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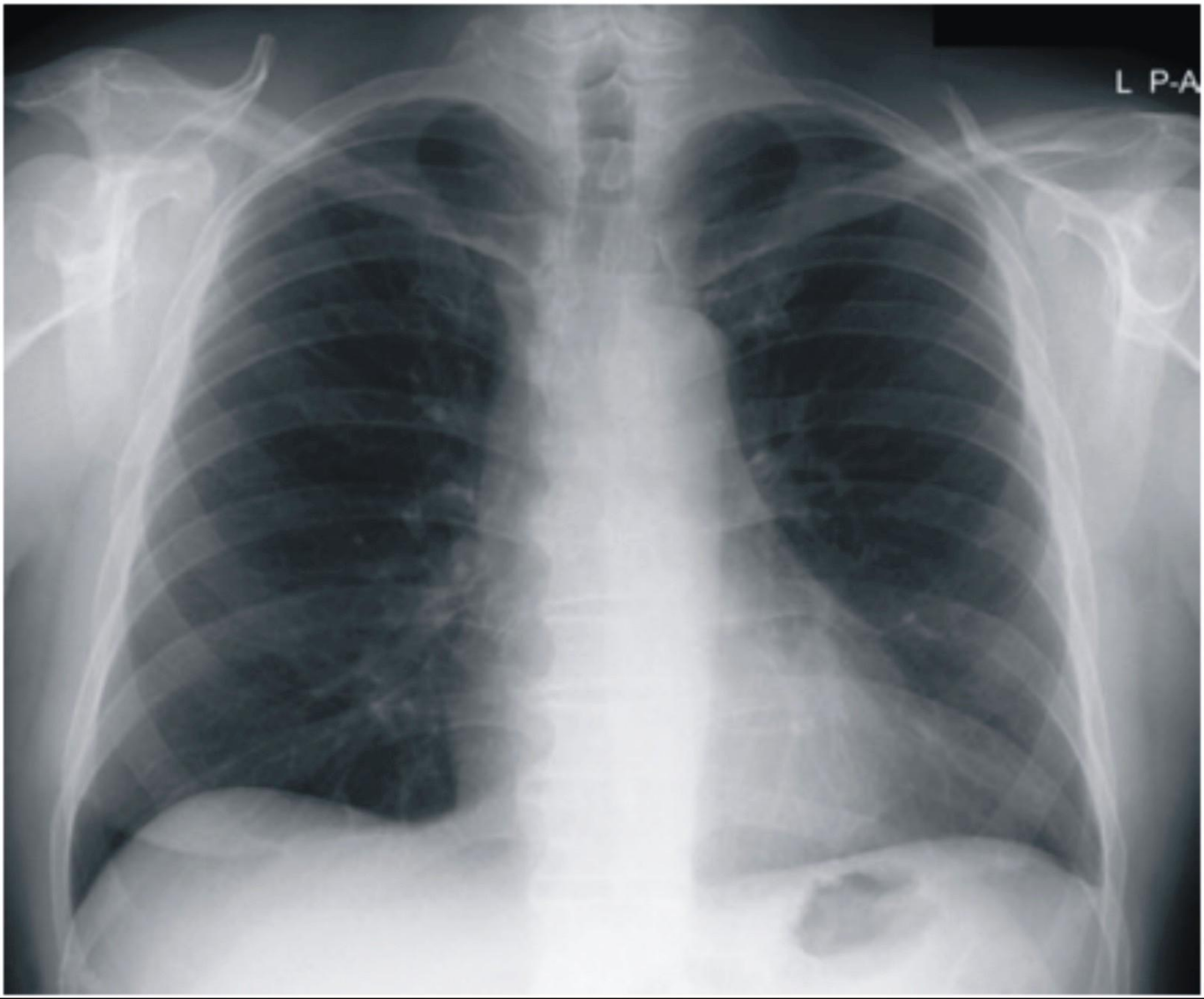

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Assessment of Radiation Safety Measures in Select Radio-Diagnostic Centres in Kaduna State, Nigeria

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ABSTRACT

Background: The risks associated with x-rays in radiography are minimized through international best practices of a regular program of quality control.

