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Evaluation of Beam Alignment Collimation, Reproducibility and Accuracy of Diagnostic X-Ray Machines at Public and Private Hospitals in Sokoto Metropolis

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Abstract: *Quality control on diagnostic X-ray machine in Radiological units of two public Hospital and two private diagnostic centers in Sokoto metropolis designated UDUTH, SHS, MDC, CDC was carried out using Beam Alignment and collimator test tool, KVP Reproducibility and Accuracy meter. The study was based on Technical standards for Radiological Protection and Quality control in medical diagnosis. The collimator and Bean alignment tests were used to measure the degree of misalignment of the target points while the kVp Accuracy and Reproducibility were also ascertained at different sets kVps. The techniques employed in measuring the percentage of misalignment was based on congruence of x-ray field and light to ascertain whether the light field accurately define the x-ray field, the value of percentage of misalignment calculated were then compared with minimum accepted value of not less than 2% as recommended by International Commission on Radiological Units and Measurements (ICRU). The hospitals under study shows to have percentage of misalignment within the range of 0.38 % to 1.13 % at 50 kVp, 4 mAs, 100 cm FFD using a film size of 24 cm x 30 cm. All four selected hospitals/centres showed a percentage misalignment which is still within the normal acceptable limit of ≤2 %. All the facility units under study shows good reproducibility characteristics but with poor percentage difference at some set kVp values. For machines with high percentage difference in kVp values, there is high risk of over-exposure.*

Keywords: *Quality control, Misalignment, accuracy, reproducibility, kilovolt peak,*

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I. Introduction

X-ray diagnostic examinations are one of the main exposures to the public. Medical uses of radiation have grown very rapidly over the past decades. The most common methods of X-ray in medical imaging are X-ray radiography, computed tomography (CT), mammography, angiography and fluoroscopy(Wolbarst, 2001).

Implementations of quality Control (QC) programs are important factors for justification and optimization of medical exposures. In Nigeria, X-rays is the most frequently used ionizing radiation in medicine despite advances in magnetic resonance imaging and ultrasound techniques. It has maintained a key role in diagnosis of diseases, injury and in radiation therapy (oncology). In effect it is the largest man-made source of ionizing radiation to the world population (ICRP, 1991).

Availability and the use of X-ray equipment in both private and government hospitals is on the increase today in developed and developing countries. Quality control of such equipment is of particular importance to prevent avoidable high doses, radiation leakages and to ensure dose optimization and deleterious effects to the population and radiation workers. In radiography, dose and image quality are dependent on radiographic parameters. The problem is caused from incorrect use of radiography equipment and from the radiation exposure to patients much more than required, hence the principle of ALARA (Oluwafisoye et al., 2010).

The amount of damage done by the ionizing radiation depends on the amount of energy deposits per kilogram of tissue (WHO, 2002). X-rays ionize atoms and molecules in human tissues through the deposition of energy. This ionization is the first step in a series of events that may lead to a biologic effect.

All medical facilities using x-ray equipment, from a simple intra-oral dental unit to an image intensified special procedures system, benefit from adopting a quality assurance program which is an established program that will monitor the imaging process from start to finish and reveal potential problems that may otherwise go unrecognized(WHO, 2002). Quality assurance in medical imaging is a rapidly evolving concept and each facility is encouraged to continually pursue ways to improve and expand its program (WHO, 2002).

Quality Control programs ensure that all components of the imaging environment perform at optimum; the end result being highest quality images with the lowest possible dose to patient and operator while maintaining high diagnostic content (Oluwafisoye*et al.,* 2010). It is the goal of the Quality Control Program to help contain costs through elimination of unproductive imaging resulting from failure of machines or materials that may occur in the complex chain leading to the finished product (Oluwafisoye*et al.*, 2010). Tests were conducted on some diagnostic x-ray facilities within Sokoto metropolis according to quality control protocol, and the measured parameter values were compared to the relevant acceptance limits.

