Article published online: 2021-07-26

Radiation dose metrics in multidetector computed tomography examinations: A multicentre retrospective study from seven tertiary care hospitals in Kerala, South India

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Abstract

Background: Presently, computed tomography (CT) is the most important source of medical radiation exposure. CT radiation doses vary considerably across institutions depending on the protocol and make of equipment. India does not yet have national or region-specific CT diagnostic reference levels. **Aim:** To evaluate radiation doses of consecutive multidetector CT (MDCT) examinations based on anatomic region, performed in 1 month, collected simultaneously from seven tertiary care hospitals in Kerala. **Settings and Design:** Descriptive study. **Materials and Methods:** We collected the CT radiation dose data of examinations from the seven collaborating tertiary care hospitals in Kerala, performed with MDCT scanners of five different makes. The data included anatomic region, number of phases, CT dose index ($CTDI_{vol}$), dose-length product (DLP), and effective dose (ED) of each examinations and patient demographic data. **Statistical Analysis:** We calculated the 25th, 50th, and 75th percentiles of the $CTDI_{vol}$, DLP, and ED according to anatomic region. We made descriptive comparisons of these results with corresponding data from other countries. **Results:** Of 3553 patients, head was the most frequently performed examination (60%), followed by abdomen (19%). For single-phase head examinations, 75th percentile of $CTDI_{vol}$ was 68.1 mGy, DLP 1120 mGy-cm, and ED 2.1 mSv. The 75th percentiles of $CTDI_{vol}$, DLP, and ED for single-phase abdomen examinations were 10.6, 509.3, and 7.7, and multiphase examinations were 14.6, 2666.9, and 40.8; single-phase chest examinations were 23.4, 916.7, and 13.38, and multiphase examinations were 19.9, 1737.6, and 25.36; single-phase neck were 24.9, 733.6, and 3.814, and multiphase neck were 24.9, 2076, and 10.79, respectively. **Conclusion:** This summary CT radiation dose data of most frequently performed anatomical regions could provide a starting point for institutional analysis of CT radiation doses, which in turn leads to meaningful optimization of CT.

Key words: Achievable dose; CT dose index; diagnostic reference level; diagnostic reference range; dose-length product; effective dose; radiation dose metrics

Access this article online	
Quick Response Code:	**Website:** www.ijri.org
	DOI: 10.4103/ijri.IJRI_394_17

Cite this article as: Varghese B, Kandanga I, Puthussery P, Vijayan D, Babu SP, Aneesh MK, *et al*. Radiation dose metrics in multidetector computed tomography examinations: A multicentre retrospective study from seven tertiary care hospitals in Kerala, South India. Indian J Radiol Imaging 2018;28:250-7.

Introduction

Multidetector computed tomography (MDCT) revolutionized diagnostic medicine by aiding in more accurate diagnosis and precise anatomical information. This is by acquisition of isotropic volume data, less than 1-mm-thick images, and multiplanar reformation. Presently, MDCT has replaced many radiographic and fluoroscopic examinations. However, CT examinations deliver the maximum radiation doses, among the diagnostic modalities. For example, radiation dose of a routine volumetric single-phase chest CT is more than a hundred times of the summative radiation dose of routine frontal and lateral chest radiographs. The number of CT examinations has markedly increased in the past three decades.[1] According to 2006 US data, even though CT represents approximately 15% of all radiologic procedures, it accounts for about 45% of collective medical radiation dose.[2] The number of patients undergoing repeat CT examinations is increasing, resulting in large cumulative doses.[3] It has also been noted that radiation doses for CT vary significantly across institutions for similar anatomical regions.[4] This depends on the make of equipment, protocols used, and the built of the patient.

