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Assessment Of Diagnostic Parameters Of Selected X-Ray Machines In Nasarawa State, Nigeria.

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Abstract: *Assessment of quality control parameters of diagnostic X-ray machines in the radiological Department of the selected Hospitals in Nasarawa State was carried out using Diavolt Dosimeter, a device capable of measuring kVp, inherent filtration, dose, and time of exposure. The parameters considered in the assessment include; Half Value Layer (HVL), Peak Kilovoltage (kVp), Absorbed dose, Misalignment, and Focal spot size. The result of the HVL test conducted were 4.18mm, 4.18mm, 5.54mm, and 3.65mm for facility 1, 2, 3, and 4 respectively. Comparing these values with the minimum recommended values at various kVps, the four facilities have high HVL values with the resulting effect on the quality of the image produced due to high absorption of X-ray photon. The kVp test indicates that only facility 2 meet the acceptance limit of ±5% with percentage difference of ±0.8%, ±0.0%, ±1.7%, ±5.0%, and ±1.9% at 50, 60, 70, 80, and 90kVp respectively. The highest percentage difference in kVp value was ±24.4% recorded in facility 3 and the least value of ±0.0% was recorded in facility 2. For machines with high percentage difference in kVp values, there is high risk of over-exposure. The maximum value of absorbed dose recorded was 989.8μGy which is below the maximum permissible recommended dose of 50,000μGy. For congruency test conducted, a misalignment of 1.6cm, 2.5cm, 0.65cm, and 0.7cm were recorded for facility 1, 2, 3, and 4. Only facility 3 and 4 had values within the acceptance limit of 1.5cm set by the regulatory authorities. Replacement or recalibration becomes necessary for such machines with misalignment greater than the acceptance limit to address the probability of exposing areas of no interest during X-ray examination. The effective focal spot which is a measure of image resolution has its highest value in facility 3 (8.69mm) and the least as 5.11mm in facility 2 with Facility 1 and 4 having effective focal spot of 7.67mm and 6.0mm both at 1.0Lp/mm. Facility 3 has the highest image resolution. The misalignments of the collimator in Facility 1 and 4 were within the tolerance limit of 25mm in the horizontal and vertical dimensions. Facility 2 and 3 had misalignment beyond the tolerance limit. On the general note, all the facilities have high probability of producing low quality image as a result of various difficulties recorded ranging from Calibration in facility 1, 3, and 4; Beam alignment in facility 1 and 2; Collimator alignment in facility 2 and 3; and low resolution in Facility 2.*

Keywords: *Half value layer, X-rays, exposure, attenuation coefficient.*

I. Introduction

The discovery of X-ray by a German Physicist Wilhelm Rontgen while investigating the effects of electron beams in electrical discharges at low pressure gasses has revolutionized the practice of medicine. The ability these rays to penetrate materials leads to wide range of applications particularly in medical diagnosis and therapy. X-rays are produced when high energetic electrons strike a metal target thereby converting the kinetic energy of the moving electrons to electromagnetic radiation (Bushberg et al., 2012; Sprawls, 1987; Lucas, 2015).X-rays have been used for decades for the evaluation of damage induced internal organs (such as the bones, lungs, intestine, brain e.t.c) which in turn has greatly assisted medical doctors in exact diagnosis of physical damage induced. The quality of the image produced from X-ray examination of internal organs is paramount for clear diagnosis. This quality is known to depend on the X-ray machine's control parameters such kVp, mAs and HVL.

Though X-ray play vital roles in medical imaging, its interaction with living tissues is capable of altering genetic information hence the need for quality assurance test on the X-ray machines to ensure they are in good working condition thereby avoiding over-exposure of patients and its attendant effects (AAPM, 2002; Loewe, 2008). The main aim of Quality Assurance Test is to obtain accurate and timely diagnosis with minimum exposure (Owuso et al, 2015; Mana, 2011). Quality Assurance Test also helps to reduce cost encored on radiographic re-examination caused by lapses in devices or materials used for diagnosis (Gholami et al., 2015). This radiation when used for diagnostic or therapeutic purposes could have direct or indirect effects on cell (FDA, 2006). For dose optimization, all exposure should be kept at minimum dose level in accordance with the ALARA principle (ALARA-as low as reasonably achievable) (Mana, 2011; James, 2012). Exposure to ionizing radiation whether for medical, occupational, or accidental reasons may cause deleterious biological consequences, such as tetratogenic effects when used on pregnant women or one of child bearing age, cancer, sterility, and cataracts depending on the exposed dose on patients (Ping et al., 2014; Sansare et al., 2011; Palma et al., 2011). No dose of ionizing radiation exposure is considered safe, and the accurate estimation of the absorbed dose is critical in determining appropriate medical care (Ping et al., 2014).

