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Radiation Doses to Patients Undergoing Selected Radiographic Examinations in Three Hospitals South-West, Nigeria

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Abstract
Entrance surface doses (ESDs) to adult patients undergoing Chest, Pelvis, Lumbar Spine and Skull were measured in three hospitals in South-West Nigeria. Measurement was based on thermoluminescence dosimetry (TLD) attached to the skin where the photon beams enter the patients. A total of 203 patients were considered in this study. The estimated mean ESDs obtained were as follows: 2.25 ± 0.79 mGy for Chest (PA), 5.63 ± 0.80mGy for Pelvis (AP), 5.39 ± 0.82mGy for Pelvis (LAT), 8.28 ± 2.80 mGy for Lumbar Spine (AP), 6.99 ± 1.82mGy for Lumbar Spine (LAT), 4.14 ± 0.87mGy for Skull (PA/AP) and 3.52 ± 0.55mGy for Skull (LAT). These values were compared with those reported in similar studies carried out in UK, Sudan and by the International Atomic Energy Agency (IAEA). The mean ESDs were found to be below the IAEA reference values in Pelvis (AP) and Skull (AP/PA) but higher than the reference value in Chest (AP). This suggests that the Radiology Departments in the hospitals investigated need to review their practices in order to bring the doses received by patients to optimum levels.

1. Introduction

The need for radiation dose assessment of patients during diagnostic X-ray examinations has become imperative by the increasing knowledge of the hazards of ionizing radiation. The use of X-rays in medical radiography has continued to increase despite technological advances in other modern imaging techniques. In many countries, especially in developing countries, conventional radiography is still a dominant diagnostic tool in comparison with other imaging techniques such as computed tomography (CT), digital radiography or Magnetic Resonance Imaging (MRI). The X-ray tube provides an environment for X-ray production via bremsstrahlung and characteristic radiation mechanisms with the former being the one employed in diagnostic imaging. Major components are the cathode, anode, rotor/stator, glass (or metal) envelope, and tube housing. For diagnostic imaging, electrons from the cathode filament are accelerated toward the anode by a peak voltage ranging from 20,000 to 150,000 V (20 to 150 kVp). For continuous fluoroscopy, the tube current is typically 1 to 5 mA, and for projection radiography tube currents from 100 to 10,000 mA are used with short exposure times (less than 100 ms). The kVp, mA, and exposure time are the three major selectable parameters on the X-ray generator control panel that determine the X-ray beam characteristics such as quality and quantity [1]. Although diagnostic imaging using X-rays produces certain benefits, the potential for radiation-induced injury to the patients exist. Thus, a good knowledge of absorbed radiation doses and the factors that affect them therefore are very important. Several studies on radiation doses delivered to patients during diagnostic X-ray imaging have been carried out locally, nationally and internationally [2], [3], [4], [5], [6], [7]. In 2000, the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) indicated that the frequency of radiographic examinations over the preceding five years had roughly doubled and in some countries even tripled [8]. The report concluded that population exposure due to medical radiation is likely to be increasing worldwide, particularly in countries where medical services are in their early stages of development.

The International Commission for Radiological Protection (ICRP) recommends that medical activities involving ionizing radiation should fulfill two basic principles of justification and optimization [9, 10]. Justification is the first step in radiological protection, which has been accepted that diagnostic exposure is justifiable only when there is a valid clinical indication, no matter how good the imaging performance may be, that every examination must result in a net benefit to the patient [11]. The optimization principle requires that the magnitude of radiation doses be as low as reasonable achievable {(ALARA Principle), [12]}.

One of the requirements of the optimization process is periodic monitoring of the performance of radiological equipment and assessment of techniques employed in their use. This form of monitoring serves to maintain standards in equipment performance, image quality and, very importantly radiation doses to patient. Scientific efforts to optimize the choice, in terms of finding the parameter settings, which yield sufficient image quality at the lowest possible radiation dose, are still rare in developing countries like Nigeria. However, it is necessary that the radiation doses to patient arising from diagnostic medical exposures are assessed in order to provide valuable guidance on optimization of radiological technique, and to ensure that the required diagnostic information is obtained with minimum radiation hazard [13]. The aim of this study is to evaluate radiological parameters and determine Entrance Surface Dose (ESD) in Chest, Pelvis, Lumbar Spine and Skull during routine X-ray diagnostic examinations in Radiology Departments of three hospitals in South-West Nigeria.

