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Assessment of Entrance Surface Air Kerma and Effective Dose for Adult Patients Undergoing Conventional Diagnostic X-Ray Examinations in Selected Hospitals in Ogbomoso, Oyo State, Nigeria

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ABSTRACT
Diagnostic x-ray examinations are key part of modern medical imaging, helping doctors to diagnose a range of health conditions. However, these procedures expose patients to ionising radiation, which carries certain risks that need careful management. This study therefore assessed the entrance surface air kerma (ESAK) and effective dose (ED) for 1583 adult patients undergoing seven common diagnostic examinations at three different hospitals in Ogbomoso, Oyo State, Nigeria using CalDose software. The results of the study ranged from 0.67 – 6.78 mGy for ESAK and 0.02 – 0.48 mSv for ED. Among the examinations considered, the lumbar spine produced the highest ESAK values across the three hospitals, for both male and female patients, with an effective dose of 0.44 mSv at X, 0.29 mSv at Y, and 0.48 mSv at Z, while the chest had the lowest dose (X= 0.06, Y = 0.02, Z = 0.02 mSv). The estimated effective doses were within the safe limits set by the International Commission on Radiological Protection. These findings emphasise the need for regular dose audits, careful optimisation of exposure settings, and ongoing staff training to reduce patient radiation exposure while maintaining good diagnostic quality.

INTRODUCTION
Exposures resulting from radiological procedures contribute the largest portion to the population exposure from artificial radiation sources (Kramer *et al.,* 2008). With the advent of modern medicine, radiology is still one of the most powerful and indispensable diagnostic tools, and about 30% - 50% of medical decisions are based on x-ray examinations (Yacoob & Mohammed, 2017, Leng *et al.,* 2024). Diagnostic x-ray examinations use ionizing radiation to produce internal body images for accurate diagnosis for conditions ranging from bone injuries to chest and abdominal problems (Sayah *et al.,* 2025; Irede *et al.,* 2026). While ensuring sufficient exposure to maintain image quality (Jaschke *et al.,* 2017; Soulis *et al.,* 2025), the procedure require careful dose management to avoid damage to biological tissue that may be detrimental to human health (ICRP, 2017; Abid *et al.,* 2021; Sathiya *et al.,* 2024). Hence, quality and safety become the hallmarks for efficient and successful medical intervention (European Commission, 1996; ICRP, 2017), an action that calls for a quality control (QC) program so as to maintain a clear image as well as keeping the radiation dose as low as reasonably achievable. Without such a program the consequences may be regrettable (Yacoob & Mohammed, 2017).
According to ICRP 60, the basic quantity associated with the risk of deleterious effects on health is the effective dose that is the valuable and central quantity for dose limitation in the field of radiological protection of the patient (ICRP, 1991; 2017). This dose descriptor is being increasingly used to determine the quantity of radiation dose received by patient undergoing diagnostic x-ray examinations (Brenner & Huda, 2008; Mettler *et al.,* 2008; Kharita *et al.,* 2010; Osei and Darko, 2013; Shahbazi-Gahrouei & Baradaran-Ghahfarokhi, 2013; Teles *et al.,* 2013). However, effective dose (ED) is

affected by patient structure and radiological method, therefore, the calculation of this quantity is of utmost importance. However, it is almost impossible to directly measure ED during clinical procedures. Thus, indirect estimates of ED start from the monitoring of patient's exposure level through Entrance Surface Air Kerma (ESAK), during diagnostic x-ray using virtual human phantoms (Kramer *et al.,* 2008). According to Internation Commission on Radiation Units and Measurement (ICRU, 2005), the ESAK is the air kerma on the central x-ray beam axis at the point where the x-ray beam enters the patient or phantom. The amount of radiation a patient receives during medical imaging depends on the type of examination, the part of the body being scanned, the patient's size, and machine settings such as kVp, mAs, and FFD. Hence, ESAK quantifies the radiation absorbed at the skin's surface where the x-ray beam enters the body, while ED considers how sensitive different organs are to radiation (ICRP, 2017).

