments carried out on more than 50% of CT scanners operating in Pudhuchery region of south India in order to establish regional DRL for select procedures. Based on the dose measurements using five point method, the CT dose indices have been calculated. To establish regional DRL, the third quartile value of $CTDI_v$ and DLP has been determined. A comparison between the $CTDI_v$ and DLP of individual scanners, third quartile values and EC DRL indicate that the third quartile values are below European Commission (EC) DRL. However, the $CTDI_v$ and DLP of certain scanners are higher than third quartile value revealing the fact that the radiation output is high due to the machine operating parameters used in these scanners. Optimization of machine operating parameters in these cases is required to prevent the patients from receiving unnecessary doses. This investigation provides data related to dose and technique to facilitate further initiatives in the optimization of patient safety in select procedures. Performance of such surveys is important in other regions of the country to formulate national reference levels.

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