Assessment of Regional Diagnostic Reference Levels in Dental Radiography in Tamil Nadu

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Abstract

Aim: The aim of this article is to assess Tamil Nadu adult diagnostic reference levels (DRLs) by collecting radiation dose data from the four different dental modalities. **Materials and Methods:** The study was carried out using routine adult exposure settings in 131 intraoral, 75 panoramic, 35 cephalometric, and 10 dental cone beam computed tomography (CBCT) X-ray devices. DRLs were assessed for intraoral and extraoral (panoramic, cephalometric, and CBCT) examinations in terms of incident air kerma ($K_{a,i}$) and kerma area product (P_{KA}), respectively. Air kerma measurements, for all dental units, were made using calibrated RTI black Piranha 557 dosimeter (RTI Electronics AB, Sweden). The dosimeter was kept at the exit cone of the X-ray tube and on the detector side of the X-ray unit for intraoral and extraoral air kerma measurements, respectively. The obtained air kerma in extraoral modalities is multiplied with the beam area to evaluate P_{KA}. **Results:** The third quartile values calculated from the median for adult intraoral (mandibular molar), panoramic, cephalometric, and CBCT were 1.5 mGy, 116 mGycm^2, 40 mGycm^2, and 532 mGycm^2, respectively. The proposed DRL in the present study was comparable to those reported in Germany, Greece, the UK, Japan, and Korea. **Conclusion:** This study revealed the need for dose management and radiation dose optimization, in various dental facilities in the state. It was also found that dental facilities employed with the digital type of detector are not always related to lower exposure.

Keywords: Cephalometric radiography, diagnostic reference levels, intraoral radiography, panoramic radiography

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Introduction

According to the United Nations Scientific Committee on the Effect of Atomic Radiation 2008 report, dental radiography is one of the most frequently used radiological procedures.[1] Moreover, dentists prefer to use radiographs more frequently than any other health professional.[2] Although radiation doses from dental exams are low and the associated health risk is stochastic, repeated dental exposures may lead to unnecessary patient exposure, leading to increased population dose and population risk. The radiation dose optimization during dental radiography is now an important concern for dental professionals and regulatory bodies.[3]

Diagnostic reference levels (DRL) is an important dose optimization tool used in medical imaging recommended by many professional and international organizations, including the International Commission on Radiological Protection (ICRP),[4] American College of Radiology,[5] American Association of Physicists in Medicine,[5] Health Protection Agency,[6] and the International Atomic Energy Agency.[7] DRLs for dental radiography, as in other imaging modalities, are usually set at the 75th percentile of the median values from the survey of radiation doses.[4]

The development in imaging technology and the modifications of examination protocols may produce sufficient image quality at lower doses. Thus, dose surveys may show variations in radiation doses between different dental facilities for the same examination and similar patient groups. DRLs are the standard tool for finding unusually high or low radiation dose levels, which calls for local review if constantly surpassed.[4]

Several countries[8,9] and organizations[10] have already proposed DRL in dental radiography. Similar DRL studies

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were undertaken by our group too, in India, in computed tomography (CT),[11] but so far no serious studies have been undertaken in dental radiography. Hence, our group at PSG Institute of Medical Sciences and Research, Coimbatore, extended the DRL work to the field of dental radiography, in consultation with and a grant from the Atomic Energy Regulatory Board of India.

Materials and Methods

Selection of dental facilities

DRL assessments were performed on 131 intraoral, 75 panoramic, 35 cephalometric, and 10 cone-beam CT (CBCT) units installed in dental clinics, colleges, and hospitals, spread across Tamil Nadu, India. These dental facilities were chosen based on their workload, clinical experience, and willingness to participate in the study for the establishment of dental DRLs in the country. Of the dental facilities surveyed, 89 facilities from more than 20 major cities in Tamil Nadu, having a total of 251 dental X-ray units, met our selection criteria and participated in the study. Before initiating the measurements in dental facilities, a questionnaire was posted to the various centers to collect data regarding the exposure parameters routinely used for imaging, radiation safety status, and type of detectors (film or digital) in use. The DRL studies were performed on all the units over a period of 2 years, between 2018 and 2020.