Initial results of a multinational research study on x-ray QC and patient dose conducted by the International Atomic Energy Agency (IAEA) revealed that up to 50% of x-ray exams performed in less developed countries are of substandard quality (Keen, 2008). As many patients in these countries are being exposed to unnecessary radiation doses due to the need to repeat procedures (WHO, 2008). In Nigeria, existing research shows that patient doses vary significantly between hospitals, often due to differences in equipment calibration, exposure settings, and staff expertise (Olowookere *et al.,* 2011; Isola *et al.,* 2016). In growing urban centres like Ogbomoso, the need for diagnostic imaging is rising, making it important to investigate the radiation doses for common x-ray exams. In view of this, the study evaluates the ESAK and ED for adult patients undergoing routine x-ray procedures in three major hospitals in Ogbomoso, using CalDose software to calculate patient-specific doses. The study highlights differences between hospitals, suggests ways to optimise radiation use, and helps set local benchmarks for safe x-ray practices.

MATERIALS AND METHODS

Study Area and Ethical consideration

The study area comprises of three different diagnostic centres from one state university teaching hospital (X), one university-based health centre (Y), and a private university teaching hospital (Z), all situated in Ogbomoso, Oyo State, Nigeria. Each diagnostic unit is equipped with Allengers floor mounted X-ray machine and presented in Table 1 is the features of the x-ray machine at each of the diagnostic centre. Ethical approval was obtained from the hospital authorities. All research activities were carried out in line with ethical standards for medical and radiological research, while keeping hospital details and patient information confidential. Only patients who were already referred for routine diagnostic x-ray examinations were included in the study and no extra radiation was given for research purposes.

Table 1: Features of the X-Ray Machines at Each Diagnostic Centre

Hospital	X-ray Type	Max kV	Max mA	Year of commissioning
X	Floor mounted	150	200	2019
Y	Floor mounted	150	200	2015
Z	Floor mounted	500	150	2010

Data Collection

The data for this study were collected from patient records and x-ray machine exposure settings. For each patient, details such as age, sex, body weight, and exposure factors including kilovoltage peak (kVp), milliampere-seconds (mAs), focus-to-film distance (FFD), and type of examination were recorded. These data were collected for seven different diagnostic x-ray examinations namely chest (PA), knee joint/femur (AP), skull (PA), pelvis (AP), lumbar spine (AP), cervical spine (AP), and thoracic spine (AP). Radiographers supported the data collection process to ensure the information was accurate.

Estimation of Entrance Surface Air Kerma

The prepared data were entered into the CalDose_X 5.0 software for analysis, following a stepwise procedure as programmed on the software based on the output of an X-ray tube. CalDose is a computer-based tool that enhances the calculations of ESAK and effective dose using patient information and sex-specific phantoms (FASH for females and MASH for males). By supplying the patient information and selecting the examination type, the section for the x-ray machine parameters becomes active from which one enters the tube voltage (kV), tube current–time product (mAs), Focus-to-Detector Distance (FDD). The software has been programme with algorithm to automatically calculate the ESAK and other parameters for posture-specific female and male adult phantoms. (Kramer *et al.,* 2008; Ofori *et al.,* 2014; Sayah *et al.,* 2025).

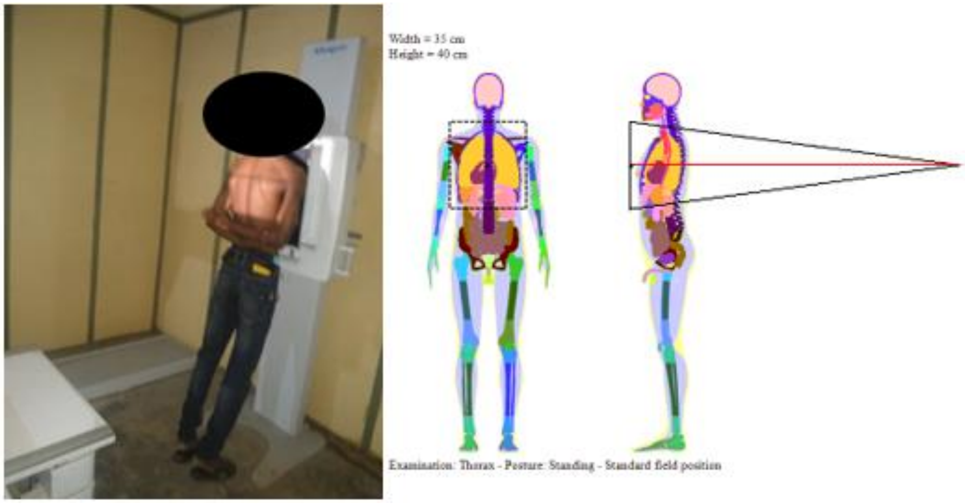

Figure 1: Sample of the exposure condition of a male patient undergoing chest x-ray examination in one of the study locations and the simulated phantom