II. Material And Method

The assessment of control parameters of diagnostic X-ray machines located in radiological department of selected hospitals in Nasarawa state was performed using a Diavolt Dodimeter, a universal model 43014 capable of measuring Dose (μGy), KVP, Peak mean voltage (PPV) Maximum voltage, and inherent filtration., 14 × 17 inches Cassette, Collimator and beam alignment tool and set of Aluminum filters.

2.1The Kilovoltage test

The Dosimeter was placed at 100cm FFD. 20mAs, 50kVp was set on the control panel of the x-ray machine, exposure was made, and the Dosimeter readings recorded. The procedure was repeated maintaining fixed value of mAs increasing kVp by 10 until a total of 90kVp was reached. The percentage difference between the selected values on the control panel and the measured value was computed using the relation;

$$\frac{x_i - p_i}{p_i} \times 100\% \tag{1}$$

Where x is the measured values and p is the selected values.

2.2 Half value layer test

A value of 50kVp and 20mAs were set on the control panel of the machine. Exposure was first made without filter; 1mmAl filter was then fixed at 10cm for the second exposure. With the dosimeter placed at 100cm, exposure was made and the readings on the dosimeter recorded. The procedure was repeated in an increment of 1mmAl until a total value of 5mmAl is attained. The values of μ in all the facilities assessed were obtained from the graph of doses against thickness of Aluminum and the values of HVL calculated using the relation;

$$\text{HVL} = \frac{0.693}{\mu} \tag{2}$$

Where μ, is the linear attenuation coefficient of the aluminum filters.

2.3 Beam alignment

The collimator tool was placed on top of a cassette loaded with radiographic film at FFD of 100cm from the x-ray machine. The cassette was placed on a radiographic table. The beam alignment tool was then placed on the collimator tool with the two spots on the beam alignment tool aligned with the centre or the central spot of the collimator tool. The collimators shutters were adjusted such that the edges of the light field coincided with the rectangular outline on the collimator tool. Exposure was then made and the film later developed to visualize the image produced. A stable mAs and kVp was maintained for the four facilities used in the four research area.

Table 1: Selected parameter for alignment test.

Facility	kVp	mAs	FFD
1	65	6.3	100cm
2	70	6.4	100cm
3	70	10	100cm
4	70	20	100cm

2.4 Focal spot test

The Focal spot tool was placed on top of a cassette loaded with radiographic film at FFD of 100cm from the x-ray machine. The cassette was placed on a radiographic table. Exposure was then made and the film later developed to visualize the image produced. A stable mAs and kVp was maintained in the four facilities assessed.

III. Result And Discussion

The results of the measurement conducted in the four facilities situated in Lafia, Nasarawa State are presented in the Tables below;

3.1 KVp accuracy test

Table 2: The % difference in KVP values at 20mA in Fac. 1

Set KVP	Measured KVP	±% difference	Remark
50	51.9	3.8	Pass
60	66.1	10.2	Fail
70	76.2	8.9	Fail
80	88.6	10.8	Fail
90	92.1	2.3	Pass

Table 3: The % difference in KVP values at 20.3mAs in Fac. 2

Set KVP	Measured KVP	±% difference	Remark
50	49.6	0.8	Pass
60	60.0	0.0	Pass
70	71.2	1.7	Pass
80	84.0	5.0	Pass
90	91.7	1.9	Pass

Table 4: The % difference in KVP values at 10mAs in Fac. 2.

Set KVP	Measured KVP	±% difference	Remark
50	59.2	18.8	Fail
55	68.4	24.4	Fail
60	71.1	18.5	Fail
65	77.9	19.8	Fail
70	81.2	16.0	Fail

Table 5: The % difference in KVP values at 20.3mAs in Fac. 4.