Dosimeter selection

Air kerma measurements, for all dental units, were made using calibrated RTI black Piranha 557 dosimeter (RTI Electronics AB, Sweden). The dosimeter, apart from air kerma, also displays the air kerma rate, tube voltage, exposure time, half-value layer, and total filtration. The calibration range of the dosimeter was suitable for the diagnostic range (35–155 kV) for all modes of dental X-ray examinations, as the Piranha readings are accurate to ± 1.5%.[12]

Quality assurance tests

Quality assurance (QA) tests were performed on all selected X-ray units before commencing the DRL assessment work. During the QA tests, parameters such as accuracy of exposure time, operating potential, the linearity of tube current (mA/mAs), consistency of radiation output, and radiation leakage level from X-ray tube housing were checked. DRL assessments were performed only on those units that passed the QA tests.

Diagnostic reference levels quantities

In the present study, DRL in the intraoral (maxillary molar) examination was determined in terms of Incident air kerma ($K_{a,i}$), expressed in mGy. On the other hand, DRLs in panoramic, cephalometric, and CBCT (small FOV) radiographs were determined in terms of Kerma Area Product (P_{KA}), expressed in mGycm^2, which, along with the air kerma, also takes into account the area of exposure. After finding $K_{a,i}$ (intraoral), and P_{KA} (extraoral) for the sample population from each center, the median value of the dose distribution was estimated for proposing the DRL.[4]

Intraoral radiography

Out of 131 intraoral units manufactured by 22 different vendors involved in the study, 64 were digital (storage phosphor-based/charge-coupled device [CCD] based), and the remaining were analog using films (E/F speed films) as image receptors. The majority of the X-ray units selected for this study were operating at 70 kV [Figure 1]. Out of the total, 91 units have preset exposure parameters. Cone lengths of X-ray units varied from 20 to 22 cm and the majority of units (126) used circular cones with 6 cm diameter (The remaining 5 units were equipped with rectangular field size having an area of 16 cm^2).

The experimental method for DRL evaluation in intraoral radiography was based on the studies performed by Izawa *et al*.[13] and Poppe *et al*.[14]. The dosimeter was kept at the exit cone of the X-ray tube and the sensitive area of the dosimeter is fully covered by the primary beam as shown in Figure 2a. After positioning the dosimeter, $K_{a,i}$ measurements were taken using routine exposure parameters in the absence of patients. The dosimeter has a lead backing that blocks surface backscattering and gives accurate $K_{a,i}$ values.

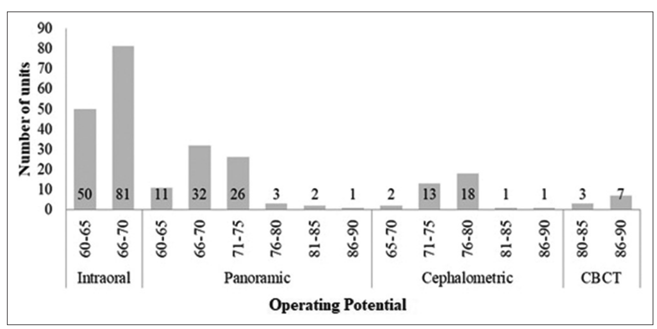

Figure 1: Operating potential distribution of dental X-ray units

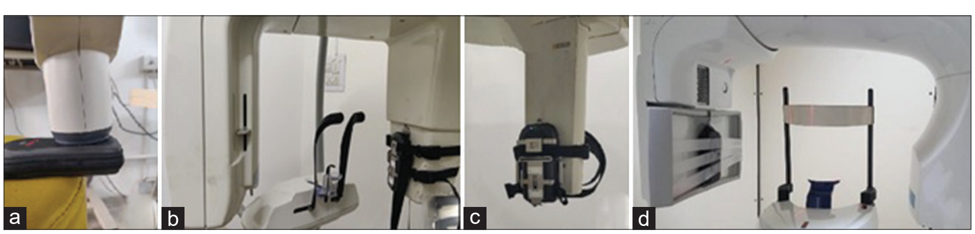

Figure 2: Pictorial representation of air kerma measurement towards diagnostic reference levels assessment used for intraoral (a), panoramic (b), cephalometric (c), and cone beam computed tomography (d) radiography

Extraoral radiography

Sixty of the 75 panoramic units, 27 of the 35 cephalometric units, and the entire CBCT units were equipped with direct digital (digital) (CCDs and complementary metal-oxide semiconductor) imaging systems. The remaining panoramic and cephalometric units were operating with a storage phosphor plate and using computed radiography (CR) cassettes as image receptors. In this study, 22, 8, and 5 different models of panoramic, cephalometric, and CBCT units, respectively were included.