Estimation of Effective Dose

The effective dose (ED) which is the sum total of the dose weighted for susceptibility to harm of different tissues taking into consideration the sensitivity of the different organs to radiation was quantified as the arithmetic mean of the two sex-specific weighted absorbed doses according as expressed by Equation 1. (ICRP 2007).

$$ED = \sum \frac{w_T H_T(Male) + w_T H_T(Female)}{2} = \frac{1}{2}[F + M] \quad (1)$$

Where W_T is the tissue weighting factor, and H_T is the equivalent dose in a tissue or organ.

RESULTS AND DISCUSSION

Patient Data

Presented in Table 2a – c are the relative contributions of different X-ray examinations at the three hospitals. In X, a total of five hundred and five (505) patient data comprising of 236 male and 269 female were collected, out of which chest (PA) contributes the highest examination type accounting for 16.95% for male and 15.99% for female. In Y, a total of six hundred and forty (640) patient data comprising of 308 male and 332 female were collected, out of which knee joint/femur (AP) contributes the highest examination type accounting for 29.87% for male and 36.15% for female. Likewise, in Z, a total of four hundred and thirty-eight (438) patient data comprising of 201 male and 237 female were collected, out of which knee joint/femur (AP) contributes the highest examination type accounting for 31.34% for male and 36.29% for female. The disparity observed in the data can be attributed to the specificity of the examination required for diagnosis by the medical doctor. The high value recorded for knee joint/femur (AP) at both Y and Z for female was as a result of increasing home accident and old age diseases specifically arthritis.

Entrance Surface Air Kerma

The results of the present study revealed that ESAK values varied across both hospitals and sexes. This pattern may be attributed to differences in body habitus, tissue thickness, and exposure parameter adjustments. The mean values of ESAK for patients across all examinations were presented in Figure 2a - g. The ESAK values at hospital X were found to be the highest for both cervical spine (AP) for male, chest (PA) for female, knee joint/femur for female and thoracic spine for male while at Y, the values were the highest for lumbar spine for male, pelvis for male and skull for male.

For the cervical spine (AP) examination (Figure 2a), the ESAK values were approximately 1.13 mGy for males and 1.08 mGy for females at Y; 1.32 mGy and 1.26 mGy at X; and 1.24 mGy and 1.18 mGy at Z, respectively. Hospital X recorded the highest doses, while hospital Y had the lowest. These results are comparable with values reported in similar studies, where median ESAK values for cervical spine AP examinations ranged between 1.2 mGy and 1.4 mGy (Bonifaz *et al.,* 2021). The relatively small differences between male and female ESAK values suggest consistent radiographic protocols across patients.

In the results obtained for the chest (PA) projection (Figure 2b), the ESAK values were about 0.46 mGy for both sexes at Y, 0.67 mGy for males and 1.05 mGy for females at hospital X, and 0.51 mGy and 0.42 mGy at hospital Z. The higher female dose observed at X may reflect differences in exposure technique or patient positioning. Reported literature indicates that typical ESAK values for chest PA examinations in digital radiography range from 0.1 mGy to 0.3 mGy (Khoshdel-Navi *et al.,* 2016). Thus, some of the recorded doses, particularly at hospital X, are above the international diagnostic reference levels (DRLs) ranging between 0.3 mGy and 0.8 mGy as recommended by the IAEA (2007) and European Commission (2018).

For the knee joint/femur (AP) examination (Figure 2c), ESAK values were approximately 0.67 mGy for both sexes at Y, 1.05 mGy for males and 1.08 mGy for females at X, and 0.67 mGy for both sexes at Z. The slightly higher doses recorded at X are notable but remain within acceptable diagnostic ranges, most especially the range of 0.5 mGy to 1.5 mGy values reported by IAEA (2007) and European Commission (2018) respectively. In addition, these results are broadly consistent with previous findings that report lower limb exposures generally below 1.0 mGy (Gholami *et al.,* 2015).

