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EVALUATION OF X-RAY EQUIPMENT PERFORMANCE IN SOME GOVERNMENT HOSPITALS IN KADUNA CITY, KADUNA, NIGERIA

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ABSTRACT

Background: In low- and middle-income countries, imaging equipment is frequently left unmonitored for extended periods of time, and only during inspections for licensing purposes is its quality assessed in terms of performance evaluation and quality control

Objective: The objective of this study was to conduct an evaluation of X-ray equipment performance in some government hospitals in Kaduna city, Kaduna state, Nigeria

Method: In this investigation, three (3) facilities were deliberately visited. At each hospital, X-ray equipment was subjected to quality control (QC) testing, and the X-ray rooms were physically inspected. Hospitals execute the following quality control tests: radiation dosage levels, radiation leakage, half value layer, beam alignment, peak tube voltage, mA linearity, and entrance skin dose. Using a survey meter (RADOS model RDS-120), the radiation dose levels in each X-ray room were measured.

Results: The acquired data revealed that only Hospital 1 and Hospital 2 exhibited a high level of compliance. Hospital 1 and Hospital 2 passed the radiation leakage test with results below the tolerance limit of 1.0 mSv/hr, demonstrating compliance with the norm. Hospital 3 passed the Half-value layer test, and all three hospitals passed the beam alignment test. Hospitals 1 and 2 passed the peak tube voltage (kVp) test because the co-efficient of variation between the set kVp and measured kVp was less than 0.05. Only Hospital 2 passed the mA linearity test, since its coefficient of linearity was 0.08, which is below the permitted level of 0.1. The outcome of the entrance skin dose (ESD) test revealed that all of the hospitals fell under the international and national tolerance limits, which is deemed safe for both patients and employees.

Conclusion: Based on the findings of this study, it can be concluded that the government hospitals in the Kaduna city are slightly in compliance with national and international standards. The visual inspection performed on the hospitals revealed that they retain a high degree of compliance to the standard.

Keywords: X-ray, Government Hospitals, level of compliance, Quality Control.

Introduction

Since its discovery by Roentgen in 1895, medical imaging has played an important role in diagnosing various clinical conditions (Otayni *et al.*, 2023). Consequently, the medical use of radiation became the most prevalent of all other uses, and its diagnostic and therapeutic applications have developed substantially throughout the years (Tamam *et al.*, 2023).

As a result of this rise, people are becoming more aware of the dangers of radiation to humans. Therefore, several measures have been taken to decrease the radiation exposure of patients and workers (Okeji et al., 2010). However, especially in low- and middle-income countries, imaging equipment is frequently left unmonitored for extended periods of time, and only during inspections for licensing purposes is its quality assessed in terms of performance evaluation and quality control (Delis *et al.*, 2017).

This is obviously insufficient to assure the safe and effective operation of the equipment, much less to ensure that a diagnostic center provides high-quality services, reduces patient and staff exposure to unneeded radiation, and produces high-quality images (Muhammad *et al.*, 2018; Valentin, 2000; Oluwafisoye *et al.*, 2010). Elsewhere, Owoade *et al*., (2022); Ijabor *et al.*, (2021); Achuka *et al*., (2020); Ike-Ogbonna *et al.*, (2020) all carried out studies to assess the performance of X-ray machines at some selected centres across different geo-political zones of the country in order to ensure safe delivery of doses to patients.

According to the Faculty of General Dental Practice (2020), it is recommended that day-to-day investigation of image quality be maintained to allow any significant fall in quality to be detected and investigated in a timely manner. Therefore, the objective of this study was to conduct an evaluation of X-ray equipment performance in some government hospitals in Kaduna city, Kaduna state, Nigeria, in order to identify the level of compliance to National and international standards.

Materials

The following items were obtained from the Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria in order to conduct the various tests for this study: RADOS survey meter (model RDS-120), measuring tape, thermoluminiscent dosimeters (TLDs), aluminium sheets, cassettes, beam alignment tool, kV meter, multifunction meter, leather bags, metallic markers, scissors, and masking tape for labelling the dosimeters.