The risk of carcinogenesis from ionizing radiation is well-known, but the risk associated with low-dose radiation of medical imaging is controversial. There are no large-scale epidemiological studies dealing with cancer risks associated with CT. Studies on atomic bomb survivors of Japan and radiation workers in the nuclear industry revealed significant association between the low-dose radiation (5-150 mSv) and cancer risk.[5] The data derived from these studies suggest that low-dose radiation from CT may eventually result in an increased incidence of cancer in the exposed population. However, there is no accurate method to calculate such risk. The risks depend on the amount of exposure, repeated exposures, and several patient factors, such as age, sex, and life expectancy. The American Association of Physicists in Medicine (AAPM) states that there is no convincing epidemiological evidence of increased cancer incidence from low radiation doses (<100 mSv) at present, in their policy.[6] AAPM also ascertains that medical imaging should be appropriate and should use the lowest radiation dose necessary to accomplish the clinical task.

It is essential to estimate and understand the radiation doses that the medical imaging delivers. The potential for harm can then be weighed against the potential for benefit. For this, the radiologist should be familiar with CT radiation exposure descriptors—volume CT dose index[7] ($CTDI_{vol}$), dose-length product (DLP), and effective dose (ED). The $CTDI_{vol}$ describes the radiation delivered to the scan volume for a standardized phantom and the SI unit is milli-Gray (mGy). DLP represents overall radiation delivered by a given CT protocol. It is the product of the $CTDI_{vol}$ and the scan length, and its value is expressed in milli-Gray centimeters.[8] ED is a parameter that reflects the relative risk (cancer induction) from exposure to ionizing radiation averaged over gender and age.[9] It is calculated by multiplying DLP with tissue weighting factor and expressed in the units of millisieverts (mSv).

International Commission on Radiological Protection (ICRP) first mentioned the concept "diagnostic reference level" (DRL) in 1990[10] and recommended it in 1996.[11] DRL is an investigational tool to identify facilities with unusually high or low doses that need optimization. DRLs are easily measurable or obtained values, which have a direct link with patient doses. They are not dose limits and do not represent a border between good and poor practices. DRLs are always analyzed together with image quality and are not constraints to individual patient exposure.[12] Therefore, DRLs provide a reference level of radiation dose under defined conditions. National and regional DRLs are usually set at the 75th percentile of the distribution of doses measured in various centers, representing the typical practice in the country or region.

Achievable dose (AD) is another investigational tool in radiation protection, for facilities with median doses already below current DRL values, to further optimize patient protection. AD is set at approximately the 50th percentile of the national or regional dose distribution study.[13] Another proposed practical investigational tool in radiation protection is diagnostic reference range (DRR), with lower level set at 25th percentile and upper level set at the 75th percentile (DRL) of the distribution of patient radiation doses.[14] Below the DRR, the image quality may not be diagnostic, and above DRR, the dose may be in excess.

Even though there is enough recently published regional CT radiation dose data from south India,[15-18] any such data have not considered the make of CT equipment (number of slices of CT) and actual number of phases in contrast CT examinations. These factors are important with regard to actual dose delivered to the patient. Our study aimed to collect and tabulate radiation dose metrics (provided in dose report generated by CT scanners) of actual CT examinations, based on anatomical regions, as requested in clinical practice. We anticipate that these data can contribute to meaningful discussions toward national reference levels in India. The region-based/national DRLs and summaries of CT radiation doses in the common practice will guide the radiology facilities in optimizing CT examinations.

Materials and Methods

We formed a study group of seven tertiary care hospitals by inviting the interested participants from different institutions in Kerala (southern most state in India with a population of 33.3 million), using professional contacts. The ethical review boards of the teaching institutions (five of seven) approved the study protocol and waived the requirement to obtain the informed consent. Authorities of other institutions (two of seven) also approved the project protocol, relying on the approval from the principal institution.

The CT equipments in the participant institutions are the following:

1. GE Optima CT660 Freedom Edition/128 slices (GE Healthcare, WI, USA): two institutions
2. GE Optima CT660/Revolution Evo/128 slices
3. Siemens Somatom Emotion 16/16 slices (Siemens AG, Erlangen, Germany): two institutions
4. Siemens Somatom Definition 64 slices FLASH dual source dual energy
5. GE Brivo 385/16 slices digital.

All MDCT scanners have automated tube current modulation capability and are equipped with iterative reconstruction technology.