Table 2a: Summary of Patients' Characteristics and Different X-Ray Examination Technique Parameters at Diagnostic Centre X

Examination type	Projection	Number of patients		Age range (years)		Mean Weight (kg)		kVp	mAs	FDD (cm)
		M	F	M	F	M	F			
Skull	PA	31	29	20-65	21-58	76	62	70	16	100
Chest	PA	40	43	18-73	20-75	78	65	80	12	180
Thoracic region	AP	32	36	40-78	45-70	85	70	80	14	100
Lumbar region	AP	38	41	29-69	19-80	80	73	80	20	100
Knee/Femur	AP	37	38	18-80	20-85	81	76	60	8	100
Cervical region	AP	28	40	30-77	26-65	77	58	65	10	100
Pelvic	AP	30	42	20-73	18-80	84	66	80	12	100
	Total	**236**	**269**							

Table 2b: Summary of Patients' Characteristics and Different X-Ray Examination Technique Parameters at Diagnostic Centre Y

Examination type	Projection	Number of patients		Age range (years)		Mean Weight (kg)		kVp	mAs	FDD (cm)
		M	F	M	F	M	F			
Skull	PA	29	30	25-45	25-50	66.	67	60	32	100
Chest	PA	55	43	25-60	30-60	68	68	62	8	150
Thoracic region	AP	24	22	30-45	30-45	68	66	62	8	100
Lumbar region	AP	34	22	29-50	30-45	67	65	65	40	100
Knee/Femur	AP	92	120	25-50	25-50	67	69	60	5	100
Cervical region	AP	28	34	30-50	30-50	67	70	60	10	100
Pelvic	AP	46	61	30-49	25-55	70	68	62	32	100
	Total	308	332							

Table 2c: Summary of patients' characteristics and different x-ray examination technique parameters at diagnostic centre Z

Examination type	Projection	Number of patients		Age range (years)		Mean Weight (kg)		kVp	mAs	FDD (cm)
		M	F	M	F	M	F			
Skull	PA	19	20	25-45	25-50	67	69	60	32	100
Chest	PA	35	43	25-60	30-60	69	68	62	8	150
Thoracic region	AP	16	15	32-47	30-46	70	67	62	8	100
Lumbar region	AP	23	15	29-50	39.6	68	68	65	40	100
Knee/Femur	AP	63	86	25-50	25-50	68	69	60	5	100
Cervical region	AP	14	17	30-40	30-50	66	71	60	10	100
Pelvic	AP	31	41	30-46	32-55	68	68	80	32	100
	Total	201	237							