The experimental methods for panoramic radiography were based on Lee *et al*.[15] and the National Radiological Protection Board assessment of panoramic X-ray sets as proposed by Napier.[16] The same method was also used in our previous studies for evaluating DRLs in panoramic radiography.[17,18] For the air kerma measurements, the solid-state dosimeter was placed directly at the detector side of the X-ray unit as shown in Figure 2b-d. It is significant that the dosimeter is positioned precisely with respect to the X-ray beam. The positional accuracy of the dosimeter was verified with the RTI's Ocean 2014 software (that connects Piranha 557 directly to the computer). After placing the dosimeter, the standard patient exposure parameter was simulated and the air kerma was recorded over a standard adult exposure cycle (Minimum 20 procedures from each dental unit). For the entire study, the air kerma was measured in the absence of the patient. The measured air kerma is then multiplied by the exposed beam area (measured) at the detector position. CR cassette was used to capture the image of the X-ray field size by placing it at the detector position. The indirectly measured P_{KA} value is then compared with the displayed P_{KA}, either in the console monitor or in the extraoral unit itself, after every exposure. The same methods were followed for the DRL evaluation with cephalometric and CBCT units too.

Statistical method

Following the guidelines of ICRP 135,[4] the present study has found the median value from each dental X-ray unit (median from minimum 20 readings). From these obtained median readings, the DRLs were found at the 75th percentile using Microsoft spreadsheets by the formula "PERCENTILE (array, k)," where the array represents the list of median indirectly measured P_{KA} or $K_{a,\,i}$ values and k denotes 0.75 in the present study.

Results and Discussion

Typical exposure parameters used by the various dental facilities are shown in Table 1.

As shown in Table 2, it was observed that, in intraoral radiography, $K_{a,\,i}$ ranged from 0.1 to 6.0 mGy with an average of 1.0 mGy (standard deviation [SD] = 1.0 mGy) for digital units and 0.2–5.2 mGy with an average of 1.6 mGy (SD = 1.1 mGy) for film based units. Notably, the maximum $K_{a,\,i}$ (6 mGy) was observed from a digital unit that was functioning with no preset exposure parameter. The existences of 60 fold variation between the minimum (0.1 mGy) and maximum (6.0 mGy) $K_{a,\,i}$ can be ascribed to the absence of an optimized preset exposure parameter, variation in the type of image receptors, exposure techniques, beam quality, inherent filters, cone length, and age of the unit. The trained X-ray engineer (who is installing the equipment) or medical physicist should educate the dentists/radiographers regarding the optimized use of exposure parameters if the preset exposure parameter is not present.

The second observation is that for panoramic radiography, the P_{KA} values of direct digital units ranged from 40.5 to 149.1 mGycm^2 with an average of 91.4 mGycm^2 (SD = 30.5 mGycm^2), whereas the P_{KA} of CR type of units ranged from 64.9 to 165.1 mGycm^2 with an average of 108.9 mGycm^2 (SD = 28.9 mGycm^2). Twenty-seven units (36%) were assessed with P_{KA} >100 mGy. cm^2, suggesting the requirement of necessary attention to be paid by the manufacturers when setting the adult standard mode of exposure parameters. The average median P_{KA} was almost 19% higher in CR systems than digital systems. This difference can be mainly ascribed to the difference in exposure parameters and beam area. The film screen-based systems in panoramic radiography, with almost the same sensitivity as digital detectors, are considerably more sensitive to radiation than intraoral films.[19] Out of 43 displayed P_{KA} values, the deviations between the indirectly measured and console display P_{KA} values were within ± 18%.

