Radiation safety concerns and diagnostic reference levels for computed tomography scanners in Tamil Nadu

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ABSTRACT

Radiation safety in computed tomography (CT) scanners is of concern due its widespread use in the field of radiological imaging. This study intends to evaluate radiation doses imparted to patients undergoing thorax, abdomen and pelvic CT examinations and formulate regional diagnostic reference levels (DRL) in Tamil Nadu, South India. In-site CT dose measurement was performed in 127 CT scanners in Tamil Nadu for a period of 2 years as a part of the Atomic Energy Regulatory Board (AERB)–funded project. Out of the 127 CT scanners,13 were conventional; 53 single-slice helical scanners (SSHS); 44 multislice CT (MSCT) scanners; and 17 refurbished scanners. CT dose index (CTDI) was measured using a 32-cm polymethyl methacrylate (PMMA)–body phantom in each CT scanner. Dose length product (DLP) for different anatomical regions was generated using CTDI values. The regional DRLs for thorax, abdomen and pelvis examinations were 557, 521 and 294 mGy cm, respectively. The mean effective dose was estimated using the DLP values and was found to be 8.04, 6.69 and 4.79 mSv for thorax, abdomen and pelvic CT examinations, respectively. The establishment of DRLs in this study is the first step towards optimization of CT doses in the Indian context.

Key words: Computed tomography, diagnostic reference level, effective dose

Introduction

Since 1970s, computed tomography (CT) has played a tremendously important role in diagnosing diseases as compared with other radiological procedures though it imparts high radiation doses to patients. While the benefits of CT are well known in diagnosing diseases, these benefits should far outweigh the radiation risk involved therein. Technological developments have improved the speed of the procedure and quality of the images, leading to encouragement of the use of CT worldwide.[1] In a recent regional survey on CT scanners in India, it was found that there has been an increase of 35% in the number of multislice CT (MSCT) scanners compared to single-slice CT scanners since the year 2000.[2] Radiation dose from CT is of concern due to the increase in number of examinations performed each day. Though CT imparts a substantial amount of manmade radiation to the human population, the clinical benefits with the use of this modality far exceed the risk involved therein.[2-4]

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It is well understood that radiation effects are either deterministic or stochastic in nature, and occurrence of either of these should be minimized. Deterministic effects are usually characterized by a threshold dose, and stochastic effects include carcinogenesis and induction of genetic mutations.[5] Children are more radiosensitive than adults, hence it is recognized that the risk of children developing radiation-induced malignancies is two to three times higher than that of adults.[5-7] Radiation safety for patients is always a concern and is dependent on the skills of the personnel performing the examination. The International Commission on Radiological Protection (ICRP) states that radiation doses from CT are relatively high, and technological developments and advances in CT generally have not led to reduction in a patient's radiation dose per examination according to the physical parameters of the patient.[8] Radiation safety is important in diagnostic radiology, not only because of regulatory requirements but also because of personnel and patient considerations.

It is reported in literature that weighted CT dose index

($CTDI_w$) and dose length product (DLP) are appropriate dose related quantities for the establishment of diagnostic reference levels (DRLs) for optimizing patient exposure.[1,7] These dose descriptors are available on the control console of most of the modern CT scanners but are not mostly available in conventional scanners.[1,9] Recommending bodies such as the National Radiological Protection Board (NRPB), United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) and the European Commission suggestreference doses, in which the $CTDI_w$ and DLP are used as dose derivatives for CT examinations.[10] The DRLs are formulated from third quartile values observed for a particular examination since they are useful in identifying centers using abnormally high doses, where patient protection measures are urgently required.[11] This study intends to evaluate radiation safety and doses imparted to patients from various CT installations in Tamil Nadu through a regional survey. This study would be one of the first steps to formulate regional reference levels and safety standards for using CT scanners in Tamil Nadu.