Set KVP	Measured KVP	±% difference	Remark
50	52.2	4.4	Pass
60	62.5	4.2	Pass
70	75.5	7.9	Fail
80	89.5	11.9	Fail
90	95.7	6.3	Fail

The kVp accuracy test gives the deviation of the set values from the measured values. This according to American Association of physicist in Medicine should be within ± 5% for acceptance (AAPM, 2002). In facility 1, a percentage difference of 3.8 and 2.3 were recorded at 50kvp and 90kvp which were within the acceptance limit. At 60, 70 and 80kvp, the results obtained were not within the acceptance limit. A percentage difference of 10.2, 8.9, and 10.2 respectively were recorded. In facility 2, the percentage difference in the five selected kVp met the acceptance limit of ± 5%. Facility 3 had a very high deviation between the set values and the measured values as no value of percentage difference met the set limit by AAPM. Facility 4 had ± 4.4% at 50kvp and ± 4.2% at 60kvp which were the only two that met the set limit of ± 5%. A deviation greater than the acceptance limits were recorded at 70, 80, and 90kvp. These high values of kVp have direct effects on the radiation dose reaching the patient as well as the contrast of the image produced (James, 2012; Thumpthy, 1978; AAPM, 2002).The deviation could be caused by faulty machines, long usage of the machines or poor maintenance (AAPM, 2002). This calls for re-calibrations or replacement of the old machines with new ones depending on what hospitals or diagnostic centres can afford. (Taha, 2015; Naji et al., 2016).

3.2 Half value layer

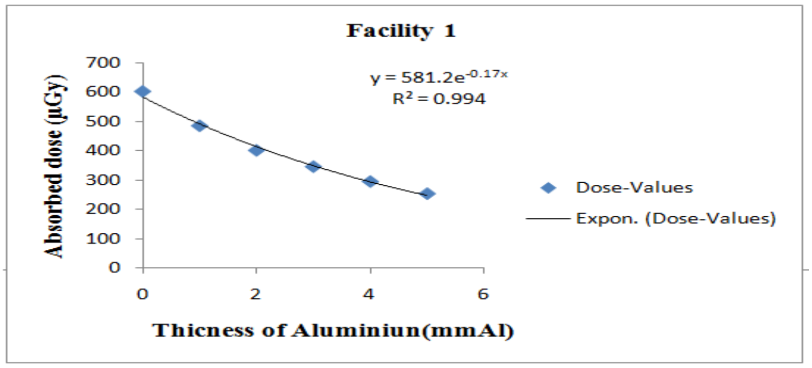

Figure 1: Variation of Absorbed Dose with Thickness in Facility 1.

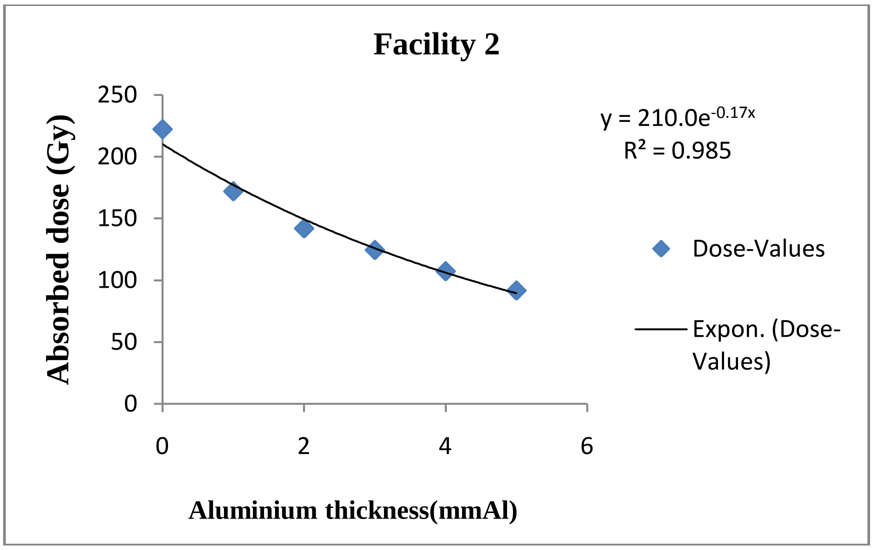

Figure 2: Variation of Absorbed Dose with Thickness in Facility 2.