2. Materials and Method

The patients' anthropometric data such as age, weight, sex, thickness of the irradiated region, and exposure parameters were obtained during the routine X-ray examinations of 203 patients at three (3) different hospitals located in two different towns in South-West Nigeria namely: Ilesa and Ido-Ekiti. The three hospitals included in this investigation were: State Teaching Hospital (OAUTHC), a Federal Medical Centre (FMC) and a Private Hospital (OAMH). For each X-ray room, available machine specific data such as type, model and year of manufactured were recorded (See Table 1). The linearity and reproducibility of each machine were performed using a calibrated kV Meter NERO ^{Tm} 6000M, manufactured by Victoreen, INC, CLEVELAND, Ohio, USA.

Direct dose measurement was carried out using TLD-100^{TM} (Lif) chips of dimension 3x3x1 mm obtained from Standard Dosimetry, LLC (Bellingham, United States). A total of 100 chips were acquired and pre-annealed using an oven obtained from the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife to empty any residual electrons trapped in the metastable state during the previous exposures. The chips were annealed under the temperature of 400°C for 1 hour and allowed to cool down in the oven for between 17 hours. The chips were packed further kept for another 24 hours before use after each annealing. The chips were packed in black polythene pouch to prevent the effect of visible light. The chips were labeled for easy identification and presented for calibration at the Secondary Standard Dosimetry Laboratory (SSDL) OF National Institute for Radiation Protection and Research (NIRPR), University of Ibadan.

Table 1. *Specifications of the X-ray Machines used in the study.*

Hospitals	Model/Type	Manufacturer	Year of Installation	Filtration	Output (mGy/mAs)
OAUTHC Ilesa	Silhouette V. R	G. E Haulum Medical System	2010	2.7	0.061
OAMH Ilesa	LEXRAY 500	R. Liecati A. G R. Liecati A. E	2013	3.0	0.058
FMC Ido-Ekiti	Giladonia R105	Ralco	2013	2.0	0.0347

During the calibration, each chip was exposed to a uniform radiation (80 kV, 1 mA, 142 s or 142 mAs and FSD of 200 cm, dose rate of 50.2 mGyhr^{-1}) in turn from a standard X-ray unit. The chips were taped to a water phantom placed at a distance of about 200 cm from the X-ray focus before irradiated. The irradiated chips were kept 24 hours before reading and calibration. During the calibration of the TLD chips, Element Correction Coefficients (ECC) and Reader Calibration Factors (RCF) were calculated using Harsaw TLD Reader Model 4500 (manual) and WinRems software (Saint- Gobain Crystals & Detector, Wermelskirchen, Germany). Golden chips were selected and bad dosimeters were discarded while the field dosimeters were made available for use. Three chips were sealed in thin black polythene coded for proper identification and placed on the patient's skin surface at the centre of the X-ray field to measure the patient's ESD.

Table 2. Patients'data for Entrance Surface Dose surveyed.

Examination	Patients Mean (range)				
	Male	Female	Age (Yrs)	Thickness (cm)	Weight (Kg)
Chest PA	45	46	48(18-87)	32(16-38)	68(67-72)
Pelvis AP	21	15	40(19-74)	28(12-35)	69(68-84)
Pelvis LAT	12	10	42(19-70)	18(13-23)	68(69-72)
Lumbar Spine AP	7	6	72(38-90)	24(18-30)	67(60-75)
Lumbar Spine LAT	7	6	72(38-90)	24(18-30)	67(60-75)
Skull AP/PA	8	7	45(26-76)	22(12-32)	71(70-74)
Skull LAT	8	5	40(22-46)	24(14-28)	70(61-74)

3. Results and Discussion

A total of 203 patients comprising of 108 males and 95 females from three X-ray rooms in three hospitals in South-West Nigeria and seven radiographic projections were included in the study. The radiographic projections were: Chest PA, Pelvis AP, Pelvis LAT, Lumbar Spine AP, Lumbar Spine LAT, Skull AP/PA, and Skull LAT.