In Nigeria where there is less knowledge about the principle of X-ray imaging technique many diagnosis are carried out using X-ray imaging. Our investigation revealed that in Sokoto metropolis majority of radiological operations took place without necessarily taking into account the danger the process might lead to. This is due to the fact that most upon than not, several unnecessary X-ray examinations are carried out on an individuals and sometimes repeated exposures are made as a result of bad radiograph.

As a result of this observations it became necessary to carried out work of this kind so as to assess the minimum recommended radiographic parameters to be used in order to minimize the dose to patient, personnel and public.

This work aimed at evaluating some quality control parameters of beam alignment, accuracy and reproducibility of diagnostic X-ray machines at public and private hospitals in Sokoto metropolis. The results of the investigation will be compared with international standards and will serve as a baseline for the assessment of X-ray units in the state. Recommendations will be made for enhancement where necessary for the safety of all those involved in X-ray examinations.

II. Materials And Method

2.1 X-ray Facility Units

The major facilities that are used in this study are the four conventional X-ray units available at radiology department of Usmanu Danfodiyo University Teaching Hospital (UDUTH) Sokoto, Specialist Hospital Sokoto (SHS), Medi-Stop Diagnostic Centre (MDC) and Caliphate Diagnostic Centre Sokoto (CDC). The table below shows the specifications of the X-ray units in each of the Hospitals/Centres.

Table 2.1: Specifications of X-ray Machines used in the four Selected Hospitals/Centers

Items	Hospital/centre			
	UDUTH	SHS	MDC	CDC
Manufacturer	Ge	Toshiba(Ecoray)	Ge (MX4)	Siemens
Model/type	2226680	SMS-CM-N	2583	4358
Year of manufacture	2007	2012	2006	2009
Year of installation	2010	2013	2018	2018
Inherent filtration	0.6mmAL	1.2mmAL	0.6mmAL	1.2mmAL
Added filtration	1.0mmAL	0.8mmAL	1.0mmAL	1.0mmAL
Film type	Agfa	Primax	Primax	Agfa
Processor	Manual	Manual	Manual	Digitizer
Use of grid	Yes	Yes	Yes	Yes
Type of unit	Static	Static	Mobile	Static
Generator type	3 –phase	1-phase	1-phase	3-phase
Maximum kVp	150	125	130	125
Maximum mAs	100	80	80	100
Last machine calibration	None	None	None	None

2.2KVpReproducibility and Accuracy

Peak kilovoltage (kVp) is a technical factor set by the technologist when performing x-rays. Its purpose is to set the penetrating power of the x-rays or the quality of the beam. The number set is the highest amount of energy that an x-ray photon could have leaving the tube (Bushong, 2001).It is important that the kVp setting reflects what is actually coming out of the tube to ensure reproducibility(Penelope & Williams, 2008).

The kVp meter RMI 245 compact was used in this study. This meter simplifies the determination of actual kVp for radiographic, fluoroscopic and mammographic x-ray systems. This highly accurate meter can be used for a wide range of energies and can store up to ten readings.

Figure 2.1: KVp Meter RMI 245 obtainable at Energy Research and Training Center Zaria.

For the Voltage reproducibility the exposure was performed at constant tube voltages and clinical tube loadings. The experiments at this step were repeated at least three times to enable statistical analysis on the obtained data. Afterwards, standard deviation (SD) and coefficient of variation (CV) were calculated for the measured voltages.

$$SD = \sqrt{\frac{(x-\ddot{x})^2}{n-1}} \qquad 2.1$$

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Average}} X\ 100\% \qquad 2.2$$

While for the Voltage accuracy, at constant tube currents, clinical tube voltages (60-120 kVp) were tested (10 kVp steps). Then, the measurements were compared with the specified values to determine the differences.The meter was placed at 100 cm FFD. 20 mAs, 60 kVp was set on the control panel of the x-ray machine. Exposure was made, and the meter readings recorded. The procedure was repeated maintaining fixed value of mAs increasing kVp by 10 until a total of 120 0kVp was reached. The percentage difference between the selected values on the control panel and the measured value was computed using the relation;

$$\text{Percentage kVp error} = \frac{(V_0 - V_s)}{V_s} X\ 100 \qquad 2.3$$

Where,

$$V_0 = \text{The measured value}$$
$$V_s = \text{The set value}$$

Based on Institute of Physics and Engineering in Medicine (IPEM) Report No.77(Rasuli et al, 2015), the measured parameters were considered to be pass or fail if less or greater than 10 % of error and CV respectively.