Methodology: Use of Questionnaires

Questionnaires were used to generate information on each of the government hospitals that are situated in Kaduna Metropolis and they were selected deliberately because of their status in the city and influx of patients to the hospitals. Such information includes X-ray machine specifications, shielding material and thickness, room size, radiation worker qualifications, training information, and regulatory agency visits.

Measurement of Radiation dose levels

The RADOS survey meter (model RDS-120) was used to measure radiation dose levels at the X-ray room, X-ray room door, Operator's stand, Reception area, adjoining offices, corridors, changing cubicle, and processing room. This test was carried out in order to know the radiation dose level (background radiation) in every one of those areas. In order to reduce error, three readings were taken in each location and the average dose rate was recorded. The IAEA recommend the individual dose limit for radiation workers averaged over 5 years is 100 mSv, and 1mSv per year for members of the general public (IAEA, 2018).

Test for radiation leakage

Radiation leakage was measured using the RADOS survey meter (RDS – 120) with the collimator completely closed. The measurements were taken at a distance of 100 cm (1 m) from the X-ray tube at four different sides of the X-ray tube (the right, left, front and back). The average of the readings was taken to give the dose rates for each side. The obtained values were compared with the acceptance limit of 1 Sv/hr (NNRA, 2006).

Test for Half Value layer

The HVL of an X-ray beam is used to judge the adequacy of filtration. Proper filtration is necessary to remove low-energy (soft) X-ray from the beam. Too low HVL will allow low energy X-ray to fall on the patient, increasing patient dose without any enhancement on diagnostic information.

Aluminum sheets of different thicknesses in conjunction with a dosimeter (model DR0393) was used for this test. The dosimeter was placed in primary beam at 40 cm from the cone. The first exposure was made without filters before 0.1 mm of aluminum sheet was taped over the dosimeter and exposure was made.

Exposures were repeated with increasing thickness of aluminum sheets within the range of 0.1, 0.2, 0.5, 1.0, 1.5, and 2.0 mmAl. Two exposures were made in each value and the dosimeter reading was recorded. The average value of the readings was obtained as HVL and compared with the acceptance limit.

Test of beam alignment

At each of the facilities, the loaded cassette was placed on the Couch, the collimator test tool was placed on the cassette and the Beam Alignment test tool was placed at the center of the collimator test tool. The tube was adjusted to 100 cm focus-to-film distance (FFD). The beam alignment tool was adjusted until its center was in line with the center of the collimator test tool and exposure was made at 70 kVp. After which the film was processed in the processing room.

Peak tube voltage test

The test is done to check the constancy of radiation output from an X-ray tube. The measurements for the peak tube voltage were done with a digital kVp meter that provides a convenient and fast method of measuring the effective kilo Peak Voltage (kVp) of a diagnostic X-ray machine. The digital kVp meter was placed on the X-ray table at the following distances: 40 cm, 70 cm, 90 cm, and 100 cm (the variation of distance was because at 100 cm, some of the X-ray machines did not reproduce any result) from the X-ray tube and the beam was collimated to the sensitive area of the meter. Exposures were made within the range of 60–120 kVp based on the kVp setting that was accessible at each of the facilities (this was due to the limitations of some of the machines) and reading on the kVp meter was recorded. Each of the exposures were repeated three (3) times for each of the measurements (mAs and kVp settings) and the average was recorded.

Linearity in mA

This was done to validate the response of the mA station. During the study, at some facilities, the kVp was set at 60 kVp and 70 kVp at some other facilities. While the kVp remained constant, the mAs was varied between 10–50 mAs. As the mAs was varied between 10–50 mAs, a multifunction meter was used to measure the mA linearity.

The coefficient of linearity was now calculated as

$$Coefficient\ of\ Linearity = \frac{(mAs)_{max} - (mAs)_{min}}{(mAs)_{max} + (mAs)_{min}})$$

Tolerance: The average ratios of exposure/mAs (in C/Kg/mAs or mR/mAs) must be ≤ 0.1 (the coefficient of linearity for timer should not exceed 0.1) (Rehani, 1995 and NNRA, 2006).

