Volume 14, No 4 | International Journal of Radiation Research, October 2016

Establishment of CT diagnostic reference levels in select procedures in South India

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► ***Original article***

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Revised: Dec. 2015
Accepted: Jan. 2016

Int. J. Radiat. Res., October 2016; 14(4): 341-347

DOI: 10.18869/acadpub.ijrr.14.4.341

ABSTRACT

Background: To suggest South India CT diagnostic reference levels (DRLs) by collecting radiation doses for the most commonly performed CT examinations. ***Materials and Methods***: A pilot study investigated the most frequent CT examinations. 110 CT sites were asked to complete a survey booklet to allow the recording of CT parameters for each of 3 CT examinations during a 1 year time period. Dose data such Volumetric Computed Tomography Dose Index ($CTDI_v$) and Dose length product (DLP) on a minimum of 50 average-sized patients in each category were recorded to calculate a mean site $CTDI_{vol}$ and DLP value. The rounded 75th percentile was used to calculate a DRL for each site and the region by compiling all results. Results are compared with international DRL data. ***Results:*** Data were collected for 16,500 patients. All equipment had multislice capability (2-256 slices). DRLs are proposed using $CTDI_{vol}$ (mGy) and DLP (mGy.cm) for CT head (47 and 1041 respectively), CT chest (10 and 445 respectively), and CT abdomen (12 and 550 respectively). These values are lower than current DRLs and comparable to other international studies. Wide variations in mean doses are noted across the region. ***Conclusion:*** Baseline figures for South India CT DRLs are provided on the most frequently performed CT examinations. It was noted that there was a wide variation in mean doses among the CT scanners used during diagnosis. The differences in CT doses between CT scanner departments as well as identical scanners suggest a large potential for optimization of examinations.

Keywords: *Computed tomography (CT), weighed computed tomography dose index ($CTDI_w$), volumetric computed tomography dose index ($CTDI_v$), dose length product (DLP), dose reference level (DRL).*

INTRODUCTION

The use of Computed Tomography (CT) for medical diagnosis has substantially increased over the past decade compared to all other diagnostic modalities especially with the rapid use of Multidetector CTs (MDCT). This disproportionately increases the contribution of CT dose to the population compared to contribution from other diagnostic techniques [1-4]. Medical X-rays correspond to a most important tool of manmade irradiation of the population. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has indicated that even if diagnostic radiology departments at the global level contribute only 20 % of the total annual effective dose, yet it accounts for more than 94% of the man made radiation sources [5]. Lee et al found that 44% of emergency department physicians

and 56% of radiologists at an American academic medical centre underestimated the radiation dose from a given CT examination [6]. While there is increasing pressure to depend on CT for diagnosis there is a lack of specific guidance to perform the CT examinations by optimizing Image Quality with minimum dose to patient [7]. The objective of Optimization in CT exposures is to obtain acceptable image quality with minimum dose to the patients; reduction of dose in itself is not the objective of medical exposures. From this point of view in recent times much work has been done on optimization of scanning parameters in routine clinical conditions [8-11]. The foundation of optimization is the establishment of dose reference levels (DRLs), first proposed by the International Commission on Radiation Protection (ICRP) in 1996 [12] and later introduced into European [13] and Irish legislation [14]. ICRP defines DRLs as 'a form of investigation level applied to an easily measured quantity, usually the absorbed dose in air or tissue-equivalent material at the surface of a simple standard phantom or a representative patient'. This definition strongly emphasizes that DRLs are not the dose limits and do not help distinguish between good and poor medical practice. Although dose limits must not be exceeded, DRLs may be exceeded if clinically necessary. DRLs also differ from dose limits for occupational exposure because they are not used to constrain individual patient exposures; this is because a dose higher than the standard dose may be required depending on the patient's body size and weight. DRLs are a tool for identifying facilities with unusually high doses and for promoting the optimization process. Separate DRLs have been established for each country and/or region because equipment and procedure protocols can vary between different facilities in countries or regions. It is usually defined for a large collection of data at the 75th percentile. It can be defined at local level for a minimum number of 10 or 20 patients and preferably for a much larger number. By averaging such data from a large number of hospitals the National DRLs can be estimated [15, 16]. Hence, establishing national DRL would definitely ensure a safer CT diagnosis from patient's perspective. The purpose of DRLs is optimization of the imaging technique rather than radiation dose reduction to patients. If a justified examination does not provide the necessary clinical information because of too low dose resulting in an inadequate image quality, then the patient has been exposed needlessly to radiation. In clinical practice, it is assumed that the necessary dosage, including to the margins, will be used. In this line, it is essential to initially establish zonal DRL viz., south, north, east, west and central and finally consolidate them to arrive at the DRL for the country. Thus, the objective of our study was to measure radiation doses for most commonly used head, chest and abdomen procedures in radiology departments in south Indian hospitals and derive DRLs and compare them with the internationally recommended DRLs to suggest dose reduction methods with no special clinical justification.