Table 1 presents the specific data of the X-ray machines investigated, all the X-ray generators are three-phase ((6 or 12) pulse) models or high frequency generators. From the table, the filtration of the machines in OAUTHC and OAMH are higher than the recommended filtration of 2.5 mmAl [14] for voltage above 75 kV while the filtration of X-ray machine in FMC is lower than the recommended value. Low filtration leads to higher doses since energy level below 40 keV is not useful for diagnostic imaging, rather contributes to patient dose.

Patient age, weight and their sex distribution by hospital and examination are shown in Table 2. The ratio of male to female can be seen to vary with type of examination. The mean weight of the patients was within 5 kg of the 70 kg of standard man [15]. The mean age ranges between 40 and 72 years.

A summary of the technical data: tube potential (kVp), product of tube current and time (mAs) and Focus – to – Film Distance (FFD) in each hospital investigated in this study is given in Table 3. The mean and range values of the kVp and mAs used in the X-ray rooms were in line with what is obtained from medical X-ray examinations in the UK – 2000 Review [16].

The FFD used in the examinations considered in this study were inconsistent with recommended value in CEC (1990) guidelines for quality radiographs. This was more obvious in Chest PA examinations in which FFD as low as 100.0 cm were used in all X-ray rooms instead of the FFD of 140.0 – 200.0 cm with the mean of 180.0 cm recommended by European Union [14] for quality radiographs.

For other examinations, the FFD of 100.0 – 150.0 cm with mean value of 115.0cm recommended by European Union Committee was not totally adhered to by the radiographers in the various hospitals.

The use of optimum FFD is considered very important, since direct relationship between shorter FFD, higher patient's dose and decreased geometric sharpness is well established [17, 18].

Table 4 shows the distribution of individual entrance surface dose (ESD) for four routine X-ray examinations (7 projections) for the three hospitals and range factor (RF) which is defined as the ratio of maximum individual ESD to minimum individual ESD for the same type of examinations. Mean Chest (PA) ESD values at OAUTHC, FMC and OAMH were 1.27, 2.48, and 3.19 mGy respectively. The mean value across the three hospitals was 2.25 mGy. Also, the mean values for Pelvis (AP), Pelvis (LAT), Lumbar Spine (AP) and Skull (LAT) across the hospitals were 5.63, 5.39, 8.28, 6.99, 4.14 and 4.10 mGy respectively. The range factor for the same examinations among the hospitals ranges from 1.2 for Pelvis (LAT) at OAUTHC to 31 for Chest (PA) at OAMH. Dose variation is a common feature in most radiological patient dose measurement [19, 16]. In a United Kingdom (UK) 2000 national survey, the variations expressed in terms of maximum to minimum ratio (max/min) ranged from 52 to 283 [16]. The variations in this study are lesser, probably due to the number of hospitals considered in this study as against the number of hospitals in the UK national survey for which variations due to the difference in patients' sizes, differences in radiographic technique used by different radiographers, radiographic equipment and film type were investigated. The observed inter hospital and intra hospital dose variations as revealed by the range factors, for the same examination are an indication that operational conditions were not fully optimized.