Entrance Skin Dose (ESD)

Three thermoluminiscent dosimeters (TLDs) were used for this test in each facility. Each of the TLDs were labelled A, B and C and they were placed in the primary beam at 10 cm from the end of the cone and exposures were made. The TLDs used at each of the facilities were kept in a leather bag and each of the bags were labelled by the name of the facility. The TLDs were transported to CERT, Zaria and the dose were measured for each of the TLDs. The ESD was assessed and compared with the recommended value of 2-3 mGy (IAEA, 2013).

Results and Discussion

The raw data can be found in DOI:10.17632/dn2d4m6hgh.1

Personnel Information

The qualifications, years of experience, and frequency of training obtained from the personnel at the facilities are presented in Table 1. The table shows that the staff in Hospitals are qualified to handle the X-ray machines but don’t undergo regular trainings. This shows the attitude of the Hospital management towards training and retraining of their staff. This is not a good practice due to the fact that the personnel are not equipped with the current trend and could overexpose or under expose patients (i.e., when the importance of optimization of doses to patients is considered).

Investigation of X-ray Machine Specifications

The information collected for the specifications of the X-ray machine at the various facilities are shown in Table 2. Three (3) government hospitals were visited for this study and the X-ray machines in each facility were all from different manufacturers with different models and types. The X-ray machines age range is from two to twelve years. The X-ray machines at Facility 1 and Facility 3 were manufactured in 2020 and 2010 respectively. The age of the X-ray machine at Facility 2 could not be calculated due to the lack of relevant information.

Visual Examination of the Premises

The X-ray units were visually inspected, and Table 3 shows the details of the radiation protection measures implemented by the facilities to safeguard patients, personnel, and the general public. Apparently, the results in Table 3 shows that all X-ray units pay close attention to radiation protection measures and also met the NNRA minimum requirement for an x-ray diagnostic room of 16 m^2 (NNRA, 2003).

Measurement of Radiation Dose Levels

The radiation dose levels measured before, during, and after exposure at each facility are presented in Table 4. According to the results, the dose rates measured during exposure at the X-ray table were found to be slightly higher than in other locations. The recorded dose rates at the remaining locations were low in all the facilities, and found to be safe for employees, patients, and the general public.

Radiation Leakage Test

A high radiation leakage contributes to the increase in dose to patients and staff. According to the EPA (2000) and NNRA (2006), X-ray tube radiation leakage should not exceed 1.0 mSv/h at a distance of 1 m. The data presented in Table 5, shows that the level of radiation leakage at Hospital 1 and Hospital 2 is well below the tolerance limit. While Hospital 3 exceeds the tolerance limit. Apparently, Hospital 1 and Hospital 2 shows a good level of compliance to the National and International standard, while Hospital 3 shows a high value at the front of the X-ray tube that exceeds the tolerance limit. Which could lead to over exposure of patients and staff.

Half Value Layer (HVL)

The HVL of an X-ray beam is a crucial criterion for determining the adequacy of filtration. In order to eliminate low-energy (soft) photons from the X-ray beam, proper filtration is required. HVL that is too low will permit low-energy X-rays to reach the patient, resulting in a higher patient dose without any improvement in diagnostic information. While excessively strong X-rays diminishes the image contrast, and result in the loss of essential diagnostic information details, a soft X-ray does not diminish the image contrast.

The HVL of an X-ray machine depends on age of the machine. Therefore, an old X-ray machine will have a smaller HVL. The measured HVL of various x-ray units is presented in Table 6. Only Hospital 3 has average values within the IAEA recommended tolerance limit while some values at Hospital 1 and Hospital 2 are within the tolerance limit of > 1.5mmAl. (IAEA, 2013). The results indicated that the filtrations of the X-ray machine at Hospital 3 are quite adequate, whereas those at Hospitals 1 and 2 are inadequate.