MATERIALS AND METHODS

The study was carried out in four states namely Tamilnadu (TN), Puduchery (PY), Kerala (KL), and Karnataka (KA). All the CT scanners (110 CT scanners) chosen for this study were manufactured after 1995 and were single-section and helical multidetector row systems (1 – 256 slices). Out of these 110 CT scanners selected for this study, 10 scanners were functioning in public hospitals and 100 were in private hospitals. These hospitals were selected on the basis of their clinical experience, capacity for dosimetry and performance of regular image quality assessment. Adult head, chest, and abdominal CT examinations were chosen for the evaluations because they are commonly performed in most radiology departments. Table 1 summarizes the make and model of the CT scanner included in this study.

Radiation Dose Calibration

Before collecting the patient dose data, CT dose index (CTDI) measurements (weighted and volumetric CT dose indexes) were carried out at all CT scanners by using recently calibrated 100

[DOI: 10.18869/acadpub.ijrr.14.4.341]

mm pencil ionization chamber (DCT10 RS, S/N 1636) and Solidose electrometer 400 (S/N 4253) of RTI Electronics, Sweden. For this purpose, polymethyl methacrylate (PMMA) head (16 cm diameter) and body (32 cm diameter) phantoms were used. The dosimetry methods recommended in the European guidelines [13] were used. The individual patient dose data [volumetric CTDI and dose length product (DLP)] were estimated from the phantom measurements.

Table 1. Details of CT scanners included in this units.

S. No	No of slice	Make	Model	No of Units				Total No: of Machines
				TN	PY	KL	KA	
1	Single	Hitachi	Pratico	2	1	1	-	10
		Philips	Secura	1	1	1	1	
		Siemens	Emotion	1	-	-	1	
2	Dual	Hitachi	CXR4	1	-	-	-	24
		Philips	Brilliance Big Bore	1	2	-	-	
		Siemens	Emotion Duo	9	-	-	-	
		Toshiba	Asteion	2	1	-	-	
		General Electri (GE)	High speed dual	8	-	-	-	
3	6	Philips	Brilliance	1	1	1	1	23
		Siemens	Somatom	5	-	2	2	
		Toshiba	Asteion	2	-	-	1	
		General Electri (GE)	Lightspeed QX-I Quad CT	6	-	1	-	
4	16	Philips	Brilliance	1	-	2	1	21
		Siemens	Somatom Emotion	3	-	2	1	
		Toshiba	Aquilion	5	-	1	-	
		General Electri (GE)	Brivo & Light speed	4	-	1	-	
4	64	Siemens	Somatom sensation	5	1	2	4	22
		Toshiba	Aquilion	1	-	-	2	
		General Electri (GE)	High speed VCT	2	-	2	3	
5	128	Siemens	Somatom Definition AS & Edge	4	-	-	1	9
		General Electri (GE)	Optima 660	2	-	-	2	
6	256	Philips	Brilliance iCT	1	-	-	-	1
Total				67	7	16	20	110

Dose measurements

Before initiating measurements in hospitals a questionnaire was prepared to collect data regarding the CT protocols and clinical practices adopted by the hospitals in south India. This data helped to record the CT dose index values for different scanning protocols adopted by the various departments. From each machine the data were collected for 50 head, 50 chest and 50 abdomen procedures (a total of 150×110 = 16,500 procedures) performed over a period of two years (2012-2014). This data abstraction has been done as per 'Nationwide Evaluation of X-ray Trends' (NEXT) protocol [17]. In addition it was desirable to have a variation in the size of the region imaged that could influence the image quality or dose for the examination. Based on these requirements routine adult head, chest and abdomen were identified as the main examinations for this study.