Materials and Methods

The survey was carried out in 25 districts of Tamil Nadu, covering a total of 127 CT scanners, for a period of 2 years, between 2006 and 2008. These machines were located in different areas, such as residential areas, commercial areas and hospitals. Fifty scanners were from General Electric (GE) Medical Systems, Milwaukee, WI, USA; 4, from Philips Medical Systems, Netherlands; 35, from Siemens, Erlangen, Germany; 35, from Toshiba Medical Systems Co. Ltd., Tokyo, Japan; and 3, from Hitachi Medical Systems, Tokyo, Japan. The MSCT scanners included dual-slice, 4-slice, 6-slice, 8-slice, 16-slice and 64-slice scanners. A questionnaire was used for collection of data from all CT centers visited as a part of the regional survey. This was similar to the 'nationwide evaluation of x-ray trends' (NEXT) protocol.[12]

The questionnaire included the following:

- Type, model of the machine
- Location of the installation
- Exposure parameters such as tube potentials, tube time-current product, rotation time and pitch in case of helical CT
- Number of scans performed per day
- Quality assurance performed routinely in each center
- Clinical protocols for abdomen, pelvis and chest
- Selection of protocols for adult and pediatric patients
- Availability of dose-reduction techniques in the CT facility
- Availability of dose derivatives on the control console
- Status of radiation protection in the installation

These nationwide surveys are conduced using the NEXT protocol every 1 to 2 years for periodic monitoring and to track trends as technology and clinical practices change. Similar surveys are also being conducted by the NRPB, IAEA and Imaging Performance Assessment of CT scanners (ImPACT). Periodic surveys are performed by ImPACT, which provides scanner matching data sets for CT users.[13]

Dosimetry

CT dosimetry technique using a 32-cm polymethyl methacrylate (PMMA)–body phantom and a 10-cc ion chamber with reader (Fluke Biomedical, USA) was adopted for determining CTDI values. These measurements were performed with an axial slice of 10-mm thickness and gantry rotation time of 1 second without table increment. The protocol involved parameters for abdomen and thorax examinations that were routinely used in each institution. Phantom measurements were made at the center ($CTDI_{100,c}$) and periphery ($CTDI_{100,p}$) and were used to calculate the weighted CTDI ($CTDI_w$) values. The $CTDI_w$ takes into account all scan parameters, including the pitch in spiral scans and a series of axial scans and is given by the equation —

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

The $CTDI_{100}$ center and periphery values were obtained using the formula —

$$CTDI_{100} = \{dose\ (mGy) * C * f * L\} / (N * T)$$

where C is the calibration factor for the electrometer, f is the conversion factor from exposure to a dose in air (0.87 rad/R), L is the active length of the pencil ionization chamber (100 mm), N is the number of acquired sections per scan and T is the section thickness.[14] Adequate care was taken during placement of ion chamber in the phantom. The dose-reduction tools such as dose-modulation techniques were not activated during CTDI measurements. Due to time constraints and problems related to availability of scanners for performing in-site survey, the CTDI measurements were not made in air. In a few modern scanners, dose-related parameters such as CTDI, $CTDI_w$ and $CTDI_{vol}$ were displayed on the CT control console. The DLP was calculated using scan length and volume CTDI ($CTDI_{vol}$) values calculated from measured $CTDI_w$ values. Table 1 shows scan lengths measured for 1,000 patients from a population in Tamil Nadu. The effective doses were estimated by multiplying the DLP values by normalized coefficients found in the European guidelines on quality criteria of CT since there were no available coefficient values in the Indian context.[10] Radiation scatter measurements

Table 1: Scan lengths for patients undergoing thorax, abdomen and pelvis CT examinations

Region	*Scan length (cm)*		
	Minimum	*Mean*	*Maximum*
Thorax	26.5	36.1	40
Abdomen	10.8	33.8	44
Pelvis	12	19.1	23.2

were made using a survey meter (Keithley 63100, Ohio, USA) at the control console of the CT room.

