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. CT applications have improved with the introduction of helical and multidetector row arrangement. However, CT is associated with relatively high radiation doses, causing concerns regarding the risk of carcinogenesis. 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. 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. 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) or guidance levels 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. 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
patient dose monitoring and image quality assessment will lead to optimal doses and meaningful DRLs and reduction of unnecessary patient doses. The dose parameters recommended in the guidelines are weighed CT dose index (CTDIw) and volumetric CT dose index (CTDIs) for a single section and dose length product (DLP) for the entire examination. 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, for the CT scanners in Tamil Nadu and the values were reported as 557 and 551 mGy for thorax and abdomen procedures, respectively. 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, 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. 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

| 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
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.[10] 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) and periphery (CTDI) 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, CTDI, and DLP were calculated using equation 1, 2 and 3.

\[
\text{CTDI}_w = \frac{1}{3} (\text{CTDI}_{100, c}) + \frac{2}{3} (\text{CTDI}_{100, p}) \tag{1}
\]

\[
\text{CTDI}_v = \frac{\text{CTDI}}{\text{pitch}} \tag{2}
\]

\[
\text{DLP} = \text{CTDI}_v \times \text{scan length} \tag{3}
\]

The CTDI thus calculated was compared with the estimated CTDI 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 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                             | 1.00  | 20.20         | 10.00                | 38.00                 |
|         |                       | Chest        | 120              | 150                             | 1.00  | 20.00         | 10.00                | 41.47                 |
|         |                       | Abdomen     | 120              | 180                             | 1.00  | 28.10         | 10.00                | 40.00                 |
| E       | Philips (Brilliance MDCT) | Head        | 120              | 200                             | 0.655 | 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
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.

![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](image)

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

From Table 4 it can be observed that the range of CTDI values is almost the same for head, chest, and abdomen scan; whereas, Table 5 reveals the fact that the range of DLP values vary significantly for head, chest, and abdomen scan. To analyze this similarity and variation, the CTDI, and DLP 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 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, for abdomen scan is less than the one reported for Tamil Nadu (521 mGy).

Figures 3 and 4 reveal the fact that the CTDI, and DLP value of machines A (Siemens (Somatom spirit)), B (Siemens (Somatom sensation)), and C (Siemens (Somatom spirit)) 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, when compared to other machines.

It can be observed from Figures 3 and 4 that for head scan, the experimentally determined CTDI, 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, 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 3: The computed tomography dose indices of few scanners operating in Pudhuchery for select procedures |
|---|
| **CT scanner** | A | B | C | D | E | F |
| **Scan region** | **Calculated CTDI**<sup>+</sup> (mGy) | **Estimated CTDI**<sup>+</sup> (mGy) | **Calculated CTDI**<sup>+</sup> (mGy) | **Difference between estimated and calculated CTDI (%)** | **Dose length product (mGy.cm)** |
| Head | 32 | 26 | 30 | 31 | 26 | 27 | 26 | 30 | 27 | 30 | 27 | 30 | 27 | 30 |
| Chest | 12 | 17 | 13 | 10 | 11 | 13 | 12 | 13 | 10 | 11 | 12 | 13 | 10 | 11 |
| Abdomen | 15 | 17 | 23 | 16 | 15 | 13 | 16 | 15 | 13 | 16 | 15 | 13 | 16 | 15 |

CT: Computed tomography, CTDI: Computed tomography dose index

| 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 spirit)) 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, and DLP has been determined. A comparison between the CTDI, 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, 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.

**References**

1. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JA, et al. Strategies for CT radiation dose optimization. Radiology 2004; 230:619-28.
2. Rehani MM, Berry M. Radiation doses in computed tomography. The increasing doses of radiation need to be controlled. BMJ 2000; 320:593-4.
3. Prokop M. Multidetector-row CT: Technical principles and future trends. Eur Radiol 2003; 13 suppl 5:M3-13.
4. Committee to assess health risks from exposure to low levels of ionizing radiation NRC. Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2. Washington: National Academies Press; 2006.
5. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. Br J Radiol 2008; 81:362-78.
6. Jangland L, Sanner E, Persliden J. Dose reduction in computed tomography by individualized scan protocols. Acta Radiol 2004; 45:301-7.
7. International Atomic Energy Agency. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. IAEA safety series no. 115. Vienna: International Atomic Energy Agency; 1996.
8. European Union. Council Directive 97/43 Euratom of 30 June 1997. Health protection of individuals against the dangers of ionizing radiation in relation to medical exposure. (Repealing Directive 84/466 Euratom.)
9. European Guidelines on Quality Criteria for Computed Tomography. Report EUR 16262 EN. Brussels: European Commission.
10. International Atomic Energy Agency. Optimisation of the radiological protection of patients undergoing radiography, fluoroscopy and computed tomography. Document no. IAE-TECDOC-1423. Vienna: International Atomic Energy Agency; December 2004.
11. Mould R. Introductory Medical Statistics. 3rd ed. Bristol: IOP publishing Ltd; 1998.
12. Huda W, Nickoloff EL, Boone JM. Overview of patient dosimetry in diagnostic radiology in the USA for the past 50 years. Med Phys 2008; 35:5713-28.
13. Hatzioannou K, Papanastassiou E, Delichas M, Bousbouras P. A Contribution to the establishment of diagnostic reference levels in CT. Br J Radiol 2003; 76:541-5.
14. Livingston RS, Dinakaran PM. Radiation safety concerns and diagnostic reference levels for computed tomography scanners in Tamil Nadu. J Med Phys 2009; 36:40-7.
15. Nationwide evaluation of X ray trends (N.E.X.T). Tabulation and graphical summary of 2000 survey of computed tomography. Available from: http://www.crcpd.org/PDF/NEXT2000 CTProl. pdf, [Last accessed on 2007 Feb].
16. AERB/RSD/MDX-CT/QAR/2010, Acceptance/Performance test for Computed Tomography (CT) scanner. Available from: http://www.aerb.gov.in/cgi-bin/X-Ray/XRAYuserform.asp [Last accessed on 2010].

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