RPE | Radiation Physics & Engineering
A Peer-Reviewed Journal
Published by K.N. Toosi University of Technology
http://rpe.kntu.ac.ir
Research Article

Radiation Physics and Engineering 2024; 5(3):35–39

Determination of diagnostic reference level in routine examinations of digital radiography in Nigeria

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HIGHLIGHTS

- This study encompassed Chest PA, Chest LAT X-ray examinations conducted in hospitals in Nigeria's Western Region.
- The mean ESDs for Chest PA (2.43 mGy) and Chest LAT (2.39 mGy) exceeded the DRLs set by CEC in 1996.
- It was found that digital X-ray machines satisfy the established criteria for acceptability.
- The equipment employed in the PFs was outdated likely contributing to the higher recorded ESDs.
- DRL was compared with the international organizations' levels, it can be reduced by adequate training of radiographers.

ABSTRACT

While ionizing radiation plays a pivotal role in precise diagnosis and treatment, it concurrently engenders risks, including an elevated incidence of cancer. The research speaks to the discernible decline in quality assurance programmes and dose measurement endeavors within Nigerian imaging facilities, with a substantial portion lacking established protocols for routine machine calibration and dose measurement. This study encompasses a large-scale survey involving 307 adult patients undergoing routine X-ray procedures in two hospitals in Nigeria. Thermo-luminescent dosimeters (TLDs) were used for measuring Entrance Skin Dose (ESD). The mean ESD values ranged from 1.16 mGy to a maximum of 3.94 mGy. Notably, these values were predominantly below the dose reference levels (DRLs) established by reputable bodies such as NRPB, CEC, IAEA, and UK for most examinations. The main purpose of this study was to determine the diagnostic reference level (DRL) for routine digital radiography examinations in Nigeria.

KEYWORDS

Diagnostic reference level (DRL)
Thermo-luminescent dosimeters
Entrance Skin Dose (ESD)
Radiography

HISTORY

Received: 7 April 2024
Revised: 1 June 2024
Accepted: 3 June 2024
Published: Summer 2024

1 Introduction

The utilization of X-ray technology has grown significantly in modern healthcare, contributing to both medical diagnosis and treatment. X-ray procedures represent a prominent source of man-made radiation exposure to the global population and play a vital role in healthcare applications (Unscear, 2000) While X-ray procedures offer numerous advantages, it's crucial to recognize their potential for causing radiation-induced harm to patients. This highlights the importance of comprehending patient and personnel radiation doses, as well as the factors that influence them (Parry et al., 1999). Monitoring radiation dosage consistently, as directed by international regulatory guidelines, helps to assess the range and diversity of patient exposure levels, identifying reasons for disparities (Johnston and Brennan, 2000). Dosimetry plays a pivotal role in evaluating areas that necessitate modifications and endeavors aimed at reducing radiation exposure (NRPB, 1992).

According to a recent assessment conducted by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), approximately half of the world's population undergoes an estimated 3.6 billion diagnostic X-ray examinations each year (UNSCEAR et al., 2000). With the world's population at around 7.9 billion (World-Bank, 2021), this exposure underscores the need for regular audits of diagnostic X-ray imaging systems.

Diagnostic reference levels (DRLs) are recommended internationally for dose optimization, but most imaging facilities in Nigeria lack operational Diagnostic Reference Levels (DRLs). Many imaging facilities do not have operational DRLs, which makes it difficult to establish guidance levels for dose optimization (Ajayi and Akinwumiju, 2000). As stated earlier, thermoluminescence dosemeter (TLD) is the most widely used for ESD measurement in

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https://doi.org/10.22034/rpe.2024.451520.1188

clinical dosimetry.

The aim of this research is to provide valuable insights on how to improve radiation safety measures in diagnostic imaging practices in Nigeria, through the analysis of adult patient doses for Chest LAT and PA radiography examinations in selected hospitals using TLD. This study will also compare the obtained entrance skin doses with some international studies. Finally, DRL will be suggested from the results of this research.

2 Material and Methods

Two most common digital radiographic examinations at 4 high-patient-load radiography centres were investigated. The direct dosimetry method was performed using thermoluminescence dosimeter. Average entrance skin dose (ESD) and the third quartile of ESD as the DRL were evaluated from the measurement made by a thermoluminescence dosemeter. In the selection of the study center, a deliberate choice was made to encompass various types of healthcare facilities that utilize X-rays. This selection included privately owned hospitals, a state-owned hospital, and a federal medical center. Additionally, the geographical distribution of the hospitals was taken into account to ensure comprehensive coverage of the Abeokuta South region in Ogun State. The cooperation and approval of the diagnostic centers' management were pivotal in the selection process. The approval of this study by most facilities was granted upon agreement to a Non-Disclosure Agreement (NDA). These facilities will be labelled H1, H2, H3, H4. Table 1 provides an overview of the chosen X-ray facilities. Additionally, the technical specifications of the digital X-ray equipment are provided in Table 2.