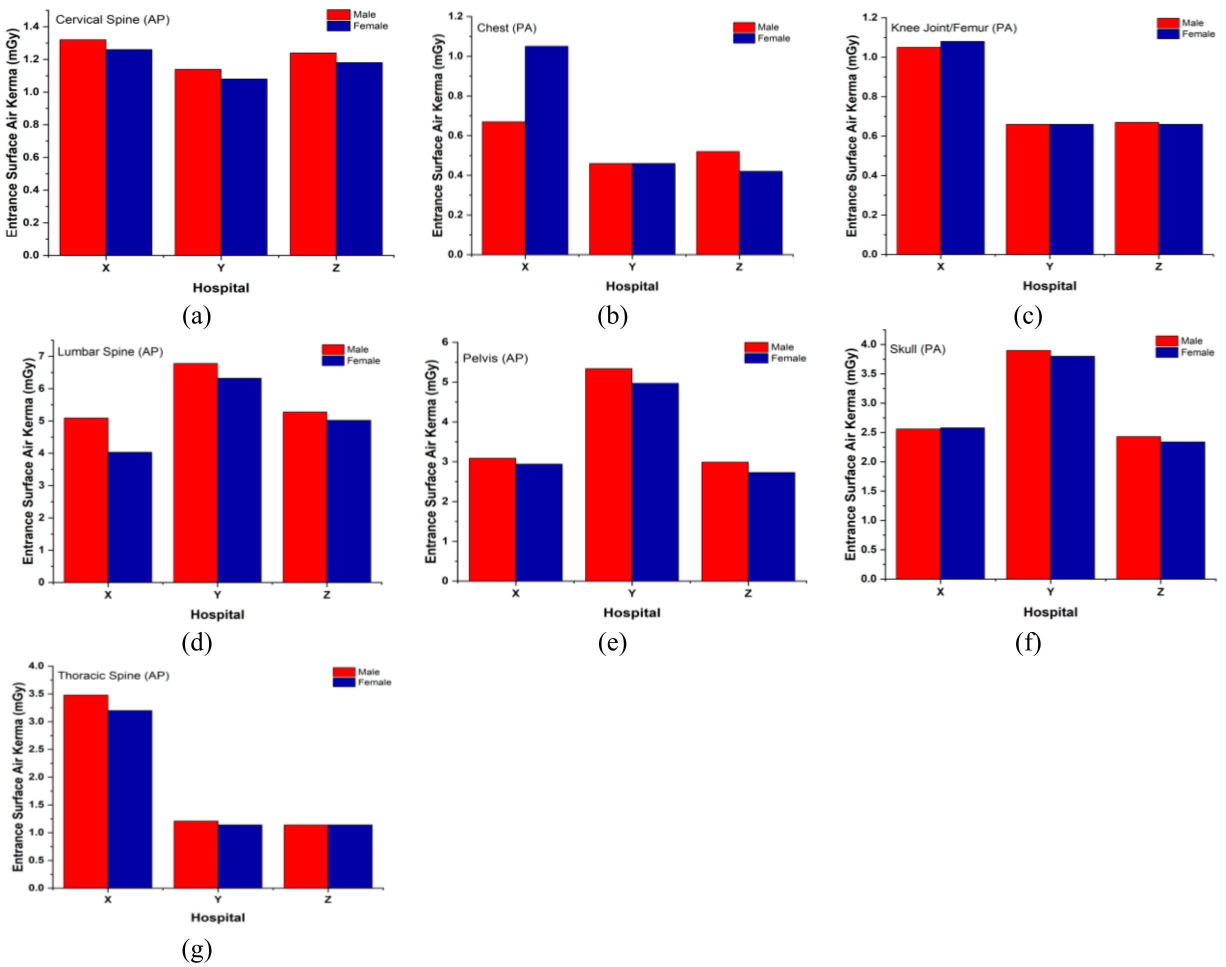

Figure 2: ESAK values for the (a) cervical spine (AP), (b) Chest (PA), and (c) Knee joint/femur (AP) examination (d) lumbar spine (AP), (e) pelvis (AP), (f) skull (PA) and (g) thoracic spine (AP) examinations

The lumbar spine (AP) examination (Figure 2d) produced the highest ESAK values across all examined sites, averaging 6.8 mGy for males and 6.3 mGy for females at Y; 5.1 mGy and 4.0 mGy at X; and 5.3 mGy and 5.0 mGy at Z, respectively. The higher exposure is expected, given the increased tissue thickness and beam penetration requirements. These values exceed those reported by Dalah (2025), who found mean ESAK values ranging between 1.5 mGy and 3.3 mGy for lumbar spine examinations. However, the observed range (4.0–6.8 mGy) aligns with international range of 4–7 mGy recommended by the IAEA (2007) and European Commission (2018) for adult lumbar spine AP DRLs. Thus, while the results of the current findings fall within acceptable limits, the relatively high values observed at Y indicate a need for dose optimisation and regular quality assurance to ensure exposures remain as low as reasonably achievable (ALARA) without compromising diagnostic image quality.

For the pelvis (AP) examination (Figure 2e), ESAK values were 5.4 mGy (male) and 4.9 mGy (female) at Y, 3.1 mGy and 2.9 mGy at X, and 3.0 mGy and 2.7 mGy at Z. The higher values observed at Y suggest a need for dose optimisation. According to Gholami et al. (2015), typical ESAK values for pelvis AP examinations average around 3.3 mGy, which aligns closely with the values recorded at X and Z but remains lower than those at Y. In addition, male patients received marginally higher ESAK values than females at all hospitals, likely due to differences in body habitus and corresponding exposure settings (kVp and mAs).

In the skull (PA) projection (Figure 2f), ESAK values were approximately 3.9 mGy for males and 3.8 mGy for females at Y, 2.55 mGy for both sexes at X, and 2.4 mGy and 2.3 mGy at Z. These findings correspond with the results of previous studies reporting ESAK values between 1.0 mGy and 2.3 mGy for skull PA examinations (Dalah, 2025). Similarly, Ahmed et al. (2009) and IAEA (2007) documented typical ESAK values for skull radiographs ranging from 2 to 5 mGy, depending on patient habitus and imaging equipment. The European Commission's reference levels for skull PA projections in adults are also approximately 4 mGy, confirming that the doses recorded in this study are consistent with recommended diagnostic reference levels (European Commission, 2018). While the recorded values are within acceptable diagnostic limits, those obtained at Y remain relatively high and may benefit from further optimisation.