Results and Discussion

The objective of this study was to evaluate radiation doses from, and radiation safety in the use of, CT scanners, through a regional survey. The survey covered a total of 147 scanners, out of which 127 scanners volunteered for in-site measurements to be performed. Out of the 127 CT scanners surveyed, 13 were conventional; 11, refurbished conventional; 53, single-slice helical scanners (SSHS); 6, refurbished SSHSs; and 44, MSCT scanners. The SSHSs have been installed since 1995, and MSCT has been in use from the year 2000. Over 13% of the scanners were installed in residential areas; 33%, in commercial areas; and 54%, in hospitals.

In Tamil Nadu, a 64-slice CT scanner was also introduced in the year 2000; since then, there has been an increase of over 44 MSCT scanners in the region. Since 2000, 38 SSHSs have been installed in the region. This shows that the number of MSCT scanners installed in the region is increasing rapidly. Most of the MSCT scanners are installed in cities, and most of the refurbished machines are installed in the towns. Information on the manufacturer's name on the CT machine was not available for a few refurbished machines. In this era of technological developments, there are institutions that are still in the process of procuring refurbished conventional scanners and SSHSs. During the survey, it was found that 4 refurbished conventional scanners had been installed in Tamil Nadu since 2004, and this may be due to the low cost involved. Refurbished scanners available in the region were, however, restricted to conventional scanners and SSHSs.

The number of patients examined each day in the region was 2,080, which involved examination of 216 patients by conventional CT; 70, by refurbished conventional scanners; 738, by SSHSs; 87, by refurbished SSHSs; and 969, by MSCT. Tables 2, 3 and 4 show effective doses for thorax, abdomen and pelvis CT examinations performed using various CT scanners installed in Tamil Nadu. Effective doses were estimated for the CT protocols that were routinely used in each center. The mean effective doses for thorax and abdomen examinations from refurbished SSHSs were higher than those from other scanners. However, it was also observed that high effective doses were imparted to patients from SSHSs, dual slicer and a 16 slicer due to the selection of high exposure parameters. The third quartile values were used in the determination of the DRLs for the region as this was much suited.[11] Table 5 shows DLP values and estimated effective doses for each anatomical region and comparisons with those reported in literature. The mean DLP values reported in Tamil Nadu were well within those reported by the European Commission and Hiles *et al.*[10,15] Mettler *et al.*, in their study, found that the effective doses reported in literature ranged from 4 to 18 mSv for thorax, 3.5 to 25 mSv for abdomen and 3.3 to 10 mSv for pelvis examinations.[16] The mean effective doses reported by Kharuzhyk *et al.* were 6.9 mSv for thorax, 7.03 mSv for abdomen and 8.8 mSv for pelvis CT examinations.[17] The mean effective doses reported in this

Table 2: Effective doses, CTDIw and exposure parameters used for thorax CT examinations performed using various CT scanners