In cephalometric radiography, almost a 6-fold difference was observed between the minimum (12.3 mGycm^2) and

Table 1: Typical exposure parameters used for different dental modalities

Exposure parameters	Range						
	Intraoral		Panoramic		Cephalometric		CBCT
	Film	Digital	CR	Digital	CR	Digital	Digital
Tube voltage (kVp)	60-70	60-70	65-90	64-85	65-80	72-90	84-90
Tube current (mA)	2-10	2-8	10-12	5-15	10-10	6-15	4-12
Exposure time (s)	0.1-1.4	0.1-0.8	12-18	9-18	0.8-2	0.5-9	11-24
Beam area (cm^2)	-	-	7-10	4-10	432-432	10-900	60-141
FOV (diameter × height) (cm^2)	-	-	-	-	-	-	5×5-15×9
Voxel size (mm)	-	-	-	-	-	-	0.2-0.3

CR: Computed radiography, CBCT: Cone beam computed tomography, FOV: Fields of view

Table 2: Median and proposed diagnostic reference levels values for different dental examinations

Parameters	Intraoral		Panoramic		Cephalometric		CBCT
	Film	Digital	CR	Digital	CR	Digital	Digital
Median $K_{a,I}$ (mGy)							
Range (average)	0.2-5.2 (1.6)	0.1-6.0 (1.0)	-	-	-	-	-
SD	1.1	1.0	-	-	-	-	-
Median P_{KA} (mGycm^2)							
Range (average)	-	-	64.9-165.1 (108.9)	40.5-149.1 (91.4)	19.4-42.4 (33.4)	12.3-79.0 (34.2)	176.1-890.5 (460.4)
SD	-	-	28.9	30.5	7.2	12.7	240.6
DRL (3rd quartile)							
$K_{a,i}$ (mGy)	2	1	-	-	-	-	-
P_{KA} (mGycm^2)	-	-	135	113	39	40	532
Deviation range (%) between console P_{KA} and indirectly measured P_{KA}	-		-	±18	-	−8-12	−15-5

SD: Standard deviation, CR: Computed radiography, CBCT: Cone beam computed tomography, DRL: Diagnostic reference level, $K_{a,i}$: Incident air kerma, P_{KA}: Kerma area product

Table 3: Comparison of present studies' and other countries' diagnostic reference levels for dental radiography

Type of dental radiography	Country	Year	Number of units	DRL (3rd quartile)
Intraoral (mandibular molar) ($K_{a,i}$ in mGy)	Japan[13]	2017	3	1.51
	Germany[14]	2006	60	1.5
	Cyprus[21]	2016	20	4.75
	Korea[22]	2012	102	3.1
	Peru[23]	2021	254	4.21
	This study	2021	131	1.5
Panoramic (P_{KA} in mGycm^2)	Greece[24]	2004	62	117
	Korea[25]	2011	42	120.3
	UK[26]	2000	16	139
	Germany[27]	2006	50	101
	Kosova[28]	2019	21	93
	This study	2021	75	116
Cephalometric (P_{KA} in mGycm^2)	Germany[29]	2007	20	32.6
	UK[30]	2011	42	41
	This study	2021	35	40
CBCT (P_{KA} in mGycm^2)	Portugal[31]	2020	69	580
	Finland[32]	2016	47	360
	UK[33]	2017	214	265
	This study	2021	10	532

CBCT: Cone beam computed tomography, DRL: Diagnostic reference level, $K_{a,i}$: Incident air kerma, P_{KA}: Kerma area product

maximum (79.0 mGycm^2) direct digital P_{KA} values whereas, there is only a 2-fold difference between the minimum (19.4 mGycm^2) and maximum (42.4 mGycm^2) values of CR units. This difference can be mainly attributed to the difference in exposure parameters, beam area, inherent filters, and the tube age. Further, the deviation between console displayed and indirectly measured P_{KA} values varied from −8% to 12% (25 units).