We collected the CT radiation dose data of consecutive examinations of six standard anatomical regions, performed in collaborating hospitals during December 2016. Standard anatomical region examinations included are head, neck, paranasal sinuses (PNS), chest, abdomen, and chest and abdomen. The data collected from dose reports of CT examinations included $CTDI_{vol}$ and DLP for each phase of scan, number of phases, total examination DLP, and patient demographic data. We included all the patients who were 14 years and above in the study. Extremity scans, angiograms, nonstandard anatomical protocols, positron emission tomography/CT, radiation oncology procedures, and CT-guided biopsies were excluded.

We calculated average $CTDI_{vol}$ by taking average of the phases and excluding that of smart prep or preparatory phase. We entered basic patient demographic data (age and gender), CT radiation doses (average $CTDI_{vol}$ and total DLP), number of phases, and anatomical region data in a excel spread sheet. When determining the number of phases, we excluded smart prep or preparatory phases taken for determination of timing for injection of iodinated contrast material. ED, measured in mSv, is calculated by multiplying total DLP with tissue weighting factor for each anatomical region as per International Commission on Radiation Protection 2007 (ICRP 103) recommendations.[19]

We calculated 25th, 50th, and 75th percentile for $CTDI_{vol}$, total DLP, ED, and DRR for all these dose data. We used Statistical Package for Social Sciences (SPSS 23) for all analyses.We compared the results with corresponding data from other countries.

Results

Overall, 3553 CT examinations of the six anatomical regions were performed during December 2016 in the seven centers. The most common imaged region was head, followed by abdomen [Table 1]. Multiphase scanning was used in 37% of examinations. The mean number of phases for multiphase examinations of chest, head, and neck was more than 2.3 and of abdomen was 3.8 [Table 1]. The commonest number of the phases for the multiphase examinations was 2 for all anatomic regions except for abdomen which was 4. More than 59% of the examinations were in female patients and 32% of patients were between 15 and 44 years of age [Table 2].

The 25th, 50th (median), and 75th percentile radiation doses of all centers are given in Table 3. The 25th, 50th (median), and 75th percentile radiation doses of three 128-slice MDCT scanners are given in Table 4, and three 16-slice scanners are given in Table 5.

We tabulated the results alongside corresponding recent data from other countries derived from the literature and made descriptive comparisons [Table 6].[20-24] The DRL values of CT head were found to be comparable to University of California’s study. The DRL values of chest, abdomen, and multiphase neck are considerably higher than the University of California’s study.

Discussion

The study provides a summary of CT radiation dose data of large number of consecutive patient examinations of

Table 1: Numbers of CT examinations included in study

Anatomical Region	Number of examinations (3553)					Total	Percentage
	Single phase		Multiphase				
	n	Percentage	*n*	Percentage	Mean number of phases		
Head	1820	85.4	310	14.6	2.3	2130	59.9
PNS	90	84.1	17	15.9	2	107	3
Neck	13	24.5	40	75.5	2.4	53	1.4
Chest	135	27.9	349	72.1	2.6	484	13.6
Abdomen	156	22.6	533	77.4	3.8	689	19.3
Chest & abdomen	10	11.1	80	88.9	4.3	90	2.5

six common anatomical regions from Kerala. CT imaging facilities can use these practical data as a starting point for assessing their own doses. Furthermore, our data can contribute to the creation of radiation dose benchmarks for anatomical regions by national healthcare regulatory bodies. It can also pave the way for more meaningful patient size-specific and protocol-specific radiation dose benchmarks at national level.

CT imaging facilities can analyze their anatomic region-based dose distributions and can compare their median doses with our DRL values [Table 7]. If median doses are found exceeding the corresponding DRLs, that should trigger investigation into possible causes. If their median $CTDI_{vol}$ and DLP are considerably higher than our DRL, the facilities can review their protocols and scanner settings. Also, if the $CTDI_{vol}$ is below our DRL, and the DLP considerably exceeds our DRL, then their practice of scan length and number of phases should be reviewed. If no such causes are found, unusually high doses could be clinically justified. Moreover, if the median doses are below the DRR, that should trigger the investigations for diagnostic quality of the CT images. The practice of use of DRL has been shown to reduce the overall dose observed in clinical practice.[25] Furthermore, improvements in equipment dose efficiency might also have contributed in these dose reductions.