2.3Beam Alignment Test

To assure that the light field accurately defines the X-ray field, the light and X-ray field mis-alignment should not exceed 2% of the source-to-image distance (SID) in either the length or width of the film. For this test an X-ray light/beam alignment test tool (Fig.2.2), loaded with 24 x 30 cm (10 x 12 inch) cassette and measuring tape were used.

A 24 x 30 cm (10 x 12 inch) loaded cassette was placed in the Bucky and the SID was set at 100 cm (40 inches). Tape measure was used to verify. The test tool was placed over the cassette (parallel to its edges). The light beam diaphragm collimator was adjusted so that the light beam covers exactly the inner pattern of the test tool. An exposure with approximately 50 kVp and 4 mAs was performed. The film was developed and kept with the image of the test tool.

Figure 2.2: Gammex 161B x-ray beam alignment test tool with a 24 x 30cm cassette obtainable at Energy Research and Training Center Zaria.

III. Results And Discussion

The results of measurement of Misalignment, kVp reproducibility and accuracy test from the four X-ray machines of the various hospitals/centres were shown below:

3.1 Beam Alignment Test

Table 3.1: X-ray light/beam alignment results for the four selected hospitals/centers

Hospital	Cassette size (cm)	FFD (cm)	kVp	mAs	% misalignment
UDUTH	24 x 30	100	50	4	1.14
SHS	24 x 30	100	50	4	0.64
MDC	24 x 30	100	50	4	0.38
CDC	24 x 30	100	50	4	0.51

3.2 kVpReproducibility and Accuracy

Table 3.2: kVpReproducibility Test of UDUTH X-ray facility Unit

Set kVp	Measured kVp				SD	CV	Remark
	1	2	3	Average			
60	61.7	61.3	61.4	61.47	0.21	0.34	Pass
70	72.5	72.3	72.4	72.40	0.10	0.14	Pass
80	83.7	83.3	83.5	83.50	0.20	0.24	Pass
90	94.5	95.1	95.7	95.10	0.60	0.63	Pass
100	105.8	105.8	104.9	105.50	0.52	0.49	Pass
120	125.8	125.4	125.2	125.47	0.31	0.24	Pass

Table 3.3: kVpReproducibility Test of SHS X-ray facility Unit

Set kVp	Measured kVp				SD	CV	Remark
	1	2	3	Average			
60	70.3	70.7	70.5	70.50	0.20	0.28	Pass
70	82.9	82.1	82.4	82.47	0.40	0.49	Pass
80	89.2	89.8	89.3	89.43	0.32	0.36	Pass
90	93.8	94.6	94.9	94.43	0.57	0.60	Pass
100	110.9	110.1	111.3	110.77	0.61	0.55	Pass
120	128.7	127.9	128.5	128.37	0.42	0.32	Pass

Table 3.4: kVpReproducibility Test of MDC X-ray facility Unit

Set kVp	Measured kVp				SD	CV	Remark
	1	2	3	Average			
60	68.1	68.9	69.2	68.73	0.57	0.83	Pass
70	72.4	72.8	73.1	72.77	0.35	0.48	Pass
80	83.1	83.9	82.5	83.17	0.70	0.84	Pass
90	95.0	94.2	94.9	94.70	0.44	0.46	Pass
100	116.3	115.1	114.8	115.40	0.79	0.69	Pass
120	127.2	125	126.2	126.13	1.10	0.87	Pass