Beam Alignment test

Beam Alignment test shows how the X-ray beam and the image receptor are aligned. According to Rehani (1995), the tolerance limit for beam alignment is 1.5°. Therefore, for any value more than 1.5°, image distortion could be observed. This could lead to a misinterpretation of the result which could lead to incorrect diagnosis and possibly a higher patient dose due to repeated exposures. Table 7 shows that the beam alignments of all the facilities are within the tolerance limit of 1.5°. This suggests that X-ray beams were perpendicular to the film at all facilities and that the images were clear enough

Peak Tube Voltage (kVp) test

Table 8 shows result of the kVp test done on the various X-ray units, including average peak voltage reading, coefficient of variation, and tolerance limit. Hospital 1 and Hospital 2 had a high level of compliance, whilst Hospital 3 showed a moderate level of compliance. It is important to note that kVp test is a very important test for reducing patient dose and enhancing X-ray beam.

mA Linearity

Table 9 shows the coefficient of linearity for each Hospitals and the tolerance limit. Coefficient of linearity value for Hospital 1 and Hospital 2 were obtained but that of Hospital 3 was not obtained because no reading was gotten for the Focus-Film-Distance (FFD). Large coefficients of linearity shows that patient doses are high even when low mAs are selected.

Entrance Skin Dose

The entrance skin dose is the measure of the radiation dose absorbed by the skin of a patient upon exposure to the radiation. It is measured with Thermoluminescence dosimeters (TLD) and the unit is in milliGray (mGy). The results from the X-ray units are in good agreement with the standard value, as shown in Table 10. The NNRA recommended entrance skin exposure of 43.8 mGy (NNRA, 2006) while the National Radiological Protection Board recommended the tolerance limit of 3.0 mGy (NRPB, 1992). However, the Entrance Skin Dose (ESD) were found to be lower than the NRPB-recommended limit value of 3 mGy (Hart et al., 2000); consequently, there will be no immediate effect on the exposed patients, except after a prolonged exposure that could lead to dose accumulation.

Table 1: Table showing Personnel information.

Hospitals	Qualifications	Years of experience	Frequency of training
Hospital 1	BSc. Radiography	3	None in 3 years
Hospital 2	MSc. Radiography	3	None in 3 years
Hospital 3	BSc. Radiography	10	Once in a Year

Table 2: X-ray machine Specifications

Hospitals	Manufacturer	Model/Type	Serial Number	Date Manufactured
Hospital 1	Techmel & Techmel USA	TT-100X / Mobile	100879	April, 2020
Hospital 2	Siemens	08633047 / Fixed	33681	-
Hospital 3	General Electric	5189248 / Fixed	67087HL7	May, 2010

Table 3: Radiation protection measures against radiation.

Parameters	**Hospital 1**	**Hospital 2**	**Hospital 3**
Number of X-ray Rooms	1	3	3
X-ray room dimension (m^2)	23	22	20
Wall type	Cement block	Cement block	Cement block
Shielding material	Lead	Lead	Lead
Material thickness (Al eq)	2.5 mm	2.5 mm	2.5 mm
Lead aprons	Yes	Yes	Yes
Warning lights	Yes	Yes	Yes
Warning signs	Yes	Yes	Yes
Radiation monitoring devices (TLD)	Yes	Yes	Yes