The questionnaire contains a number of parameters including (i) make and model of the CT scanner, (ii) patient physical parameters such as height, weight, lateral diameter and Antero-posterior diameter, (iii) indication, (iv) interested organ, (v) phase such as pre-contrast, post-contrast, arterial phase, venous phase, full bladder and delay phase, (vi) routine scan parameters such as tube potential, tube current, scan time, rotation time, slice thickness, slice beam collimation, pitch, total slices, field of view, start couch level and end couch level, (vii) dose related data such as displayed volumetric CTDI and DLP.

[DOI: 10.18869/acadpub.ijrr.14.4.341]

CT dose experiments were carried out by placing the standard head and body phantom at the isocentre of the CT scanner and applying one axial slice of a clinical head protocol in sequential scan mode. The dose received by the phantom at the five positions for a set of scan parameters was measured by placing the ion chamber in one hole at a time while plugging the rest of holes with acrylic rods.

The CTDI is defined as [18]:

$$CTDI = [1/nT] \int D_z \, dz \text{ (integration limits from -50 mm to +50 mm)} \quad (1)$$

Where, n is the number of data channels in the multiscan CT scanner, T is the slice thickness corresponding to one channel and the integration is done over the length of the pencil chamber (100 mm).

The CTDI was measured as per the above definition by the pencil chamber-electrometer system and displayed on the dosimeter unit. CTDI is defined for a single complete rotation of the CT scanner. Using these dose values, the other CT dose indices viz, $CTDI_w$, $CTDI_v$, and DLP were calculated using the following relations:

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

$$CTDI_v = CTDI_w / \text{pitch} \quad (3)$$

$$DLP = CTDI_v \times \text{Scan length} \quad (4)$$

RESULTS

The CT scanners examined cover a wide range of manufacturer and models are shown in table 1. Data in regard to 16,500 examinations in patients who underwent routine head, chest and abdomen CT scans were collected. Out of the 16,500 examinations, 5500 were from head CT examinations, 5500 were from chest CT examinations and 5500 were from abdominal CT examinations. The average weight for the combined sample of patients who underwent chest CT and those who underwent abdominal CT was slightly lower than 75 kg because the average weight of Indian individuals is lower than that of European and American individuals. Before carrying out the regional dose estimation, complete QA (electrical, mechanical and radiation checks) were performed for all the machines involved in this work. One among these tests was the measurement of $CTDI_w$ for standard protocol involving tube potential of 100 kV, 120 kV & 140 kV, tube current-time product of 100 mAs and 5 mm slice thickness [19]. These values were compared with the $CTDI_v$ displayed in the console to ensure that the radiation output from the machines were satisfactory. $CTDI_w$, $CTDI_v$ and DLP have been calculated as per equations 2, 3 and 4. The percentage difference between measured and console $CTDI_v$ is given in figure 1.

Finally the 75th percentile of the $CTDI_v$ and DLP distributions was calculated as the respective DRLs. The mean, range and proposed DRL are tabulated in table 3 and table 4. The DRL proposed for four regions in south India has been compared with DRL proposed by EC 1999 [13], Germany 2010 [22], Switzerland 2010 [23], UK 2003 [24] and Norway [28] for the respective procedures.