Analysis of our data showed that there is significant variation in $CTDI_{vol}$ with change in number of detectors/channels in MDCT. This may be attributed to different CTDIw (weighted average of dose across a single slice) for different makes of MSCT scanners, depending on beam geometry, filter configuration, X-ray tube design, and absorption and scatter of X-rays.[26] The pitch factor in MSCT being lower, the $CTDI_{vol}$ will logically increase ($CTDI_{vol}$ = CTDIw/pitch), in spite of the advantage of better image quality.[27] The DRLs and median doses of 128-slice CT equipment are higher than that of

Table 2: Demographic distribution of study population

	Number of examinations	Percentage
Sex		
Male	1426	40.1
Female	2127	59.9
Total	3553	100.0
Age group		
15-44	1136	32.0
45-64	1366	38.4
≥65	1051	29.6
Total	3553	100.0

Table 3: CT Radiation dose metrics of adults

Anatomical region and type of study	CTDI vol			DLP			Effective dose		
	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile
Head									
Single phase	47.2	56.8	68.1	816.0	915.8	1120.0	1.5	1.7	2.1
Multiphase	46.9	47.2	56.8	1088.0	1438.5	2040.0	2.0	2.7	3.8
All	47.2	56.6	67.4	816.0	952.0	1215.2	1.5	1.8	2.3
PNS									
Single phase	15.9	16.9	21.4	119.7	179.6	248.0	0.22	0.34	0.47
Multiphase	15.9	15.9	15.9	376.0	449.0	505.0	0.71	0.85	0.95
All	15.96	16.1	210.4	127.0	211.0	303.0	0.24	0.40	0.57
Neck									
Single phase	16.2	22.4	24.9	404.0	552.2	733.6	2.1	2.8	3.8
Multiphase	16.2	20.9	24.9	886.5	1273.1	2076.0	4.6	6.6	10.7
All	16.2	21.1	24.9	768.5	956.0	1844.9	3.9	4.9	9.5
Chest									
Single phase	8.1	14.4	23.4	306.0	519.2	916.7	4.4	7.58	13.3
Multiphase	5.4	9.9	19.9	540.5	839.0	1737.6	7.8	12.24	25.3
All	5.9	11.0	21.7	473.1	734.1	1314.7	6.8	10.71	19.1
Abdomen									
Single phase	5.4	9.2	10.620	257.25	418.63	509.3	3.9	6.4	7.7
Multiphase	6.7	10.0	14.685	954.10	1434.00	2666.9	14.5	21.9	40.8
All	6.5	9.6	13.710	614.21	1118.72	2336.4	9.3	17.1	35.7
Abdomen and chest									
Single phase	9.5	14.9	20.085	580.56	752.87	1053.7	8.70	11.2	15.8
Multiphase	14.1	16.8	18.755	2961.08	3753.05	4656.6	44.41	56.2	69.8
All	14.0	16.6	18.811	1705.50	3716.99	4491.6	25.58	55.7	67.3