Objective: To assess the radiation safety precautions taken in five radio-diagnostic centers in Kaduna State, Nigeria

Methodology: Measuring tapes, radiation meters and other accessories were used to assess for x-ray room dimension, x-ray tube leakage, kVp accuracy, half value layer (HVL), mA linearity, optical and x-ray beam congruence, beam alignment, and timer accuracy.

Results: Only one centre complied with the $16m^2$ minimum room dimension required for an x-ray room, passed area monitoring without a compromise, and wholly complied with kVp error limit of 5%. Two centres passed optical radiation beam congruence, beam alignment and timer accuracy tests. Three centres passed mA linearity test. All the five centers passed the tube leakage test with none of the centers recording up to 1mSv/h at 100cm from the tube surface.

Conclusion: X-ray machines used in Kaduna States are safe. However, there are uncoordinated attention to other safety precautions. More efforts should be made to ensure that holistic regulatory standards are met in order to consolidate radiation protection.

Keywords: Quality control, radiation protection, tube leakage , room dimension, HVL

Introduction

Dose limits do not apply to medical exposures, nevertheless radiation protection measures to prevent unnecessarily high doses should be undertaken [1]. The emphasis in radiation protection has been on stochastic effects where the probability, rather than its severity, increases with dose [2]. The main tools to achieve radiation protection in medical practice are justification of practices, optimization of protection and the use of dose limits [3]. A good programme of radiation protection guarantees that patient doses will be reasonable, and will produce optimum image quality that is adequate for diagnosis [4].

A periodic quality control assessment enhances the optimization of the radiation protection of the patients and helps to minimize the dose used in examinations [5]. This is necessary because, safety in the utilization of radiation sources in medicine and industries has received inadequate attention globally, in spite of the efforts of national and international radiation agencies [6].

Sub-optimal standards of safety increases the risk of radiation induced fatal cancer from exposure to low doses of ionizing radiation [7]. Incidentally, only about 60% of Nigerian employers and employees in x-ray diagnostic centers have good knowledge of hazards associated with radiation exposure [8]. Equipment is an integral part of the physical infrastructure of a hospital setup [9]. In Africa generally, some quality control studies undertaken on infrastructure painted a worrisome picture [10, 11, 12].

In our locality, many of such radiation infrastructure abound for medical use. The main focus of this research is to reveal the level of safety practiced in the target hospitals, as a quality control measure to guarantee radiation protection of patients, personnel, and the public.

Material and methods

This was an approved survey carried out in 2015 in a public and four private radio-diagnostic centres: National Ear Care Center Kaduna (A), Alheri Diagnostic Center Zaria (B), Zazzau Radiological Center Zaria (C), First Scan Diagnostic Center Zaria (D) and Salama Hospital, Zaria (E). They were included because their machines were functional and they gave speedy approval for the work. Materials used included: survey meters with GM detectors, kV meter (RMI) model 245, exposure meter (Rad check), collimator and beam alignment test tools (model 161B and 162A), loaded x-ray cassette (24 x 30 cm), metallic L/R anatomical marker, aluminum sheets, thermoluminescent dosimeters (TLD), and tape rule.

Area Monitoring

Two calibrated survey meters were used simultaneously to assess the radiation exposures to strategic areas within the x-ray room and the surroundings. For each location, three exposures were taken and the average recorded. Background radiation was measured before exposures were taken.

Quality Control Tests

The following quality control tests were performed on the x-ray machines: tube leakage test at a recommended distance of 100cm from x-ray tube, peak kilovoltage (kVp) test accuracy, evaluation of half value layer (HVL), mA linearity and reproducibility, optical and x-ray beam congruence, beam alignment test, and timer Linearity**.**

For leakage radiation from the x-ray tube, the x-ray tube collimator was completely closed and exposure factors ranging from 90 -110kVp and 30 - 200mAs were set on the control console. A TLD was positioned in each of the four interfaces of the x-ray tube at a distance of 100cm from the source. Exposures were subsequently made.

Peak kVp accuracy and reproducibility was done using a multifunction meter located on the couch at 100cm focus-film distance (FFD). A tube potential ranging from 60 – 100 kVp was varied under constant mA and mAs. The average of three exposures was recorded.