Table 1: Selected X-ray study centers in ogun states characterized by their ownership.

	Types Of Centres	
	State / Public	Private
H1	Yes	-
H2	-	Yes
H3	Yes	-
H4	-	Yes

This study encompasses a large-scale survey involving 307 adult patients undergoing routine X-ray procedures in four hospitals in Nigeria. Thermo-luminescent dosimeters (TLDs) were used for measuring Entrance Skin Dose (ESD). The investigational purpose was transparently communicated to the patients, ensuring the solicitation of their informed consent. While a minority of patients opted not to participate, primarily on the grounds of religious beliefs, only those individuals who provided explicit consent were included in the study. Notably, certain healthcare facilities stipulated written procedural descriptions, while others mandated prior approval from the research ethics committee as prerequisites for study participation and facility utilization.

The investigation was done between November 2021 and October 2022. Given the impracticality of getting patients of precisely standardized dimensions (20 cm - anteroposterior thickness and weight of 70 kg), only individuals who exhibit an average weight within the range of 70 ± 20 kg, were included in this study agreeing with (Compagnone et al., 2005). This is in accordance with the guidelines provided by the Commission of the European Communities (Communities, 1996).

This study explored affixing Thermoluminescent Dosimeters (TLDs) directly to the patients skin at a location that coincides with the center of the incident X-ray beam (Communities, 1996). The thermoluminescent dosimeters (TLDs) utilized in this study were lithium fluoride chips that were activated with magnesium and titanium to enhance their sensitivity. They were calibrated at National Institute of Radiation Protection and Research, University of Ibadan, and was read at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife.

The process of calibration involved sequentially exposing each batch (comprising 10 chips) to a uniform radiation of 80 kV, 142 mAs, 50.2 mGy.h^{-1} (dose rate). Essential parameters known as element correction coefficients (ECC) and reader correction factors (RCF) were obtained through the WinREMS PC. The ECC acts as a multiplier, modifying the reader output (charge in nanocoulombs) to normalize the response of individual dosimeters with the mean response of a set of calibration dosimeters (Hasford et al., 2012). Following this, the Reader Calibration Factor (RCF) was employed to convert the raw charge data extracted from the Photomultiplier Tubes (in Nano coulombs) into dose (D) on the TLD Card, as defined by the International Atomic Energy Agency (Podgorsak, 2005). The combination of these factors was applied in accordance with Eq. (1) to compute the dose (D).

$$\text{Dose} = \frac{\text{ECC} \times \text{C}^0}{\text{RCF}} \quad (1)$$

where ECC is the Element Correction Coefficient, RCF is the Reader Calibration Factor and C0 is the raw charge data from the Photomultiplier Tubes (in Nano coulombs). After field exposure, the TLDs were annealed and made ready again to be taken back to the field. This was done five more times.

TLDs were affixed prior to each examination on every patient. Pertinent exposure parameters, including tube potential kVp, tube loading mAs, and focus-to-skin distance (cm), were meticulously recorded. Additionally, physical attributes such as height, weight, and gender were documented.

Quality assurance tests were done on each of the X-Ray machines to ensure optimal performance. Accuracy and reproducibility of each of tube output kVp, exposure timer mAs, collimation accuracy, and half value layers checks were all done in this study. The results are presented were satisfactory.

3 Results and Discussion

H1 had the highest number of exposures followed by H2 then H3 and H4. H3 had the lowest contribution of all the

Table 2: Radiographic technical data for the two X-ray units.

Technical Data	Hospitals			
	H1	H2	H3	H4
Manufacturer	General Electric	General Electric	Shimadzu	General Electric
Year	2018	2018	2012	1992
Filtration	1.5 mm Al at 100 kV	1.3 mm Al at 75 kV	1.5 mm Al at 75 kV	2.0 mm Al at 100 kV
Max. Voltage	150 kV	150 kV	150 kV	150 kV

Table 3: Mean values and range (in parentheses) of Exposure parameters.