Type of machine	*Mean tube potential (range)*	*Mean mAs (range)*	*Mean CTDIvol ± SD (range)*	*Thorax Effective dose in mSv ± SD (range)*		
				Minimum scan length (26.5 cm)	*Maximum scan length (40 cm)*	*Mean scan length (36.1 cm)*
Conventional	122 (120-130)	205 (150 - 270)	13.6 ± 2.25 (10.2 - 16.7)	6.12 ± 1.02 (4.61 - 7.51)	9.24 ± 1.53 (6.95 - 11.3)	8.34 ± 1.38 (6.28 - 10.23)
Conventional*	119 (110-130)	215 (130 - 360)	13.3 ± 3.59 (8 - 20.45)	5.99 ± 1.62 (3.6 - 9.2)	9.04 ± 2.44 (5.46 - 13.9)	8.15 ± 2.2 (4.9 - 12.6)
Spiral	121 (110-130)	188 (70 - 510)	12.6 ± 5.14 (5.5 - 36.5)	5.68 ± 2.32 (2.5 - 16.44)	8.58 ± 2.32 (2.5 - 24.82)	7.62 ± 3.2 (3.2 - 22.4)
Spiral*	120	242 (150 - 300)	15.6 ± 3 (11.8 - 19.1)	7.02 ± 1.14 (5.32 - 8.6)	10.6 ± 1.72 (8 - 12.95)	9.56 ± 1.55 (7.24 - 11.7)
Multislice						
Dual slicer	123 (120-130)	189 (60 - 510)	11.97 ± 6.6 (3.15 - 28.63)	5.4 ± 2.96 (1.42 - 12.9)	8.14 ± 4.5 (2.14 - 19.5)	7.34 ± 4.03 (1.93 - 17.6)
4-slicer	120	183 (120 - 300)	13.4 ± 4.3 (11 - 22.03)	6.04 ± 1.9 (4.96 - 9.9)	9.11 ± 2.9 (7.5 - 15)	8.22 ± 2.62 (6.76 - 13.5)
6-slicer	120 (110-130)	188 (140 - 240)	13.6 ± 4.13 (10.23 - 20.5)	6.11 ±1.86 (4.6 - 9.2)	9.22 ± 2.8 (6.95 - 13.9)	8.32 ± 2.54 (6.3- 12.6)
8-slicer	120	340	13.37	6.02	9.09	8.21
16-slicer	120	400	40.59	18.29	27.6	24.91
24-slicer	120	200	11.8	5.32	8.02	7.24
64-slicer	122 (120- 135)	215 (140 - 300)	13.72 ± 3.89 (6.29 - 18.4)	6.18 ± 1.75 (2.84 - 8.3)	9.33 ± 2.64 (4.28 - 12.5)	8.42 ± 2.4 (3.9 - 11.3)

*Refurbished machines

Table 3: Effective doses, CTDIw and exposure parameters used for abdomen CT examinations performed using various CT scanners

Type of machine	*Mean tube potential (range)*	*Mean mAs (range)*	*Mean $CTDI_{vol}$ ± SD (range)*	*Abdomen effective dose in mSv ± SD (range)*		
				Minimum scan length (10.8 cm)	*Maximum scan length (44 cm)*	*Mean scan length (33.8 cm)*
Conventional	122 (120 - 130)	205 (150 - 270)	13.6 ± 2.25 (10.2 - 16.7)	2.2 ± 0.37 (1.66 - 2.7)	8.97 ± 1.5 (6.75 - 11)	6.89 ± 1.14 (5.2 - 8.5)
Conventional*	119 (110 - 130)	215 (130 - 360)	13.3 ± 3.59 (8 - 20.5)	2.15 ± 0.58 (1.3 - 3.3)	8.77 ± 2.4 (5.3 - 13.5)	6.74 ± 1.82 (4.1 - 10.4)
Spiral	121 (110 - 130)	188 (70 - 510)	12.6 ± 5.14 (5.5 - 36.5)	2.04 ± 0.83 (0.89 - 5.9)	8.18 ± 3.4 (2.5 - 24.1)	6.39 ± 2.6 (2.79 - 18.5)
Spiral*	120	242 (150 - 300)	15.6 ± 3 (11.8 - 19.1)	2.52 ± 0.41 (1.9 - 3.1)	10.3 ± 1.67 (7.8 - 12.6)	7.9 ± 1.28 (5.98 - 9.65)
Multislice						
Dual slicer	123 (120 - 130)	189 (60 - 510)	11.97 ± 6.6 (3.2 - 28.6)	1.94 ± 1.1 (0.51 - 4.64)	7.9 ± 4.33 (2.1 - 18.9)	6.1 ± 3.3 (1.6 - 14.5)
4-slicer	120	183 (120 - 300)	13.4 ± 4.3 (11 - 22.03)	2.17 ± 0.69 (1.78 - 3.6)	8.84 ± 2.8 (7.3 - 14.54)	6.79 ± 2.2 (5.58 - 11.2)
6-slicer	120 (110 - 130)	188 (140 - 240)	13.6 ± 4.13 (10.2 - 20.5)	2.2 ± 0.67 (1.66 - 3.3)	8.95 ± 2.73 (6.75 - 13.5)	6.87 ± 2.1 (5.2 - 10.37)
8-slicer	120	340	13.37	2.17	8.83	6.78
16-slicer	120	400	40.59	6.58	26.79	20.58
24-slicer	120	200	11.8	1.91	7.79	5.98
64-slicer	122 (120 - 135)	215 (140 - 300)	13.7 ± 3.89 (6.3 - 18.4)	2.22 ± 0.63 (1.02 - 2.98)	9.05±2.56 (4.15-12.15)	6.95 ± 1.97 (3.19 - 9.33)