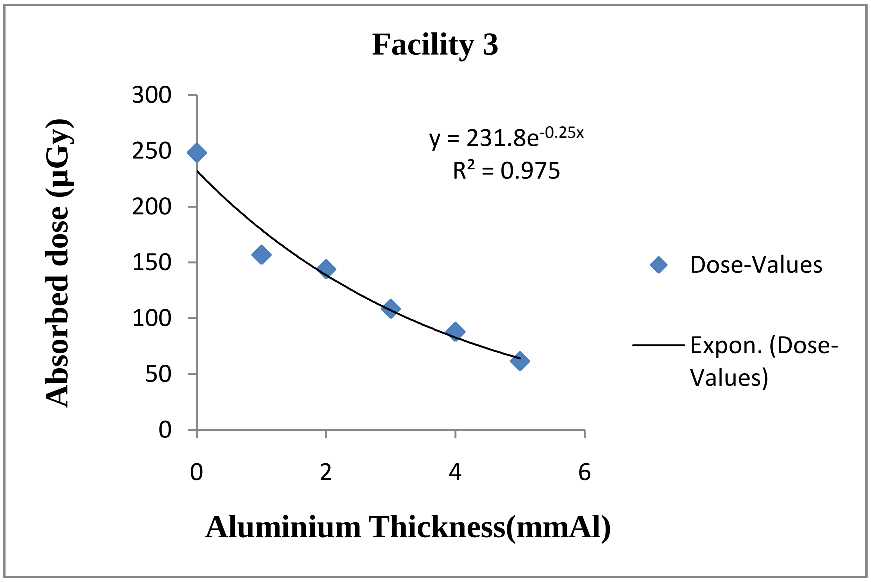

Figure 3: Variation of Absorbed Dose with Thickness in Facility 3.

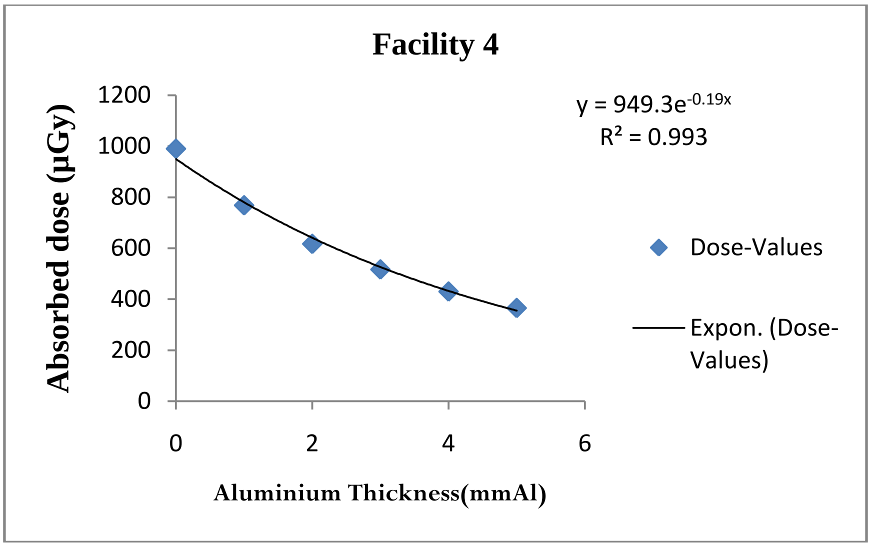

Figure 4: Variation of Absorbed Dose with Thickness in Facility 4.

Table 6: Calculated Half value layer

Facility	Equation	$\mu(mm^{-1})$	Calculated $HVL(mm)$
1	$y = 581.2e^{-0.17x}$	0.17	4.18
2	$y = 210.0e^{-0.17x}$	0.17	4.18
3	$y = 231.8e^{-0.25x}$	0.25	5.54
4	$y = 949.3e^{-0.19x}$	0.19	3.65

The HVL calculated in facility 1, 2, 3 and 4 are; 4.18mm, 4.18mm, 5.54mm and 3.65mm respectively. These values were high when compared with the recommended minimum acceptance limit of 2.3mm at 80kVp.The high values of HVL indicate high level of absorption of x-ray beams by the filters with the resulting effect on the quality of the image produced (Akaagerger et al., 2015). In a situation where the image produced did not give clear picture of the purpose for which the radiographic examination is carried out, re-exposure is inevitable in a bid to obtain radiographic image of high contrast. This act violates the aim of ALARA principle or the principle of dose optimization (Mana, 2011).