EXAMINATION	Tube Loading (mAs)			
	FMC	UD	GH	FD
CHEST PA	4.3 (3 - 5)	4.35 (3 - 5)	4.26 (3 - 5)	4.4 (3 - 5)
CHEST LAT	7.32 (6 - 8)	7.48 (6 - 8)	7.57 (6 - 8)	7.08 (6 - 8)
EXAMINATION	Tube Potential (kVp)			
	FMC	UD	GH	FD
CHEST PA	109.82 (100 - 120)	94.5 (90 - 100)	111.05 (100 - 120)	109 (100 - 120)
CHEST LAT	111.23 (90 - 130)	96.52 (90 - 100)	112.17 (90 - 130)	109.73 (90 - 130)

participating facilities (PF) due to a broken X-ray machine which took a long period to repair.

Individuals included in this research were grown-ups with an average height of 1.60 meters, aged between 19 and 65 years, which is comparable to the age range utilized in similar studies conducted in Malaysia (14 to 92 years) and the United Kingdom (16 to 99 years) (Brennan et al., 2004). The patients' average thickness and body mass index (BMI) were determined to be 20 centimeters (ranging from 16 to 24 centimeters) and 20.6 kg/m2. The World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP) consider a BMI within the range of 18.5 to 24.99 kg.m^2 to be indicative of a normal (healthy weight) individual (Clement et al., 2012). This also underscores that the mean BMI of the selected patients fell within the WHO's defined normal BMI range.

Figure 1 shows the distribution of patients per examination for all the participating facilities. There were 163 patients (53%) for Chest LAT, 144 patients (47%), Chest PA. This aligns with a study conducted by (Tuokye, 2016), who emphasized that chest radiography remains a highly common and frequently conducted X-ray procedure in the field of diagnostic radiology.

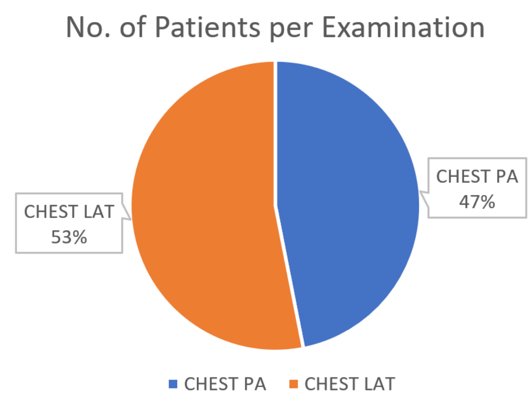

Figure 1: Distribution of patients per examination for all participating facilities.

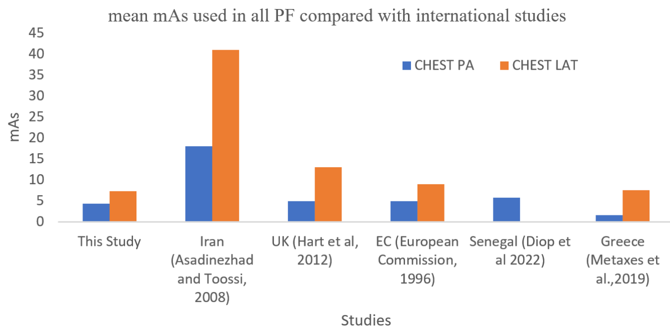

Figure 2: Mean mAs used in all PF compared with international studies.

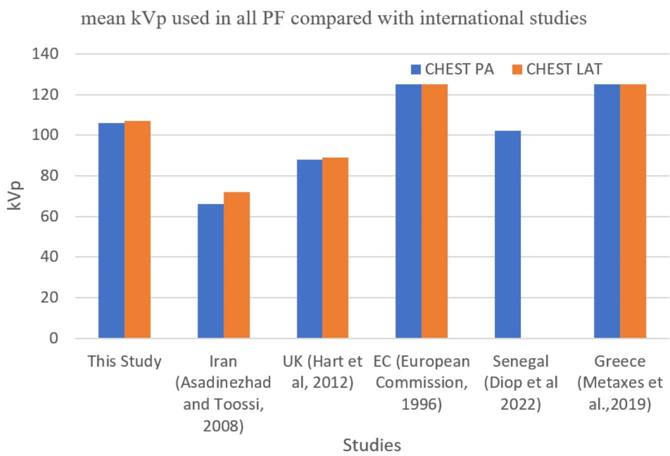

Figure 3: Mean mAs used in all PF compared with international studies.