Half -Value Layer (HVL) was evaluated using an exposure meter and a series of aluminum sheets of thickness 0.1, 0.5, 1 and 2mm. The exposure meter was placed on the couch at 100cm FFD. The radiation field was collimated to the size of the sensitive chamber of the meter. The first exposure was made at 80 kVp with a variable tube current ranging from 20 – 100 mAs without any filter interposed. The next exposure involved a filter. Each thickness of the filter was used in a similar fashion. The average of three exposures was recorded.

The test for mA Linearity and reproducibility was achieved using radiation exposure meter (Rad check). The mA exposure meter was located on the couch at 100cm from the x-ray tube. The required mAs was set.

Three exposures were made in each instance using mAs of 100, 75, 50, and 25, respectively. The coefficient of linearity was then calculated using formula:

$$\text{Coefficient of linearity} = \frac{\left({}^{mR}/_{mAs}\right)_{max} - \left({}^{mR}/_{mAs}\right)_{min}}{\left({}^{mR}/_{mAs}\right)_{max} + \left({}^{mR}/_{mAs}\right)_{min}}$$

To assess optical and x-ray beam congruence, a cassette loaded with four metallic markers was used. The objective was to find out the mismatch, if any, between light and x-ray beam. Mismatch may be caused due to shifts in the relative positions of light bulb, reflecting mirror and anode focal spot. As a result there may be cut-off on the radiograph and exposure to unwanted areas of the body. This could lead to several repeats with its attendant radiation risks. The cassette loaded with film was located on the couch under the light beam of the x-ray unit with an FFD of 100cm. The beam was collimated to about 20 x 25 cm area on the cassette at the centre. The metallic markers were placed at the four corners of the light field on the cassette. An exposure was made at about 70kVp and 30mAs. The light field was then widened to cover the entire cassette. Another exposure was made with similar factors. The film was subsequently, processed.

The test for beam alignment required a collimator test tool, beam alignment test tool, and a cassette loaded with film. It is done to assess the perpendicularity of the x-ray beam to the image receptor and the patient. If the x-ray beam is not perpendicular to the film, the images may be distorted and diffused leading to repeat. The loaded cassette was located on the couch. The collimator test tool was placed on the cassette and the beam alignment tool was placed at the center of the collimator test tool.

The tube was adjusted to 100cm FFD. The beam alignment tool was adjusted until its centre coincided with the centre of the collimator test tool. The film was exposed with 70kVp and 20mAs, and then processed.

Timer accuracy and linearity test is achieved using an exposure meter (Rad check). The test is done to assess the accuracy and linearity of the machine timer since the dose administered to patients is directly proportional to the time of exposure with other parameters constant. The mA exposure meter was located on the couch at 100cm FFD. The required exposure time was set on the console under constant mA and kVp. A variable time (s) of 100 – 500 miliseconds in steps of 100 seconds was used with the constant mA. The coefficient of linearity was calculated using the previously used equation.

Other assessments made include staff competence, personnel monitoring, repair log book, radiation protection unit/committee, acceptance tests certificate, and QC documentation using personal observation and interview of radiographers. The data was analysed using a simple calculator.

Discussion

A large space is required in an x-ray room for easy access of patients on trolley and beds, for easy manipulation of equipment, and for radiation safety of staff and the public. By convention, the minimum room dimension required for diagnostic x-ray by NNRA is $16m^2$ [13]. From this study only center B complied with the minimum room dimension required.

Tube Leakage test is done to show the amount of radiation that leaks from the x-ray tube outside the area of interest during exposure. Local radiation code stipulates that leakage radiation should not exceed 1mSv/h at 1m from the source. It appeared that x-ray machines in use in the locality are not leaking as evidenced by the highest amount of leakage detected in this stuy (0.44mSv/h). A previous work done in India with a leakage o< 0.5mSv/h corroborates our work [10].