Table 3. *Mean (Range) of radiographic data used.*

Examination	Hospitals	Radiographic Data		
		Tube Voltage (kVp)	Product of tube current and exposure time (mAs)	FFD (cm)
Chest (PA)	OAUTHC	69(57-80)	25(10-40)	149(100-180
	FMC	82(70-119)	27(8-40)	161(110-180)
	OAMH	75(52-100)	26(12-40)	111(100-120)
	ALL	78(52-119)	26(8-40)	150(100-180)
Pelvis (AP)	OAUTHC	72(55-81)	40(25-63)	118(105-122)
	FMC	84(75-85)	31(25-32)	100(81-124)
	OAMH	95(70-100)	42(40-50)	92(80-114)
	ALL	87(55-100)	38(25-63)	104(80-104)
Pelvis (LAT)	OAUTHC	73(69-72)	36(10-50)	115(105-120)
	FMC	77(75-80)	29(22-32)	95(81-123)
	OAMH	89(75-100)	40(25-64)	99(80-114)
	ALL	78(69-100)	37(10-64)	101(80-123)
Lumbar Spine (AP)	OAUTHC	87(73-96)	91(40-125)	117(110-125)
	FMC	97(95-100)	45(40-50)	92(90-95)
	OAMH	75(73-77)	45(40-50)	105(100-110)
	ALL	95(73-100)	65(40-125)	107(70-125)
Lumbar Spine (LAT)	OAUTHC	90(81-96)	110(64-125)	114(110-123)
	FMC	92(90-95)	43(40-50)	95(90-100)
	OAMH	87(77-96)	45(40-50)	105(100-110)
	ALL	88(77-96)	96(40-125)	116(100-123)
Skull (AP/PA)	OAUTHC	74(70-80)	38(32-40)	112(106-115)
	FMC	75(70-80)	29(20-40)	111(93-153)
	OAMH	103(100-103)	40(40-43)	93(70-100)
	ALL	84(70-103)	37(20-43)	105(70-153)
Skull (LAT)	OAUTHC	72(63-85)	91(40-125)	117(110-125)
	FMC	73(63-85)	24(16-40)	100(93-116)
	OAMH	105(100-110)	33(25-40)	85(70-100)
	ALL	92(63-110)	76(16-125)	97(70-125)

Table 4. *Distribution of Entrance Surface Dose (ESD) for seven projections in the hospitals.*

Examination	Hospital	ESD (mGy)						
		Min	FirstQuartile	Median	Mean	Third Quartile	Max	RF
Chest (PA)	OAUTHC	0.23	0.84	1.30	1.27	1.71	2.70	12.0
	FMC	0.32	1.87	2.67	2.48	3.68	4.53	14.0
	OAMH	0.23	2.33	3.22	3.19	4.84	7.24	31.0
	ALL	0.23	0.92	1.90	2.25	3.22	7.24	31.0
Pelvis (AP)	OAUTHC	3.79	4.18	4.75	6.74	1.19	17.32	4.6
	FMC	3.54	3.78	4.55	4.81	4.56	7.69	2.0
	OAMH	3.61	6.23	6.39	6.02	3.61	7.69	2.0
	ALL	3.54	4.18	4.75	5.63	4.56	17.32	4.9
Pelvis (LAT)	OAUTHC	4.31	4.49	4.56	4.59	4.32	4.90	1.2
	FMC	4.80	6.06	6.88	6.56	7.69	7.69	2.0
	OAMH	3.42	4.49	4.87	5.21	3.42	7.69	2.0
	ALL	3.42	4.49	4.80	5.39	4.32	7.69	2.0
Lumbar Spine (AP)	OAUTHC	3.75	3.79	4.25	4.33	3.75	5.29	2.0
	FMC	11.04	11.04	18.30	15.99	18.29	18.64	2.0
	OAMH	3.15	7.16	7.43	3.15	12.23	11.04	4.0
	ALL	3.15	3.79	4.92	8.28	11.04	18.64	5.9
Lumbar Spine (LAT)	OAUTHC	2.52	2.61	3.15	3.21	2.52	4.52	2.0
	FMC	10.15	10.14	3.29	10.15	12.51	17.23	2.0
	OAMH	3.80	3.29	7.87	7.57	3.80	10.75	3.0
	ALL	2.52	3.29	4.90	6.99	2.52	17.23	6.8
Skull (AP/PA)	OAUTHC	0.93	0.96	3.68	2.89	0.93	4.76	5.0
	FMC	2.52	3.58	4.22	4.62	3.59	7.69	3.0
	OAMH	0.63	3.79	4.76	4.82	3.68	10.15	16.0
	ALL	0.63	3.58	3.89	4.14	3.59	10.15	16.0
Skull (LAT)	OAUTHC	0.93	0.96	3.68	2.89	0.93	4.76	5.0
	FMC	1.32	1.52	2.81	3.59	4.09	7.42	5.6
	OAMH	3.63	4.09	4.16	4.23	3.63	4.98	1.4
	ALL	0.93	1.53	4.10	3.52	4.23	7.42	7.9