*Refurbished machines

Table 4: Effective doses, CTDIw and exposure parameters used for pelvis CT examinations performed using various CT scanners

Type of machine	*Mean tube potential (range)*	*Mean mAs (range)*	*Mean CTDIvol ± SD (range)*	*Pelvis effective dose in mSv ± SD (range)*		
				Minimum scan length (12 cm)	*Maximum scan length (23.2 cm)*	*Mean scan length (19.1 cm)*
Conventional	122 (120 - 130)	205 (150 - 270)	13.6 ± 2.3 (10.2 - 16.7)	3.1 ± 0.51 (2.3 - 3.8)	6 ± 0.9 (4.51 - 7.4)	4.93 ± 0.82 (3.71 - 6.05)
Conventional*	119 (110 - 130)	215 (130 - 360)	13.3 ± 3.6 (8 - 20.5)	3.03 ± 0.82 (1.8 - 4.7)	5.86 ± 1.6 (3.54 - 9.02)	4.82 ± 1.3 (2.9 – 7.42)
Spiral	121 (110 - 130)	188 (70 - 510)	12.6 ± 5.1 (5.5 - 36.5)	2.88 ± 1.17 (1.3 - 8.3)	5.6 ± 2.3 (2.4 - 16.1)	4.6 ± 1.87 (2 – 13.25)
Spiral*	120	242 (150 - 300)	15.6 ± 3 (11.8 - 19.1)	3.55 ± 0.56 (2.7 - 4.3)	6.9 ± 1.1 (5.2 - 8.4)	5.7 ± 0.92 (4.3 - 7)
Multislice						
Dual slicer	123 (120 - 130)	189 (60 - 510)	12 ± 6.6 (3.2 - 28.6)	2.73 ± 1.5 (0.7 - 6.5)	5.3 ± 2.9 (1.4 - 12.6)	4.3 ± 2.38 (1.14 - 10.4)
4-slicer	120	183 (120-300)	13.4 ± 4.3 (11 - 22)	3.06 ± 0.97 (2.5 - 5)	5.9 ± 1.9 (4.9 - 9.7)	4.9 ± 1.55 (4 - 8)
6-slicer	120 (110 - 130)	188 (140 - 240)	13.6 ± 4.1 (10.2 - 20.5)	3.09 ± 0.94 (2.3 - 4.7)	6 ± 1.82 (4.5 - 9)	4.9 ± 1.5 (3.71 - 7.42)
8-slicer	120	340	13.4	3.05	6	4.85
16-slicer	120	400	40.6	9.25	18	14.73
24-slicer	120	200	11.8	2.69	5.2	4.28
64-slicer	122 (120 - 135)	215 (140 - 300)	13.7 ± 3.9 (6.3 - 18.4)	3.13 ± 0.89 (1.4 – 4.2)	6.1 ± 1.71 (2.8 - 8.1)	5 ± 1.41 (2.3 - 6.68)

*Refurbished machines

study were 8.04, 6.69 and 4.79 mSv for thorax, abdomen and pelvis CT examinations, respectively.