3.3Beam alignment

Table 7: Collimation test for Facility 1

	Inside	Outside	Sum
Top	0.2cm		1.7cm
Bottom		1.5cm	
Left	1.0cm		2.5cm
Right		1.5cm	

Table 8: Collimation test for Facility 2

	Inside	Outside	Sum
Top	1.0cm		2.8cm
Bottom		1.8cm	
Left		2.4cm	3.4cm
Right	1.8cm		

Table 9: Collimation test for Facility 3

	Inside	Outside	Sum
Top		1.2cm	2.8cm
Bottom	1.6cm		
Left	2.2cm		3.9cm
Right		1.9cm	

Table 10: Collimation test for Facility 4

	Inside	Outside	Sum
Top		0.2cm	0.7cm
Bottom	0.5cm		
Left	0.4cm		1.0cm
Right		0.6cm	

For perfectly working machines, the central ray of the x-ray beam is expected be aligned to the centre of the image receptor. This helps to remove image cut-off and to avoid irradiating unnecessary tissues (AAPM, 2002).The sum total of misalignment on x and y dimensions should be less than $\pm$ 4% of SID (source-to-image receptor distance) or less than 25mm (AAPM, 1981; Mana, 2011). Facility1 had 2.5cm and 1.7cm for vertical and horizontal misalignments, facility 2, had a vertical misalignment of 3.4cm and a horizontal misalignment of 2.8 cm. Facility 3 had misalignment of 3.9cm and 2.8cm in the x and y-dimensions respectively and the forth facility had a value of 1.0cm and 0.7cm as misalignments in the x and y-dimensions respectively. The results indicate that collimator lights were not in good forms in some of the machines examined. In all the Facilities, only Facility 1 and 4 had misalignments within the tolerance limit of 25mm in the horizontal and vertical dimension.

Table11: Beam Alignment test of the four X-ray Machines

Facility	Congruency(cm)	Perpendicularity(cm)
1	1.6	0.6
2	2.5	0.2
3	0.65	1.0
4	0.7	0.7

Beam alignment test gives the deviation of the centre from the middle of the exposed film to the middle of the test tool (perpendicularity test).The congruence test on the other hand gives the value of the misalignment between the light field and the radiation field. The test enables the radiologist to position the field to expose only the anatomy of interest. Misalignment must not be greater than $\pm 2\%$ of SID or tolerance limit of 2° for acceptance (AAPM, 2002).The value of misalignments for congruency test conducted in the four machines were; 1.6cm, 2.5cm, 0.65cm, and 0.7cm for facility 1,2,3 and 4 respectively. In the tests conducted for perpendicularity, a misalignment value of 0.6cm, 0.2cm, 1.0cm and 0.7cm were recorded for facility 1, 2, 3and 4 respectively. Misalignment might be caused by rough handling of the tube housing, hitting the tube housing with stretcher or mirror shifting (AAPM, 2002).

3.4 Effective focal spot test

The effective focal spot is a measure of image resolution. A group of three bars is said to be resolved when exactly three bars can seen clearly on the film. The quality of a machine is best known in its ability to resolve the minimum number of groups (AAPM, 2002). The Effective focal spot size in their decreasing order are; 8.69mm, 7.67mm, 6.0mm and 5.11 for facility 3, 1, 4, and 2 respectively. This is an indication that facility 3 had the highest image resolution and facility 2, the least image resolution.

IV. Conclusion

The result of the research showed a significant deviation in the measured kVp values from the set values in some of the facilities. The four facilities assessed had a high value of HVL which indicates a high absorption of X-ray beam with the resulting effect on the quality of the image produced. Comparing the maximum value of the absorbed dose with the recommended maximum permissible absorbed dose, the output doses to patients are below the recommended maximum exposure limit. The alignment test had only one facility operating within the tolerance limit. For the the three facilities there is high probability of image cut-off rate and a high rate of exposure to areas of no interest. From the result obtained for resolution test in the four Facilities, Facility 3 has the highest image resolution. There is therefore need for maintenance and re-calibration and if possible replacement of the diagnostic X-ray machines.

Recommendation

From the results of the research conducted, the following recommendations are drawn:

I. There is need for yearly quality control test on X-ray machines in hospitals or diagnostic centres by qualified Physicists.

II. Research should be carried out on the relationship between kVp and film density, and also the exposure time which are other parameters that affect image quality.

Aknowlegement

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