As shown in Figure 2g, the thoracic spine (AP) procedure exhibited ESAK values ranging between 1.0 mGy at Y/Z and up to 3.5 mGy at X for male patients, with females showing a slightly lower mean value of 3.2 mGy. The increased ESAK at X suggests either longer exposure times or higher tube loading factors, possibly to compensate for anatomical density differences. These findings mirror those reported by Olowookere et al. (2011), where thoracic examinations demonstrated dose variability depending on radiographic technique optimization.

Disparity was observed in the dosages delivered to the patients undergoing the same type of X-ray examination across the 3 facilities investigated. This variability may be influenced by factors like patient body weight, applied tube voltage (kVp), and current-time tube product (mAs) as presented in Table 2a-c. Finding reveals that, several factors contribute to the radiation dose received by the patient, including as the quality and condition of the imaging system, the features of the patient and the specific anatomical areas being examined, and the technical components of the procedure (Babikir *et al.,* 2015; Sayah *et al.,* 2025). It is important to note that, the fundamental objective in radiography is to determine the optimal level that ensures the necessary quality of diagnostic images. This involves identifying the parameters that can achieve this level of quality while minimizing the amount of radiation exposure to the patient, in accordance with international dose reference values.

Across all anatomical sites, consistent patterns emerged with the male patients generally received slightly higher ESAK values than females, likely due to anatomical and physiological factors such as greater tissue thickness and higher required exposure parameters. Inter-hospital variation was evident, with Y frequently recording higher ESAK values than X and Z. Such differences could result from disparities in equipment calibration, radiographic technique, exposure factors, or image receptor sensitivity. In terms of relative dose magnitude, the highest ESAKs were associated with the lumbar spine (AP) examinations, while the lowest were observed in chest (PA) projections. This ranking aligns with previous research demonstrating that chest radiography typically results in the lowest patient dose, whereas spinal imaging yields the highest exposures due to increased anatomical density and required beam intensity (ICRP, 2017).

Presented in Table 3 is the comparison of the ESAK obtained in this study with those of other related studies. It was observed that the values recorded in the present study conform to those reported in literature. In addition, when compared with established Diagnostic Reference Levels (DRLs), several of the ESAK values observed in this study exceed recommended thresholds, especially for lumbar spine and pelvis projections. According to the Health Information and Quality Authority (HIQA, 2023) and the International Atomic Energy Agency (IAEA, 2023), DRLs serve as essential tools for dose optimisation, providing benchmarks for identifying situations where patient doses are unusually high. Therefore, the results suggest that hospitals, particularly hospital Y should review and optimise radiographic protocols to align with the as low as reasonably achievable (ALARA) principle.

Effective Dose

The calculated effective dose values derived from the mean sex-specific weighted ESAK for each anatomical region across the three hospitals are shown in Figure 3. Among all the examined projections, the lumbar spine and pelvic examinations exhibited the highest effective doses, ranging from 0.28 to 0.48 mSv, particularly at X and Z. This pattern reflects the larger field size, higher tube loading factors, and increased attenuation associated with these regions. The thoracic spine also demonstrated comparatively high effective dose values (up to 0.35 mSv at X), while the chest (PA) and knee joint/femur produced the lowest exposures (<0.05 mSv), consistent with established diagnostic reference levels (DRLs) (European Commission, 2018; ICRP, 2017). The cervical spine and skull examinations revealed intermediate effective doses, averaging 0.05–0.15 mSv, with the highest values recorded at X. The general trend indicates that X exhibited higher effective doses across most anatomical regions compared to Y and Z. This variation likely results from differences in exposure optimization, patient positioning, and calibration status of radiographic equipment. Similar inter-facility variations have been observed by Ofori *et al.* (2012), emphasizing the need for routine dose audits and harmonization of exposure protocols. Overall, all effective dose values obtained in this study are within the acceptable limits recommended by the ICRP and comparable to published national and international DRLs (ICRP, 2017; Abid *et al.,* 2021). However, continuous dose monitoring and adherence to the ALARA principle remain essential to ensure patient protection without compromising diagnostic image quality. Presented in Table 4 is the comparison of the effective dose obtained in this study with other published works and it was observed that the findings of the present study conform to the values reported in literature.