DISCUSSION

This investigation revealed an observable change in CT practices, with a much wider range of studies being performed currently. This reflects the improved capacity of CT scanners to scan longer distances and at finer resolutions as permitted by helical and multislice technology. Figure 1 shows percentage difference between console and calculated $CTDI_v$ for various CT scanner. A positive percentage means that the measured $CTDI_v$ is higher than console one. Whereas a negative percentage means that the measured $CTDI_v$ is lower than console one. As per Atomic Energy Regulatory Board (AERB), India recommends difference between measured and console $CTDI_v$ value should be expected level (±20%) and maximum acceptable limit (±40%) [20]. Figure 2 reveals that the percentage difference between the measured and console $CTDI_v$ for the head, chest and abdomen procedure lies within the maximum acceptable limits (±40%) recommended by AERB. However in some of the CT machines the percentage difference between the estimated and calculated $CTDI_v$ for head,

[DOI: 10.18869/acadpub.ijrr.14.4.341]

chest and abdomen procedure is above the expected level (±20%). This may be attributed to deviations from routine scan parameters viz., pitch, field of measurements, beam shaping filter, kV, slice thickness, slice collimation, acquisition, tube rotation, exposure time per rotation, scan mode, angular tube current modulation, longitudinal tube current modulation and couch increment and so it is suggested that such CT scanners should undergo periodical QA [21]. In addition, the specific make and model of the CT scanner may lead to some variation in doses owing to inherent differences such as filtration, beam geometry, number of detector rows and scattered X-rays. Also, some of the CT scanners have used smaller slice thickness for routine CT procedures to achieve better resolution and image quality [25-27]. It leads to an increase in the patient radiation dose as well as the measured $CTDI_v$, so it is suggested that such CT scanners should select appropriate slice thickness and scanning parameters in order to reduce the patient dose. If these routine scan parameters for head, chest and abdomen procedures are optimized than the dose indices would comply with AERB recommendations and that would lead to a good scan practice without disturbing image quality.

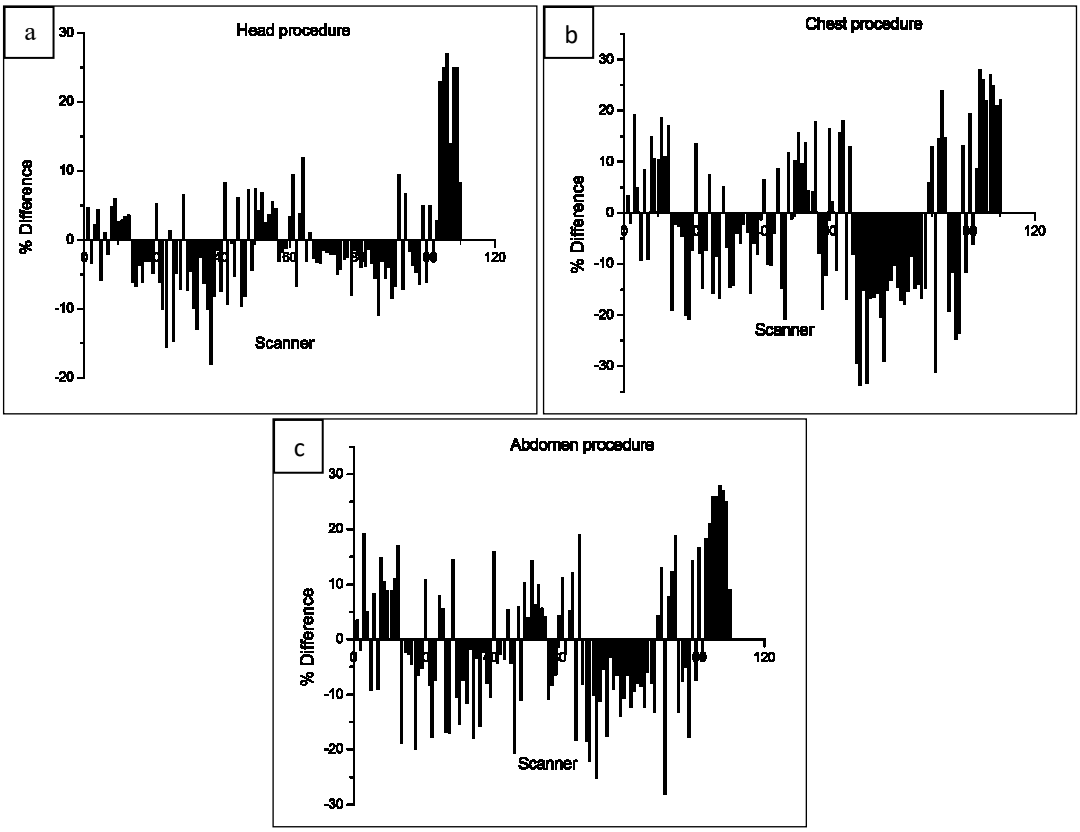

Figure 1. Percentage difference between console and measured $CTDI_v$ a) head, b) chest, c) abdomen.