Following the division proposed by Ludlow,[20] small FOVs, in CBCT, are defined as any field with a height ≤ of 10 cm. All operators used small FOV in the present study. The majority of CBCT units (7 units) are operating at 86–90 kVp. The P_{KA} values of CBCT units ranged from 176.1 to 890.5 mGycm^2 with an average of 460.4 mGycm^2 (SD = 240.6 mGycm^2) [Table 2]. The difference in tube rotation time, preset exposure parameters, voxel size, and FOV might also result in variation in P_{KA}. It was observed that different FOVs were set at various dental facilities by the X-ray engineer for the same CBCT units and the same examination, resulting in unnecessary radiation exposure to anatomical regions not related to the diagnostic examination. Apart from that, the lack of training for the X-ray operators in radiation protection also makes them use the same FOV size, independent of the anatomic region, during the X-ray procedure. Regarding the P_{KA} values shown by the equipment, all the equipment have P_{KA}-meter included, and the deviation range between console P_{KA} and indirectly measured P_{KA} values were between -15% and 5% for CBCT units.

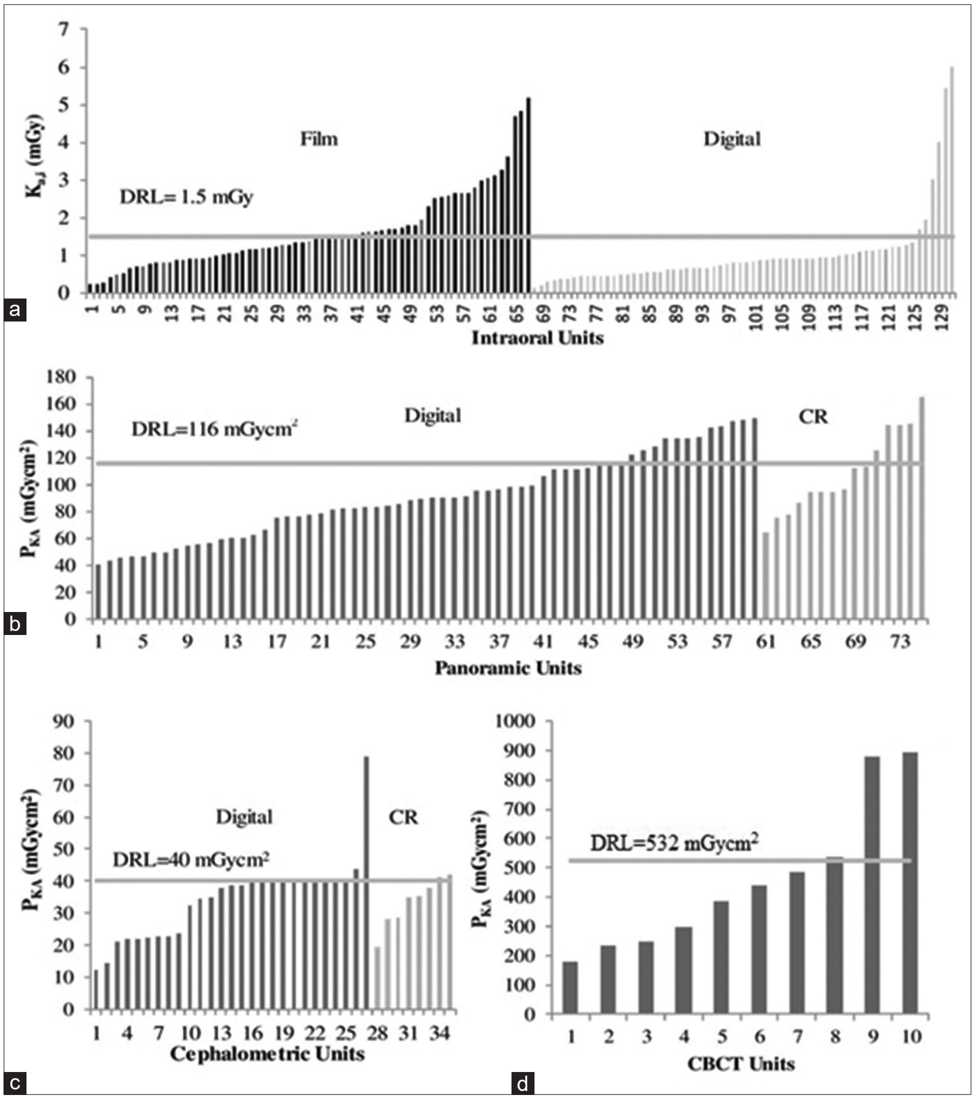

Figure 3: Proposed diagnostic reference levels (horizontal bar) for intraoral (a), panoramic (b), cephalometric (c) and cone beam computed tomography (d) examinations