Table 5. *Comparison of hospitals' mean ESDs (mGy) obtained in this study with some International Dose Reference Levels.*

Examination/Projection	This Study			Countries/Organizations with DRLs			
	OAUTHC	FMC	OAMH	UK 2016	SUDAN 2006	NRPB 2000	IAEA 2008
Chest (PA)	1.27	2.48	3.19	0.40	0.24	0.20	0.33
Pelvis (AP)	6.74	4.81	6.02	4.00	1.55	4.00	3.68
Pelvis (LAT)	4.59	6.56	5.21	_	_	_	_
Lumbar Spine (AP)	4.33	15.96	3.15	5.70	2.06	6.00	4.07
Lumbar Spine (LAT)	3.21	10.15	7.57	10.00	5.20	14.00	_
Skull (AP/PA)	2.89	4.62	4.82	1.80	1.41	3.00	_
Skull (LAT)	2.89	3.59	4.23	1.10	0.99	1.50	_

A comparison between the ESD obtained in this study and some internationally established reference dose levels (NRPB 2000 [20], UK 2016 [21], Sudan 2006 [22] and IAEA 2008 [11]) in Table 5. The mean ESD obtained in the three hospitals are higher than ESD values recommended by NRPB, IAEA, and also higher than value obtained by radiographers in most chest (PA) examination as the radiographers in the hospitals included in this study employed mAs as high as 40 mAs and tube voltage as low as 52 kVp as it can be seen in Table 3. The use of high tube voltage technique for chest examinations has been reported to reduce the entrance surface dose by a half and therefore any value lower than the recommended tube voltage should not be selected [23, 24]. Also Bushberg *et al*., [1] have shown that radiation dose (entrance dose) plummets with increasing kVp.

The mean ESD values for Pelvis AP for the three X-ray rooms are 6.74, 4.81 and 6.02 mGy for OAUTHC, FMC, and OAMH respectively. It was observed that mean ESD values of the three X-ray rooms are higher than mean ESD values of NRPB, IAEA and that obtained in Sudan but lower than the mean ESD value obtained in UK.

As can be seen from Table 5, the mean ESD value of the Lumbar Spine (AP) for the three X-ray rooms are 4.33, 15.96 and 7.43 mGy respectively were higher than the recommended Dose Reference Levels (DRLS) values of IAEA and that obtained in Sudan (2006) but the values obtained in OAUTHC and OAMH are lower than the value obtained in UK (2005). For Skull (AP/PA) the OAMH has the highest value of mean ESD 4.82 mGy which is higher than DRLS value recommended by NRPB and the values obtained in UK and Sudan while the mean ESD of 2.89 mGy obtained in OAUTHC was lower than DRLS value of 3.00 mGy recommended by NRPB (2000). The large variation observed within the same hospital and in different hospitals may be due to the equipment performance and radiographic techniques employed by the radiographers. The high ESD observed in this study shows that the radiographic techniques employed in most of the hospitals are not yet fully optimized. The use of low mAs technique may cause low optical density of radiograph and decrease patient dose without adversely affecting image quality, so this technique is proposed to X-ray machines operators.

4. Conclusion

In this study, ESD measurements on adults undergoing radiological examinations on four common types of X-ray examinations in the three hospitals show doses very much higher than recommended values. Determination of patient doses or entrance surface dose values and their comparison with diagnostic reference levels are an important part of the optimization process in diagnostic radiology. The observed dose variation in this study could mean unjustified risk to patients undergoing similar radiographic examinations, which requires urgent attention. The dose variations may be due to lack of standardization in procedures or malfunction of equipment. For this reason, quality assurance (QA) program must be set up and executed on regular basis by the regulating authority. Also, there is need to develop National Dose Reference Levels (NDRLS) against which local hospitals could compare their dose results.

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