Table 3.5: kVpReproducibility Test of CDC X-ray facility Unit

Set kVp	Measured kVp				SD	CV	Remark
	1	2	3	Average			
60	**63.9**	63.5	64.5	63.97	0.50	0.79	Pass
70	**73.4**	73.8	73.1	73.43	0.35	0.48	Pass
80	**87.9**	87.7	88.4	88.00	0.36	0.41	Pass
90	**99.3**	99.7	100.4	99.80	0.56	0.56	Pass
100	**112.9**	113.3	114.8	113.67	1.00	0.88	Pass
120	**126.1**	126.5	126.2	126.27	0.21	0.16	Pass

Table 3.6: The percentage difference in KVP values at 20mA in UDUTH

Set kVp	Measured KVP	±% difference	Remark
60	61.5	2.50	Pass
70	72.4	3.43	Pass
80	83.5	4.38	Pass
90	94.8	5.33	Pass
100	105.8	5.80	Pass
120	125.6	4.67	Pass

Table 3.7: The percentage difference in KVP values at 20mA in SHS

Set kVp	Measured KVP	±% difference	Remark
60	70.5	17.50	Fail
70	82.5	17.86	Fail
80	89.5	11.88	Fail
90	94.2	4.67	Pass
100	110.5	10.50	Fail
120	128.3	6.92	Pass

Table 3.8: The percentage difference in KVP values at 20mA in MDC

Set kVp	Measured KVP	±% difference	Remark
60	68.5	14.17	Fail
70	72.6	3.71	Pass
80	83.5	4.38	Pass
90	94.6	5.11	Pass
100	115.7	15.70	Fail
120	124.6	3.83	Fail

Table 3.9: The percentage difference in KVP values at 20mA in CDC

Set KVP	Measured KVP	±% difference	Remark
60	63.7	6.17	Pass
70	73.6	5.14	Pass
80	87.8	9.75	Pass
90	99.5	10.56	Fail
100	113.1	13.10	Fail
120	126.3	5.25	Pass

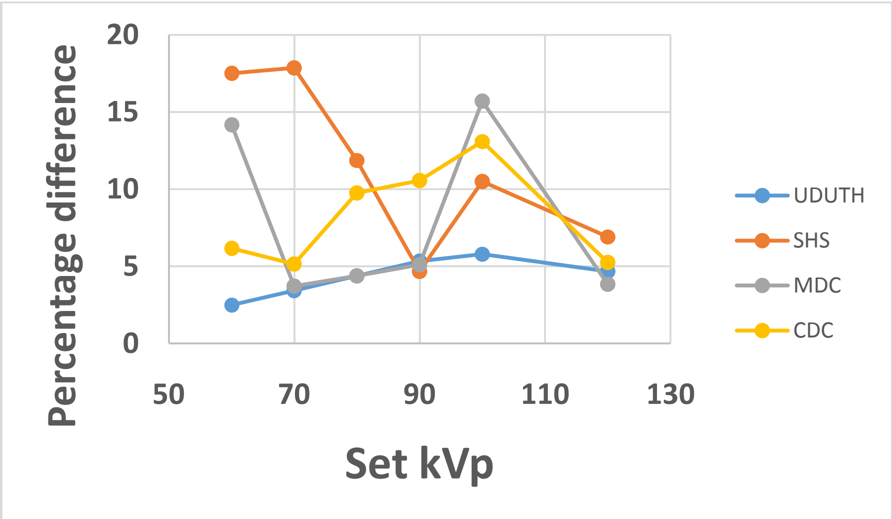

Figure 3.1: The percentage difference in KVP values in the study areas

IV. Discussion

The technical characteristics of the X-ray facilities involved in the study are shown in Table 2.1. Among the studied devices, two devices were made by General electronic company, one by Toshiba and the other by Siemens companies. Two of the devices are one-phase generators and the other two are three-phase generators. Considering the X-ray light/beam alignment test, Table 3.1 shows the degree of X-ray tube misalignment in relation to the normal acceptable limit of ≤ 2 % of the source-to-image distance (SID) in either the length or width of the film. All the four selected hospitals/centers showed a percentage misalignment which is still within the normal acceptable limit. This shows that unintended body parts of patients are properly protected in all the hospitals and centers in this study.