Table 4: CT Radiation dose metrics of adults in 128 slice MDCT

Anatomical region and type of study	CTDI vol			DLP			Effective dose		
	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile
Head									
Single phase (711)	56.4	57.0	76.6	915.8	916.7	1132.0	1.7	1.7	2.1
Multiphase (77)	56.4	57.2	68.4	1577.0	2175.0	2848.0	2.9	4.1	5.4
All	56.4	57.0	76.0	915.8	916.7	1186.7	1.7	1.7	2.3
PNS									
Single (58)	15.9	20.0	21.4	111.7	141.5	217.8	0.21	0.26	0.41
Multi (5)	13.8	19.6	20.9	317.9	411.3	740.4	0.60	0.78	1.4
All	15.8	20.0	21.4	117.9	151.0	244.8	0.22	0.28	0.46
Neck									
Single (8)	22.4	24.1	28.4	570.	675.8	855.07	2.9	3.5	4.4
Multi (22)	23.6	24.8	26.5	1313.8	1927.8	2434.75	6.8	10.0	12.6
All	23.06	24.7	26.5	907.4	1341.1	2235.75	4.7	6.9	11.6
Chest									
Single (85)	13.0	22.2	23.5	515.0	860.4	980.8	7.5	12.5	14.3
Multi (182)	12.4	18.8	24.3	1027.3	1649.9	2539.6	14.9	24.0	37.0
All	12.8	20.0	23.6	826.4	1079.4	2098.5	12.0	15.7	30.6
Abdomen									
Single (64)	10.6	10.6	11.8	457.4	508.4	556.0	6.9	7.7	8.5
Multi (277)	11.5	14.5	17.6	1646.9	2580.3	3320.7	25.1	39.4	50.8
All	10.6	13.6	17.0	1023.4	2242.7	3102.3	15.6	34.3	47.4
Abdomen and chest									
Single (10)	9.5	14.9	20.0	580.5	752.8	1053.7	8.7	11.2	15.8
Multi (71)	15.0	17.0	18.8	3528.6	3848.9	4682.8	52.9	57.7	70.2
All	14.7	17.0	18.8	2844.3	3745.4	4635.9	42.8	56.1	69.5

corresponding values of a 16-slice CT, in this study. So it is more logical to provide separate reference dose levels for different slice/channel MDCT equipments. The methods used in determining DRL differ among different studies and limit the scope of comparison. For denoting the actual practice, the DRL should be calculated for single-phase and multiphase studies separately. In case of multiphase studies, it must include delayed phases also. We have followed this method in our study.

The strength of our study is the large sample size of consecutive actual patient examinations, reflecting real scenario in the Radiology Department. Moreover, we provided separate reference dose metrics for 16- and 128-slice/channel CT, which is more meaningful and unique. We have also provided DRR, which is an upcoming concept, linked with diagnostic image quality.

The study has several limitations. We did not calculate size-specific dose estimate (SSDE), which is used to more accurately estimate dose at the center of the scanned region of an individual patient. We could not factor it, as it is not yet automatically reported by CT manufacturers in the dose report. Even though our CT facilities tailor each CT examination of particular anatomic region, to the clinical question being asked, that was not factored in the study. For instance, routine follow-up carcinoma imaging and quadriphase liver scanning were given equal weightage. Our data might not be appropriate for certain specialty centers such as urology practice, where the major work load would be low-dose renal stone survey. Yet another limitation was that optimization of dose was not correlated with diagnostic adequacy of images and ability in addressing the clinical question. Finally, DRLs are dynamic values, which can vary after changes in equipment and practice. So they should be reviewed periodically.

For creation of national benchmarks, there is need for establishment of a national dose index registry with automated collection of dose metrics from all registered facilities and consensus coding of common protocols. Equipments also need appropriate categorization based on the number of slices and sources. This helps in minimizing errors of manual collection and aids in frequent updates.

To create dose awareness among radiological staff, clinicians, and patients, the dose report of the CT examination may be provided with the images and reports. When an imaging study for any patient is considered, radiation dose history and imaging history of the patient