Usage frequency	Everyday	Throughout working hours	Throughout working hours

Table 4: Measurement of radiation dose levels in each Hospital

Hospital 1	**Location**	**Before exposure (uSv/hr)**	**During Exposure (uSv/hr)**	**After Exposure (uSv/hr)**	**Average in Dose rate (uSv/hr)**
	X-ray room/Table	0.12	0.14	0.12	0.13
	x-ray room door	0.11	0.11	0.11	0.11
	Operator's stand	0.11	0.11	0.11	0.11
	Reception	0.10	0.10	0.10	0.10
	Attached Offices	0.10	0.11	0.10	0.10
	Corridors	0.10	0.11	0.10	0.10
	Changing Booth	0.10	0.11	0.10	0.10
	Processing room	0.10	0.10	0.10	0.10
Hospital 2	**Location**	**Before exposure (uSv/hr)**	**During Exposure (uSv/hr)**	**After Exposure (uSv/hr)**	**Average in Dose rate (uSv/hr)**
	X-ray room/Table	0.10	0.59	0.10	0.26
	x-ray room door	0.10	0.10	0.10	0.10
	Operator's stand	0.10	0.10	0.10	0.10
	Reception	0.10	0.10	0.10	0.10
	Attached Offices	NA			
	Corridors	0.10	0.10	0.10	0.10
	Changing Booth	0.10	2.40	0.10	0.87
	Processing room	NA			
Hospital 3	**Location**	**Before exposure (uSv/hr)**	**During Exposure (uSv/hr)**	**After Exposure (uSv/hr)**	**Average in Dose rate (uSv/hr)**
	X-ray room/Table	0.12	2.51	0.12	0.92
	x-ray room door	0.10	1.20	0.10	0.47
	Operator's stand	0.10	0.15	0.10	0.12
	Reception	0.10	0.10	0.10	0.10
	Attached Offices	0.10	0.10	0.10	0.10
	Corridors	0.10	0.10	0.10	0.10
	Changing Booth	0.10	0.10	0.10	0.10
	Processing room	0.10	0.10	0.10	0.10

NA – Not Available

Table 5: Radiation Leakage test in each of the Hospitals

Hospital 1	**Position**	**First (mSv/hr)**	**Second (mSv/hr)**	**Average (mSv/hr)**	**Tolerance Limit (mSv/hr) NNRA, 2006.**
	Front	0.12	0.12	0.12	1.0
	Back	0.11	0.11	0.11	1.0
	Right	0.11	0.11	0.11	1.0
	Left	0.11	0.11	0.11	1.0
Hospital 2	**Position**	**First (mSv/hr)**	**Second (mSv/hr)**	**Average (mSv/hr)**	**Tolerance Limit (mSv/hr) NNRA, 2006.**
	Front	0.87	0.42	0.65	1.0
	Back	0.11	0.12	0.12	1.0
	Right	0.11	0.12	0.12	1.0
	Left	0.49	0.30	0.40	1.0
Hospital 3	**Position**	**First (mSv/hr)**	**Second (mSv/hr)**	**Average (mSv/hr)**	**Tolerance Limit (mSv/hr) NNRA, 2006.**
	Front	1.20	1.35	1.28	1.0
	Back	0.11	0.11	0.11	1.0
	Right	0.13	0.14	0.14	1.0
	Left	0.12	0.12	0.12	1.0

Table 6: Half Value Layer test for each Hospitals

Hospital 1	**kVp**	**(mmAl)**	**First HVL (mmAl)**	**Second HVL (mmAl)**	**Average HVL (mmAl)**	**Tolerance limit (mmAl)**
	82	0.1	1.72	1.65	1.69	>1.5
	82	0.2	1.60	1.50	1.55	>1.5
	82	0.5	1.34	1.10	1.22	>1.5
	82	1.0	0.90	0.70	0.80	>1.5
	82	1.5	0.64	0.42	0.53	>1.5
	82	2.0	0.49	0.21	0.35	>1.5
Hospital 2	**kVp**	**(mmAl)**	**First HVL (mmAl)**	**Second HVL (mmAl)**	**Average HVL (mmAl)**	**Tolerance limit (mmAl)**
	70	0.1	102.6	74.2	88.40	>1.5
	81	0.2	104.2	62.8	83.50	>1.5
	85	0.5	89.4	40.3	64.85	>1.5
	90	1.0	0.52	0.29	0.41	>1.5
	96	1.5	0.31	0.15	0.23	>1.5
	102	2.0	0.12	0.07	0.10	>1.5

Hospital 3	kVp	(mmAl)	First HVL (mmAl)	Second HVL (mmAl)	Average HVL (mmAl)	Tolerance limit (mmAl)
	50	0.0	4.20	4.01	4.11	>1.5
	50	0.1	4.06	3.85	3.96	>1.5
	55	0.2	3.95	3.77	3.86	>1.5
	60	0.5	3.51	3.25	3.38	>1.5
	65	1.0	3.24	2.85	3.05	>1.5
	70	1.5	2.30	2.15	2.23	>1.5
	75	2.0	1.23	1.15	1.19	>1.5

Table 7: Beam Alignment tests for all the x-ray units

Hospitals	Beam Alignment (°)	Tolerance limit
Hospital 1	1.0	< 1.5
Hospital 2	1.0	< 1.5
Hospital 3	1.0	< 1.5

Table 8: Peak tube voltage (kVp) test for the Hospitals.