Figures 1, 2 and 3 show distribution of radiation doses for CT examinations of thorax, abdomen and pelvis, respectively. The effective doses reported by Wall and Hart were 8 mSv for thorax, 10 mSv for abdomen and 10 mSv for pelvis examinations.[18] Considering these values for comparison, it was found that 60 scanners imparted doses above 8 mSv for thorax examinations; 8 scanners, above 10 mSv for abdominal CT examinations; and 3 scanners, above 10 mSv for pelvis CT examinations. Variations in effective doses in comparison with those reported in studies found in literature may be attributed to the stature of the Indian population, selection of CT protocols, differences in scan lengths and machine-related parameters. CT machines are

Table 5: Comparison of DLP and effective doses in the current study with those reported in literature

Region	*Mean effective dose in mSv (range)*	*Regional DRLs from the current study*		*European reference[10]*	*Mettler et al.[16]*	*Reported values in literature[16]*	*Wall and Hart[11]*	*Hiles et al.[15]*	*Kharuzhyk et al.[17]*
		Mean DLP in mGy cm (range)	*Third quartile*	*DLP (mGy cm)*	*Mean effective dose (mSv)*	*Effective dose (mSv)*	*Effective dose (mSv)*	*DLP (mGy cm)*	*DLP (mGy cm)*
Thorax	8.04 ± 3.28 (1.93 – 24.9)	476 ± 191.67 (113.72 – 1465.4)	557	650	7	4 - 18	8	663	500
Abdomen	6.69 ± 2.69 (1.6 – 20.58)	445.8 ± 179.46 (106.5 – 1372)	521	780	8	3.5 - 25	10	745	600
Pelvis	4.79 ± 1.93 (1.14 – 14.73)	251.9 ± 101.41 (60.17 – 775.29)	294	570	6	3.3 - 10	10	-	490

Table 6: Details on availability of radiation safety accessories in various CT centers

Safety accessories	*Number of centers*	
	Available	*Not available*
Safety placard	50	77
Warning light	68	59
Leadlined door	125	2
Leadequivalent glass	127	-
Personnel dosimeters	56	71
Lead rubber apron	122	5

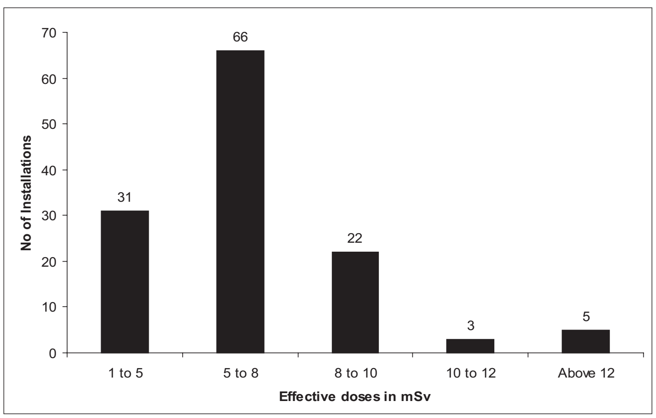

Figure 2: Mean effective doses for abdomen CT examinations from various CT installations

invariably imported from various countries, and the preset parameters are in accordance to the population of the respective countries. These preset parameters need to be altered in order to optimize doses for the Indian population. It is the need of the hour that examination protocols set in the machine are tailored according those required for the Indian population. In various centers, exposure parameters were increased or preset parameters were employed to achieve good-quality images. In this context, it is worth suggesting that dose-modulation techniques that are available in most of the modern CT scanners be adopted. These techniques are programmed in such as way that the exposure parameters are adjusted according to the age and weight of the patients.[19]