Table 3.2 – 3.5 shows the results of the reproducibility test of all the tested set kVp values at different study areas.The results shows good reproducibility characteristics with all the tested kVp values. The coefficient of variation of the repeated readings at all study areas falls within the range of 0.14 % to 0.88 %, with the highest CV of 0.88 % for the CDC facility unit.This is by far below the limit of 10 %. This shows that there is very low variability in the repeated readings of the set kVp values.

On the other hand the kVppercentage of accuracy of the tested kVp values at all study areas Table 3.6 - 3.9 shows the results. At UDUTH the percentage of the accuracy of all the tested kVp values falls within the rage of 2.50% to 5.80 %. While at SHS the percentage difference is within the range of 4.67 % to 17.86 %. At SHS only two tested kVp (90 kVp and 120 kVp) values pass the criteria. At MDC, the percentage difference of the facility unit is within the range of 3.71 % to 15.70 %. Half of the tested kVp values (60 kVp, 100 kVp and 120) fails the criteria. The facility unit at SHS and MDC has single phase generator. Most devices with single-phase generators did not have a good presentation in voltage accuracy test, which can be due to high ripple voltage (Rasuli et al, 2015). Moreover, single-phase generators hardly met linearity (mA) criteria, which was due to the high performance of filament in machine tube and the imbalance between the generated heat and outgoing electrons. Whileat CDC, the percentage difference of the facility unit is within the range of 5.14 % to 13.10 %. Only two tested kVp values (90 kVp and 100 kVp) fails the criteria.

The kVp percentage difference (accuracy) test indicates that only UDUTH facility unit meet the acceptance limit of not greater than 10 %. However at the remaining three study areas there is fluctuation of the percentage of accuracy of the tested set kVp's. The percentage accuracy of some set kVp's are below the designed limit. Specifically the accuracy of 100 kVp is above the limit at all the three areas (SHS, MDC and CDC) as depicted in Fig.3.1. For machines with high percentage difference in kVp values, there is high risk of over-exposure(Tyovenda et al, 2017).

Quality control test of radiology facility units depends on factors such as the examiner, age of the device, working load, dosimeters and the technologist's working procedures. However the results of the QC assessment in different periods and places cannot be very. In 2015, Akaagerger et al 2015 assessed X-ray facility units in Makurdi, Nigeria. The results related to beam alignment were in accordance with our study.Ike-Ogbonna et al, in 2017, assessed X-ray facility units in Plateau state, Nigeria. The results related to beam alignment were in accordance with our study except the case of two (out of ten) facility units that failed the criteria.Also A.A Tyovendaet al, in 2017, assessed X-ray facility units in Nasarawa state with two facility units (out of four) having misalignment beyond the tolerance limit. Moreover the voltage accuracy in the present study is better than the mentioned study.

X-ray tube peak potential (kVp) is important parameter that affects the quality of the X-ray beam, exposure of the patient and contrast of the image (ICRP 2007). Accuracy of X-ray beam and quality at different kVp settings is necessary to be checked regularly to ensure accurate density on radiographs as ascertained by Carlton and Adler (2006).The hospitals/centers under study where the measured kVp has exceeded the normal acceptable limit of 10 % kVp should therefore make an effort to adjust the kVp where inconsistency occurred so as to make sure that the set kVp is always reproducible and accurate. Therefore, it is considered very important to measure the peak tube voltage accuracy.

V. Conclusion

A hospital needs to have a QA committee to ensure proper implementation and monitoring of the QA program in all departments of the hospitals/centres. Lack of QA program leads to frequent breakdown of machines and poor quality of radiographs resulting in greater risks of ionizing radiation. QC tests of X-ray facility units at the radiology departments of hospitals and diagnostic centers in the Sokoto metropolis have been done and findings of the investigation have been concluded as all the four selected hospitals/centres showed a percentage misalignment which is still within the normal acceptable limit of ≤ 2cm. kVp reproducibility test of all the facility units involved in the study are within the limit but the percentage difference of some facility units failed to meet with criteria.

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