The third quartile $K_{a,\ i}$ value for mandibular molar intraoral radiography was 1.5 mGy (For Film, DRL = 2 mGy and for Digital, DRL = 1 mGy). The third quartile P_{KA} values for panoramic, cephalometric, and CBCT radiography were 116 mGycm^2 (For CR, DRL = 135 mGycm^2 and for Digital, DRL = 113 mGycm^2), 40 mGycm^2 (For CR, DRL = 39 mGycm^2 and for Digital 40 mGycm^2) and 532 mGycm^2, respectively.

Figure 3 shows the graphical representation of proposed DRLs for intraoral, panoramic, cephalometric, and CBCT examinations. The third quartile values of all the examinations are marked in the figure. Alongside with the P_{KA} values, the image detectors used are also indicated in the graphs. There exists a large difference between the radiation doses of dissimilar X-ray units for the same examination. As an example, the assessed P_{KA} values for panoramic examinations varied from 40.5 to 165.1 mGycm^2.

Based on the questionnaire study, it was observed that the majority of dental units included in this study were digital detector-based and, many participants (dentists and radiographers) were unwilling to adjust the exposure parameters according to the tooth location and patient size. However, the higher radiation dose observed in many digital-based dental units in the present study further confirms that after replacing film/screen with digital systems, the exposure parameters were not changed effectively to achieve dose optimization.

The variation in dose quantity values among different dental facilities indicates the scope for publishing technical guidelines and image quality criteria for dental radiography modalities. The observed differences between indirectly measured P_{KA} and the console P_{KA} [Table 2] were less than the tolerance interval (±30%) and the observed variation can be attributed to the difference in the measurement method and dosimetry.

Comparison of the third quartile value of $K_{a,i}$ for the intraoral procedure, with the other countries' DRLs [Table 3], reveals that the values obtained in this study are close to values obtained in studies in Japan[13] (1.51 mGy) and Germany[14] (1.5 mGy), and lower than values obtained in Cyprus[21] (4.75 mGy), Korea[22] (3.1 mGy), and Peru[23] (4.21 mGy). The vast use of fast-speed films and digital detectors may also have contributed to the lower DRLs in the present study.

Our results in panoramic radiography were similar to the results of Greece,[24] and Korea,[25] lower than the results of the UK[26] and higher than Germany[27] and Kosova[28] results [Table 3]. In cephalometric radiography, the measured P_{KA} values were comparable to the values in Germany[29] and the UK.[30] The variation in the present study P_{KA} may be attributed to the difference in patient physical parameters, exposure parameters, tube inherent filtration, type of dosimeter and the method of use, and the year of study (older and newer units).

DRL studies for CBCT radiography have been carried out only in some countries such as Portugal,[31] Finland,[32] and the UK[33] [Table 3]. Finland[32] and the UK[33] chose the data without adapting the values to the most used FOV.[34] The DRL for small FOV in Portugal[31] is comparable with the present study.

The previous study[17] done by our team has used mean value rather than the median for proposing DRL in panoramic radiography as per the earlier recommendations.[35,36] However, the latest ICRP recommendation on DRL (ICRP 135, 2017)[4] recommends the use of a facility's median value (rather than mean value) for calculating 75th percentile as this is renowned to be more robust and representative of the patient population.

The constraint of this study is the limited number of X-ray devices studied. However, it is suggested to include a representative number of dental X-ray facilities for the assessment of national DRLs in dental radiography.

Conclusion

Dental DRLs were proposed in intraoral, panoramic, cephalometric, and CBCT dental radiography in India. The proposed DRLs are comparable with the other countries' DRLs. The selection of suitable exposure parameters for dental radiography should be driven by the clinical suggestion from the dentists. However, the wide dose distribution obtained in the present study indicates the need to improve the radiation dose optimization without affecting the image quality. Further surveys are suggested at different states across the country to propose the national DRL as well as to establish criteria for optimal levels of image quality considering patient dose. It is suggested to conduct more training programs in the use of image receptors and dose optimization in dental radiography for radiographers and dentists.

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Conflicts of interest

There are no conflicts of interest.

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