Table 3: Comparison of ESAK (Mgy) Per Examination of This Study and Those Reported By Others

Examination Type	Present Study			Sayyah et al. (2025)	Yacoob & Mohammed (2017)			Isola et al. (2016)	Seo et al. (2014)	Ofori et al. (2014)	Kim et al. (2007)	Korir et al. (2007)	UNSCEAR (2000)	European Commission (1996)
	X	Y	Z		AD	ED	DS							
Skull (PA)	2.56 2.58	3.90 3.80	2.43 2.34	0.52	4.14	0.63	2.54	-	2.08	-	2.04	14.16	-	-
Chest (PA)	0.67 1.05	0.46 0.46	0.52 0.42	-	1.43	0.79	3.74	0.25	0.37	0.27	0.21	1.85	0.31	0.30
Cervical (AP)	1.32 1.26	1.14 1.08	1.24 1.18	-	1.45	0.47	3.54	1.20	1.21	1..05	0.48	3.89	9.91	-
Pelvis (AP)	3.09 2.94	5.34 4.97	2.99 2.73	-	4.17	5.09	4.78	2.01	2.34	1.31	2.48	9.02	-	10
Thoracic (AP)	3.48 3.20	1.21 1.14	1.14 1.14	0.77	-	-	-	2.25	-	2.10	-	-	9.91	7.0
Lumbar (AP)	5.09 4.03	6.78 6.32	5.28 5.02	-	-	-	-	2.8	-	3.26	-	-	5.95	10.0

Present study: upper value (male), lower value (female), -: data not available

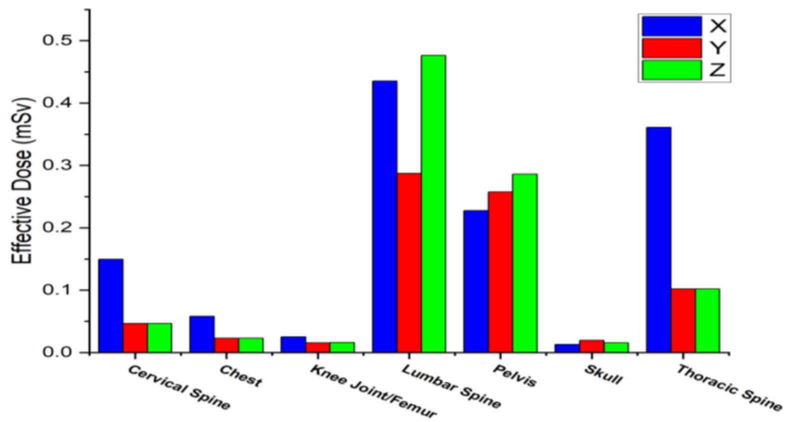

Figure 3: Effective dose values for all the examinations

Table 4: Comparison of Effective Dose (Msv) Per Examination of This Study and Those Reported By Others

Examination Type	Present Study			Yacoob and Mohammed (2017)			Isola et al. (2016)	Ofori et al.(2014)	Ciraj et al. (2005)
	X	Y	Z	AD	ED	DS			
Skull (PA)	0.01	0.02	0.02	-	-	-	-	-	-
Chest (PA)	0.06	0.02	0.02	0.45	0.24	0.42	0.03	0.01	0.03
Cervical (AP)	0.15	0.05	0.05	-	-	-	0.05	0.06	0.06
Pelvis (AP)	0.23	0.26	0.29	0.83	1.23	0.93	0.16	0.09	0.29
Thoracic (AP)	0.36	0.10	0.10	-	-	-	0.24	0.13	0.14
Lumbar (AP)	0.44	0.23	0.48	-	-	-	0.27	0.41	0.70

CONCLUSION

This study quantifies the entrance surface air kerma and effective dose for seven common x-ray examinations in three hospitals in Ogbomoso. The results showed differences between the hospitals, with Y often recording higher ESAK values compare to others. This variability is attributed to the patient's body weight, kVp, mAs of the x-ray systems and the technical know-how of the radiographers at each facility. The results suggest the necessity for the application of a QC program in any medical imaging procedure to optimize the doses delivered to patients for the given purpose. Thus, when technical and clinical factors are optimized, patient doses will reduce substantially. It is therefore recommended that a diagnostic facility should employ a well-trained Medical Physicists to implement an optimized QC program so as to ensure low dose to patient as well as high image quality.

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