Table 5: CT Radiation dose metrics of adults in 16 slice MDCT

Anatomical region and type of study	CTDI vol			DLP			Effective dose		
	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile
Head									
Single phase (985)	46.9	47.2	68.5	748.0	816.0	1116.0	1.4	1.5	2.1
Multiphase (228)	46.6	47.2	47.2	1020.0	1292.0	1632.0	1.9	2.4	3.1
All	46.9	47.2	67.6	748.0	884.0	1118.0	1.4	1.6	2.1
PNS									
Single (31)	15.9	15.9	26.9	201.0	218.0	281.8	0.38	0.41	0.53
Multi (12)	15.9	15.9	15.9	389.0	451.5	496.0	0.73	0.85	0.94
All	15.9	15.9	15.9	210.0	269.0	376.0	0.39	0.51	0.71
Neck									
Single (5)	6.4	16.2	16.2	212.5	390.0	419.5	1.1	2.0	2.1
Multi (17)	7.3	16.2	16.2	793.0	854.0	955.5	4.1	4.4	4.9
All	6.8	16.2	16.2	420.2	820.5	951.2	2.1	4.2	4.9
Chest									
Single (43)	4.9	7.1	9.2	183.2	267.1	337.0	2.6	3.9	4.9
Multi (149)	3.9	4.9	6.3	359.0	522.0	606.0	5.1	7.5	8.8
All	4.0	5.2	7.0	261.8	477.5	583.7	3.7	6.9	8.5
Abdomen									
Single (88)	4.6	6.3	8.7	211.2	286.7	377.0	3.2	4.3	5.7
Multi (205)	4.3	5.9	7.3	705.0	926.0	1141.4	10.7	14.1	17.4
All	4.3	5.9	7.6	407.6	745.0	1016.0	6.2	11.3	15.5
Abdomen and chest									
Single (0)									
Multi (6)	4.8	5.9	6.6	788.9	896.0	1497.0	11.8	13.4	22.4
All	4.8	5.9	6.6	788.9	896.0	1497.0	11.8	13.4	22.4

Table 6: Summary of ADL, DRL and DRR in adults

Anatomical region and type of study	CTDI vol (mGy)			DLP (mGy-cm)		
	ADL	DRL	DRR	ADL	DRL	DRR
Head						
Single phase	56.8	68.13	47-68	915.8	1120	816-1120
Multiphase	47.23	56.87	46-56	1438.5	2040	1088-2040
PNS						
Single phase	16.95	21.4	15-21	179.6	248	119-248
Neck						
Single phase	22.4	24.9	16-25	552.2	733.6	404-733
Multiphase	20.9	24.9	16-25	1273.1	2076	886-2076
Chest						
Single phase	14.4	23.4	8-23	519.2	916.7	306-916
Multiphase	9.9	19.9	5.4-20	839	1737	540-1737
Abdomen						
Single phase	9.2	10.6	5.4-11	418.6	509.3	257-509
Multiphase	10	14.6	6-15	1434	2666.9	954-2666
Abdomen and chest						
Single phase	14.9	20	9-20	752.8	1053.7	580-1053
Multiphase	16.8	18.7	14-19	3753	4656	2961-4656

should be reviewed. This may allow for a more focused, lower-dose current examination in many instances. The real goal of radiologist is not in using as little radiation as possible, but in achieving as high a benefit-to-risk ratio as possible on behalf of patients. The risk of not performing an appropriate exam can lead to missing a diagnosis or delay in initiating treatment. This ultimately can reduce patient's overall life expectancy more than the benefits of avoided radiation.

Conclusion

The purpose of the analysis was to provide a summary of radiation doses based on anatomic region protocols, using a large number of consecutive patient CT examinations. Other institutions can use our DRL values as a starting point to assess their median CT doses. Further studies should continue to update and add to these data and will ultimately lead to well-optimized CT examinations for every patient. We also anticipate that our study will be a forerunner for establishment of a national dose index registry in future, which in turn leads to creation of a national benchmark for CT doses in India.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Table 7: International DRL comparisons

Anatomical region scanned	DRL											
	Kerala-India (2017)		ACR-AAPM 16 (2013)-Phantom study		University California 17-USA (2013)		ACR registry 18 (2017)		UK 19 (2014)		Japan 20 (2015)	
	CTDI vol	DLP	CTDI vol	DLP	CTDI vol	DLP	CTDI vol	DLP	CTDI vol	DLP	CTDI vol	DLP
Head												
Single phase	68	1120	75		62	1120	57	1011	60	970	85	1350
Multiphase	56	2040			55	2130						
PNS												
Single phase	21	179			29	530						
Neck												
Single phase	24	734			23	650						
Multiphase	24	2076			18	1150						
Chest												
Single phase	23	916	21		17	610	12	443	12	610	15	550
Multiphase	20	1737	21		17	1430						
Abdomen												
Single phase	10	509	25		17	860	16	781	15	745	20	1000
Multiphase	14	2666	25		17	1790						
Chest with abdomen												
Single phase	20	1053			18	1800					18	1300
Multiphase	18	4656			17	2160						

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