Table 1: Layout and design of the x-ray rooms

	X-ray centre				
Parameter	A	B	C	D	E
Room					
Located in a	Bungalow	Bungalow	Bungalow	Bungalow	Bungalow
Dimension	12.35m^2	22.28m^2	15.21m^2	12.91m^2	13.32m^2
Wall					
Type	Cement block	Cement block	Brick block	Cement block	Cement block
Thickness	0.27m^2	0.27m^2	0.27m^2	0.27m^2	0.27m^2
Pb thickness (mm)		1.30	1.30		1.30
Pb lining height (m)		2.30	1.84	-	2.20
Door					
Number	1	1	1	1	1
Type	Wooden (2- leaved)	Wooden (2- leaved)	Wooden (1- leaved)	Wooden (1- leaved)	Wooden (1- leaved)
Dimension (m)	1.10 x 2.00	1.23 x 2.00	0.84 x 1.94	0.74 x 1.55	0.80 x 2.00
Thickness(cm)	5.00	5.00	4.00	4.00	4.00
Lead lining		Present	Absent	Absent	Absent
Pb thickness (mm)	1.30	1.30	-	-	-
Ceiling					
Height from floor (m)	2.50	2.50	3.65	2.20	3.00
Type	Wooden board	Wooden board	Wooden board	Wooden board	Wooden board
Window					
Number	2	1	1	1	1
Height from floor(m)	1.70	1.00	2.10	1.35	
Distances					
Operator –tube (m)	2.50	3.00	2.64	1.90	2.00
Operator-chest stand (m)	3.00	4.28	3.00	1.90	1.90
Control cubicle					
Type	Pb screen	Concrete	Pb screen	-	Pb screen

Table 2: X-ray machine specifications

	Centre				
Parameter	A	B	C	D	E
Machine type	Mobile	Fixed	Mobile	Mobile	Mobile
Manufacturer	Picker Intl	LIN Ltd	Watson ltd	Shimadzu	G&C Ltd
Year manufactured	1986	2005	-	2001	-
Country	Japan	-	-	Japan	-
Tube rating					
Inherent filter (Al)	0.7mm	1.5mm	-	2mm	-
kVp max	125	150	160	100	200
mA max	-	400	150	30	200
Common kVp	70-80	90-100	70-80	70-80	100
Common mAs	10-30	40-80	20-40	20-60	9

Table 3: Throughput of patients

Center	Mean throughput/ day	Mean exposure/ patient	Total Exposure/ day
A	04	02	08
B	12	03	36
C	10	02	20
D	10	02	20
E	01	02	02

Tube potential (kVp) accuracy is a key component of optimization of x-ray beam and this minimizes patient dose [14]. This test should be performed annually and the result should be within 5% of the value set on the machine [15]. Out of the five centres studied, only A and C showed moderate compliance in kVp accuracy.