Due to the increase in the number of CT examinations

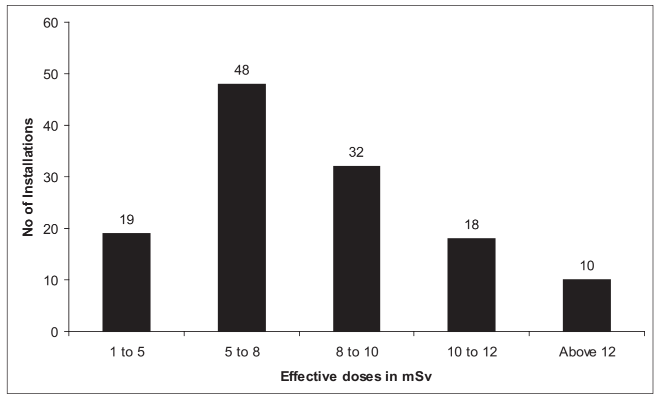

Figure 1: Mean effective doses for thorax CT examinations from various CT installations

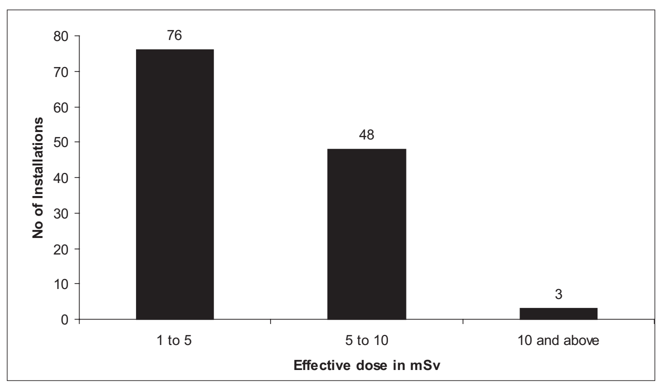

Figure 3: Mean effective doses for pelvis CT examinations from various CT installations

performed each day, it is necessary that each scanner is provided with dose derivatives on the CT console.[2,20] In the survey in Tamil Nadu, it was found that 74 (58%) scanners had dose descriptors such as CTDI, DLP, $CTDI_w$, $CTDI_{vol}$ and effective doses displayed on the control console of the scanner. None of the conventional and refurbished conventional scanners had dose descriptors displayed on the control console. Out of the 59 SSHSs, 30 scanners had dose descriptors displayed on the console, while all the MSCT scanners had dose descriptors displayed on the console. In the survey, it was found that machine calibrations were performed in 73 centers once in every 6 months or 1 year, while no calibration was performed for the rest of the machines. Routine air calibration protocols were used before clinical work in 16 centers, while 109 machines were restricted to warming up the scanner. At almost all centers, users had limited knowledge of interpreting the dose descriptors displayed on the console, and often these parameters were neglected.

Table 6 shows availability of radiation safety accessories in Tamil Nadu. The room layout and the safety regulations were verified in accordance to the rules promulgated by the AERB.[21] Seventy-two installations had room sizes below the prescribed room size of 25 m^2. It was observed that most of the operators operating the CT scanner were not aware of the basic concepts of radiation protection. Various centers did not have personnel for monitoring devices, and there was lack of availability of safety placard or warning light. Radiation safety in the Indian scenario is of concern because of the increase in the number of examinations performed each day. Hence adequate orientation and training of personnel are required currently in order to maintain doses as low as reasonably practicable (ALARP).

Conclusion

This study presents the results of the initial survey on CT scanners in order to formulate regional DRLs for CT scanners in Tamil Nadu. Significant variation of doses was recorded during the survey, and this discrepancy could be due to differences in scanning protocols and scanner-related parameters. Standardization of protocols and optimization of exposure parameters are required in the current scenario. Personnel operating the CT scanner should be aware of radiation-safety–related issues and have adequate knowledge about dose descriptors displayed on the CT console. Performance of such surveys is essential in various regions of the country in order to formulate national reference levels.

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