Table 3. Range, Mean, and third quartile values for volumetric CTDI for select procedures.

Study region	Volumetric CTDI (mGy)							
	South India DRL			Other country DRLs				
	Range	Mean	75th percentile	EC 1999	Germany 2010	Switzerland 2010	UK	Norway
Head	63 - 21	40	47	60	60	60	65	75
Chest	17 - 2	7	10	12	12	10	13	15
Abdomen	22 - 2	9	12	35	20	15	14	15

[DOI: 10.18869/acadpub.ijrr.14.4.341]

Table 4. Range, Mean, and third quartile values for Dose length product (DLP) for select procedures.

Study region	DLP (mGy.cm)							
	South India DRL			Other country DRLs				
	Range	Mean	75th percentile	EC 1999	Germany 2010	Switzerland 2010	UK 2003	Norway 2009
Head	1622 -510	955	1041	1050	1050	800	930	1000
Chest	775 - 70	284	445	650	400	400	580	400
Abdomen	1092 - 100	430	550	900	770	710	560	710

From table 3, it was noted that the 75th percentile of $CTDI_v$ of head, chest and abdomen procedure are well below the EC Reference Level as well as other reports such as Germany, Switzerland, UK and Norway. From table 4, it was also observed that the DLP of head procedure is lower than the values reported by EC, and Germany DRLs and higher than the Switzerland, UK and Norway DRLs. The DLP of chest procedure is lower than EC, Norway and UK DRLs slightly higher than Germany and Switzerland, as well as the abdomen procedure concern 75th percentile values are well below the other reported values expect Norway. This may be ascribed due to difference in choosing scan length and justified scan parameters have been used with respect to clinical needed for those countries. Also the wide range of results reported in this study, reveals the difference in the techniques used at different hospitals, which is due to several reasons such as patients' history, indications, CT operator experience, and technical parameters applied for the given region.

The resultant values based on the exposure parameters were found to be lower when compared to EC and other International standards. However the total exam scan lengths were increased due to the additional number of series or phases used. The examination phase series was believed to be a factor in higher scan lengths thus causing an increase in the effective dose. A small number of centres have unacceptable higher patient doses and are considered as outliers. The volume CTDI pattern on CT head, chest and abdominal practice, which is used as a guide for adjusting tube potential and tube current, was not related to patient weight but rather more related to scanner centre characteristics. This finding suggests further study on why patient weight is not being used as a guide the scan exposure factors and the need of continuing education on CT applications and dose optimisation. This study also showed that the abdominal circumference is an available alternative method in manipulation of tube potential and tube current in examinations.

CONCLUSION

In this work, regional DRLs for $CTDI_v$ and DLP of selected CT procedures for adult were established in South India. From this result clearly indicate that these DRLs are smaller or slightly higher than previous DRLs, which were partly derived from national survey. The experimental wide dose distribution indicates that the notion of DRLs has not clearly understood and implemented in routine clinical procedure in India. Further audit are mandatory to reduce patient doses, these include periodical re audits, establishment of periodical QA, and opening clinical audits among radiologist to categorize and get rid of unjustified CT procedures. Finally, the survey data suggestion DRL values for CT head, chest and abdominal examination that confidently can be accepted and used for dose optimization in future.

ACKNOWLEDGMENT

Authors would like to thank the Atomic Energy Regulatory Board (AERB), India and PSG College of Technology, India for having granted funds for conducting the study. Also, we would like to thank the management of hospitals that allowed us to carry the work.

[DOI: 10.18869/acadpub.ijrr.14.4.341]

Conflict of interest*: *Declared none.

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[DOI: 10.18869/acadpub.ijrr.14.4.341]