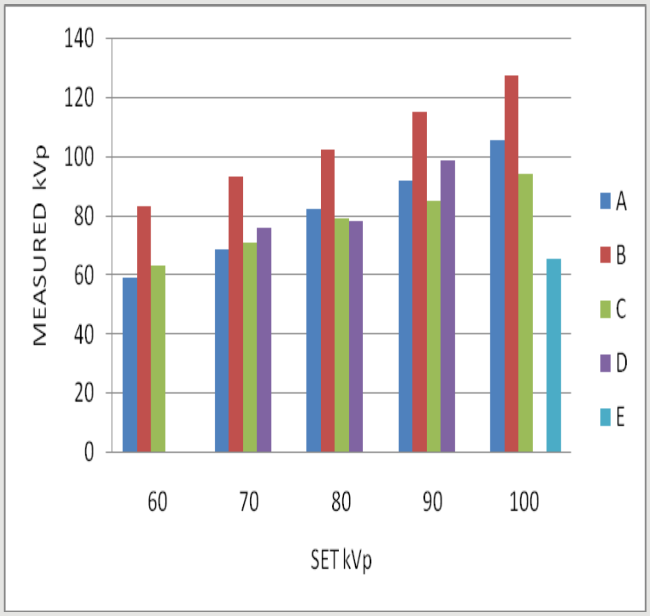

Figure 1: Kilovoltage peak (kVp) accuracy test

Table 4: Area monitoring of the x-ray centres

	Dose rate (µSv/h)				
Location	A	B	C	D	E
Background	0.12± 00	0.10±00	0.12±00	0.13±00	0.13±00
Operator's stand	*1.60±00**	0.13±00	*6.13±0.04**	Not accessible	0.45±00
X-ray room door	0.10±00	0.20±00	0.84±00	*7.60±0.04**	31.00±0.09*
Dark room door	*32.50±00**	0.10±00	0.13±00	*7.20±0.04**	1.55±0.01
Adjoining offices	0.10±00	0.10±00	0.10±00	0.12±00	0.10±00
Waiting area	0.10±00	0.10±00	0.10±00	0.13±00	0.10±00
Corridor	Not sighted	0.14±00	0.10±00	Not sighted	0.13±00
Changing cubicle	*5.30±0.03**	0.10±00	*5.30±0.03**	Not sighted	Not sighted
Behind x-ray room	0.13±0.01	0.12±00	0.10±00	No access	No access
X-ray room window	0.13±00	0.65±0.01	*5.30±0.03**	No access	No access
Toilet	0.13±00	0.10±00	0.10±00	0.64±0.01	Not sighted

* Notable deviations

Table 5: Leakage Test

	Dose rate (mSv/h) *Acceptable limit: 1.0 mSv/h.					
INTERFACE	A	B	C	D	E	Tolerance
Right	0.44	0.08	0.10	0.10	0.05	1.0
Left	0.06	0.04	0.15	0.05	0.05	1.0
Back	0.16	0.07	0.07	0.07	0.05	1.0
Down	0.10	0.05	0.20	0.08	0.10	1.0

Table 6: HVL of x-ray machines in the 5 centres

X-ray unit	HVL (mm Al)	Limit (mm Al)
A	4.5	>2.5
B	4.5	>2.5
C	1.2	>2.5
D	5.0	>2.5
E	2.5	>2.5

The HVL of an x-ray beam is a very important parameter. Too low HVL shows that the x-rays generated are soft and therefore, very weak in penetration thereby, leading to more patient dose. The HVL of an x-ray machine is age dependent. Older machines are expected to have lower HVL

A minimum HVL of 2.5mm Al at 80kVp is required for a diagnostic facility [15]. This study shows compliance in all but one centre. From this work and the work of Taha, (2010) in which none of the six x-ray machines that were tested, failed HVL test, we can deduce that HVL of most machines are within acceptable limit.

Table 7: Coefficient of mA linearity of the machines

	Coefficient of linearity	
x-ray unit	Acceptable limit:0.1 (Rehani, 1995)	tolerance
A	0.04	<0.10
B	0.11	<0.10
C	0.49	<0.10
D	0.11	<0.10
E	-	<0.10

The tolerance limit of coefficient for tube current (mA) linearity is 0.1 [15]. Large coefficient of mA linearity means higher dose to the patient even with little mAs selected. Three of the centers studied complied with the mA linearity.

The optical and radiation field congruence test shows the correlation between the field delineated by the light beam and the actual exposure field by the x-ray beam. It is required that the shift should not be greater than 2% of the FFD which corresponds to 2cm. Similarly, beam alignment shows the perpendicularity between the x-ray beam and the image receptor. Acceptable error limit is 1.5^0 [15]. The error detected in C and E are far beyond the acceptable limit. Image distortion is likely to be common in these centers.

Table 8: Optical and radiation field congruence

Center	Optical radiation congruence (cm)	Tolerance limit (Rehani, 1995)
A	1.8 and 0.2	2.0cm
B	1.1 and 0.7	2.0cm
C	3.8 and 2.0	2.0cm
D	7.1 and 0.1	2.0cm
E	2.0 and 1.6	2.0cm

Table 9: Beam alignment

Center	**Beam alignment (degree)**	**Tolerance limit (degree)**
A	1.5	1.5
B	1.5	1.5
C	>3.0	1.5
D	0.5	1.5
E	>3.0	1.5

Table 10: Other Assessments

Assessed	A	B	C	D	E
Radiographer	Yes	No	No	No	No
RSO	Present	Absent	Absent	Absent	Absent
PMD	Nil	Nil	Nil	Nil	Nil
QC log book	Absent	Absent	Absent	Absent	Absent

PMD: Personnel monitoring device; QC: Quality control;
RSO: Radiation safety officer;

Conclusion

In conclusion**,** x-ray machines used in Kaduna States are safe. However, there are uncoordinated attention to other relevant safety precautions. More efforts should be made to ensure that wholistic regulatory standards are met in order to consolidate radiation protection.

Recommendation

Regular quality control tests should be performed annually in every x-ray diagnostic center by certified experts.

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