Hospital 1 (FFD = 70 cm)	**kVp Station**		**Average Reading (kVp)**	**Coefficient of Variance**	**Tolerance limit (NNRA, 2006)**
	kVp	mAs			
	60	10	64.5	0.010	0.05
	70	10	71.2	0.002	0.05
	80	10	80.0	0.010	0.05
Hospital 2 (FFD = 100cm)	**kVp Station**		**Average Reading (kVp)**	**Coefficient of Variance**	**Tolerance limit (NNRA, 2006)**
	kVp	mAs			
	70	10	70.7	0.002	0.05
	81	10	79.9	0.002	0.05
	90	10	89.5	0.020	0.05
	102	10	102.7	0.003	0.05
Hospital 3 (FFD = 90 cm)	**kVp Station**		**Average Reading (kVp)**	**Coefficient of Variance**	**Tolerance limit (NNRA, 2006)**
	kVp	mAs			
	70	10	71.4	0.01	0.05
	80	10	88.4	0.01	0.05
	90	10	106.9	0.22	0.05

Table 9: mA linearity for each Hospitals

Hospital 1	kVp Station		Average Rad-check (mR)	Relative mR/mAs	Coefficient of Linearity	Tolerance limit: ≤ 0.1 (NNRA, 2006)	Remark (Pass/Fail)
	kVp	mAs					
	70	50	106.8	2.136	0.34	0.1	Fail
	70	40	83.9	2.098			
	70	30	66.9	2.230			
	70	20	41.9	2.095			
	70	10	42.5	4.250			
Hospital 2	**kVp Station**		**Average Rad-check (mR)**	**Relative mR/mAs**	**Coefficient of Linearity**	**Tolerance limit: ≤ 0.1 (NNRA, 2006)**	**Remark (Pass/Fail)**
	kVp	mAs					
	70	48	8.9	0.185	0.08	0.1	Pass
	70	40	7.5	0.188			
	70	32	5.5	0.172			
	70	20	4.0	0.200			
	70	10	1.9	0.190			
Hospital 3	**kVp Station**		**Average Rad-check (mR)**	**Relative mR/mAs**	**Coefficient of Linearity**	**Tolerance limit: ≤ 0.1 (NNRA, 2006)**	**Remark (Pass/Fail)**
	kVp	mAs					
	70	50	No reading for the FFD.			0.1	
	70	40					
	70	30					
	70	20					
	70	10					

Table 10: Entrance Skin Dose (ESD) for all the x-ray units.

S/No	TLD ID	Dose (mGy) (Skin Dose)	Tolerance Limit (mGy)
1	Hospital 1 A	0.95	3.0
2	Hospital 1 B	2.08	3.0
3	Hospital 1 C	0.81	3.0
4	Hospital 2 A	0.86	3.0
5	Hospital 2 B	0.54	3.0
6	Hospital 2 C	1.14	3.0
7	Hospital 3 A	0.18	3.0
8	Hospital 3 B	0.61	3.0

9	Hospital 3 C	0.29	3.0

Conclusion:

According to Delis et al. (2017), imaging equipment is frequently left unchecked for extended periods of time in low- and middle-income nations. Consequently, an evaluation of X-ray equipment performance in government hospitals in Kaduna City, Kaduna State, Nigeria, is required. Based on the findings of this study, it can be concluded that the government hospitals in the Kaduna metropolitan area are slightly in compliance with national and international standards. The visual inspection performed on the hospitals revealed that they have a high degree of standard compliance.

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