Understanding Exposure parameters used, Table 3 shows that the range of tube voltage (60 to 130 kVp) mostly selected for all the radiographic examinations was within the range of tube potential selected in the UK (50 to 150 kVp) (Tsapaki et al., 2007). For tube loading (mAs), according to a UK survey, the recommended range is 5 to 485 mAs (Tsapaki et al., 2007). It is observed that the limits in this study (3 to 8 mAs) falls slightly below the lower limit for data from a UK Survey which was 5 to 485 mAs. The highest mean kVp was used in H3 for Chest LAT with 112.17 kVp. In its publication titled European Guidelines on Quality Criteria for Diagnostic Radiographic Images (Communities, 1996), the European Commission advises employing a high kilovolt peak (kVp) of 125 kVp for chest radiography. The values in this study fall within the endorsed range of 70 to 125 kVp as shown in Figs. 2 and 3.

Figure 4 provides a comparison between the mean ESD values observed in the study and the recommended values according to the CEC 1996 guidelines. It's evident that in most cases, the observed mean ESD values exceed the recommended levels. This suggests that there may be a need for dose optimization measures to ensure that patient exposure is within safe limits. The high mAs used in H2 might be the reason for these high ESDs. H3 used slightly lower mAs however, it recorded the low ESDs. This may be attributed to the age of the X-ray tube which were manufactured over 10 years ago. During radiographic examinations, prioritizing the patient's well-being involves reducing the milliampere-seconds (mAs) rather than the kilovolt peak (kVp). Employing lower mAs values can notably decrease the patient's radiation exposure, leading to significant dose reduction (Parry et al., 1999) evident in the discussed study. Suggested DRLs in this study are presented in Table 4 compared with DRLs from international studies. DRL for the examinations of digital radiography was obtained as: Chest (postero-anterior [PA]): 3.01, Chest (lateral [LAT]): 3.07 mGy.

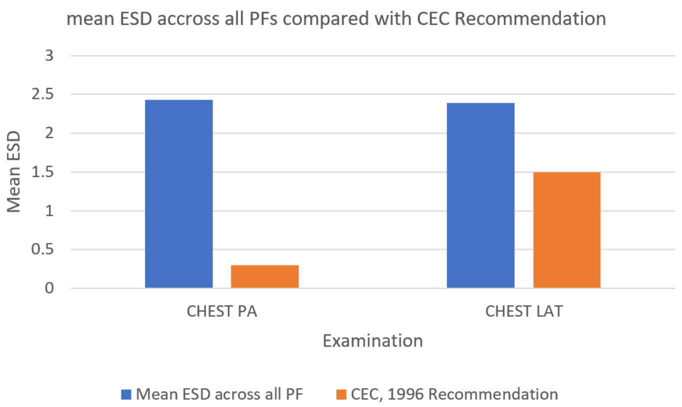

Figure 4: Mean ESDs measured in all PF compared with CEC Recommendation.

Table 4: Recommended DRLs compared to international reference DRL.

EXAMINATIONS	CHEST PA	CHEST LAT
Nigeria (This Study)	3.01	3.07
France (IRSN, 2020)	0.3	0.3
UK (Hart et al., 2010)	0.15	0.15
Germany (Diop et al., 2022)	0.3	0.3
Italy (Compagnone et al., 2005)	0.4	0.4
EC (Commission, 2014)	0.3	0.3
Nigeria (NNRA, 2012)	5	5

4 Conclusions

This study encompassed Chest PA, Chest LAT X-ray examinations conducted in hospitals in Nigeria's Western Region. The entrance surface doses (ESDs) were measured using thermoluminescent dosimeters (TLDs). However, it's worth highlighting that the mean ESDs for Chest PA (2.43 mGy) and Chest LAT (2.39 mGy) exceeded the DRLs set by CEC in 1996 (0.3 mGy). Quality control assessments conducted on digital X-ray machines have shown that these machines satisfy the established criteria for acceptability. However, it is noteworthy that adherence to routine equipment audits is not strict. Furthermore, the equipment employed in the PFs was outdated, having been manufactured over 10 years ago and as far back as 1992, likely contributing to the higher recorded ESDs. DRL was high compared with the international organizations levels, it can be reduced by adequate training of radiographers.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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To cite this article:

Fatile, O., Ajayi, O. S., Arogunjo, A., Ibikunle, S. B. (2024). Determination of diagnostic reference level in routine examinations of digital radiography in Nigeria. *Radiation Physics and Engineering*, 5(3), 35-39. doi: 10.22034/rpe.2024.451520.1188

DOI: 10.22034/rpe.2024.451520.1188

To link to this article: https://doi.org/10.22034/rpe.2024.451520.1188