Original Research Article

QUALITATIVE ASSESSMENT OF X-RAY MACHINES' MECHANICAL PARAMETERS AT SOME SELECTED DIAGNOSTIC CENTRES IN NIGERIA

ABSTRACT

Introduction:This study assessed the presentstatus of conventional X-Ray machines used for common diagnostic X-Rayexaminations in Nigeria.

Materials & Methods: Total of 112 X-Ray machines from 106 diagnostic centres from six geopolitical zones in Nigeria were considered. Structured questionnaires and Diavolt Dosimeter were respectively used for data collection and measurements of parameters: Half-Value Layer(HVL), tube voltage (kVp) reproducibility, kVp accuracy and beam output linearity/stability.

Results: By zonal distribution of X-Rayunits, the highest number (36%) and the least (7%) was fromthe south-west and south-south respectively. In all, 71% were owned by private institutions, 71% were non-mobile, 64% were operated on 3-phase generator and 35% were within the age of ten years.The HVLs of 97% of the X-Rayunits were within the standard thickness of 2.3 mmAl(at 80 kVp, 100 cm FFD), 88% have acceptable kVp reproducibilityand51% have kVp accuracy within ±5%. Only X-Rayunits (64%) operated on 3-phase generator produced beam output that are within acceptable stability.

Conclusion:This study showed that some (65%) of the X-Ray units considered are aged (>10 years) and about 49% of the units failed kVp accuracy test. This may be due to inconsistency in the quality assurance checks of X-Ray units by some diagnostic centres, especially those in the south-south region.The authors therefore recommended strict measures, to be put in place by the regulatory authority, that will make all diagnostic centres in Nigeria to comply with the requirements for peaceful radiation practices.

Keywords: Diagnostic radiology, Quality Assurance, Quality Control, image quality, X-Rayunit, mechanical parameters, radiation exposure

INTRODUCTION

Since the discovery of X-Rayin 1895 by Wilhelm Rontgen, medical imaging with X-Rayhasbecome an indispensable healthcare delivery procedure in the diagnosis and treatment of diseases[1].The major concern of clinicians in medical X-Rayimaging is how to obtain image quality that is consistent with clinical diagnosis of the diseaseat a minimum radiation dose to patients [2,3].This is because;the medical use of ionizing radiation has the potential of significantly increasing the exposure of the population to ionizing radiation if the principles of radiation protection are compromised. Hence, the need for proper quality assurance procedures in diagnostic radiology to reduce to the barest minimum, the detrimental health effect of over exposure to ionizing radiation on patients, operators and the general public.

The World Health Organization (WHO) defines quality assurance (QA) programme in diagnostic radiology as an organized effort by the staff operating theradiation facility to ensure that the diagnostic images produced are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient [4].

The roles of quality assurance program in diagnostic radiology cannot be overemphasized as ithelps the X-Rayfacility to consistently producingoptimal radiological information with minimal radiation dose, as low as reasonably achievable. An integral part of quality assurance program is the quality control measurements of mechanical parameters of X-Ray units, especially those that have direct bearing on the magnitudeof ionizing radiation emitted from the X-Ray tube. Some of thesemechanical parameters are beam alignment, beam collimation, kVp reproducibility, kVp accuracy, time accuracy, half value layer (HVL), leakage test, linearity test, machine output, among others[5].

Most diagnostic centres in Nigeria lack therequired quality control equipmentand personnel,for testing theperformance characteristics of their machines'mechanical parameters and this has prevented their X-Raymachines from undergoing comprehensive quality control measurements.

Therefore, this study was carried out to assess thepresent performance characteristics of some of the mechanical parameters of X-Rayunitsat some selected diagnostic centres in Nigeria and give recommendation, based on findings, that would improve the quality of diagnostic images produced at optimal radiation exposure to patients.

MATERIALS AND METHODS

Selection of Diagnostic Centres

Between the year 2016 and 2017, the records of diagnostic centres, who registered with the Nigerian Nuclear Regulatory Authority (NNRA), Abuja were assessedfrom theRegulatory Authority Information System (RAIS)for selection of registered diagnostic centres across the six geopolitical zones in the country.Between the year 2018 and 2020, data collection and measurements were carried out at the diagnostic centreswith complete details of their locations and with records of vital information about their X-Ray machines.

Out of about 800 diagnostic centres extracted from RAIS, only 106 (13%) centres satisfied the inclusion criteria for this study.The Management of these centres were thereafter contacted and their consents were sought for a visit to their facility.The centres were also categorized intothe six geo-political zones in Nigeria, namely: North Central, North West, North East, South South, South West and South East. The centres were also classified based on the ownership of the facility namely: Federal Government (Teaching hospital), State Government and Private owned centres. There are total of 112 X-Raymachines in all the 106 diagnostic centresconsidered in this study and their mechanical parameters, whose performance characteristics were measuredare Half Value Layer (HVL), kVp reproducibility, kVp accuracy and machine output consistency. The parameters tested are limited by the capability of the dosimeter used for measurement.

In addition, relevant questionnaires were designed and distributed to the Radiographers/Operators in charge of the diagnostic facilities to obtain machine data such as year of manufacture, modelname/number, type of generator, total filtration, etc.Other information obtained from the centres was the daily patient workload.

Evidence of ethical approval waspresented at the diagnostic centres before access was granted into their facilities for various measurements on theX-Raymachines.

Calibration of Diavolt Dosimeter

The dosimeter used for measurement of X-Raymachines' mechanical parameters in all the diagnostic centres is a multipurpose Diavolt dosimeter, model 330 and wasmanufactured by the Gammex PTW, USA. Prior to its use at the various diagnostic centres, it was subjected to calibrationat the national Secondary Standard Dosimetry Laboratory (SSDL), University of

Ibadan, Ibadan in Oyo State. This SSDL is located in the radiation dosimetryand training institute of the NNRA, Abuja.

The calibration of the Diavolt dosimeter was performed against the reference ionization chamber, Exradin A3,using the diagnostic X-Raybeam energy source at SSDL. The Ionization chamber and Diavolt dosimeter were exposed in succession to the same X-Rayenergy source,which was set at a constant tube voltage (kVp) of 80 and varying tube loading (12.5 – 75.0)(mAs). The distance of the detectors (Ionization chamber orDiavolt) from the X-Raysource was kept at 100 cm. The detectors were exposed three times each using the same machine settings and the mean and standard deviation were calculated and recorded. The detectors were carefully hanged to ensure that backscatter influence was avoided [5].

Measurement Set-Up at Each Diagnostic Centre

At each diagnostic centre, the calibrated Diavolt dosimeter was mounted (shown in fig. 1) on an Aluminium retort stand, which has a movable clamp so that the position of the dosimeter can be easily adjusted in relation to the central axis of the X-Raybeam and the patient'scouch (6). The detector-to-table distance (DTD) was kept at 25cm to prevent the influence of scatter on the table and the aluminum stand. The values of the X-Raytube loading (mAs) and tube voltage (kVp) for each measurement were set on the control console with the assistance of the operator at each of the centre. The ranges of values covered for each measured quantity were guided by the operational data entry in the questionnaire previously completed by the centre.

Half Value Layer Measurements

This was done by keeping the focus-detector distance (FDD) setting at 100 cm while the tube voltage and tube loading were set at 80 kVp and 20 mAs respectively.Dosimeter readings were first taken with inherent filter only (that is, no filter was placed between the x-ray source and the dosimeter) and thereafter, an Aluminum filter is addedin steps of 1mm thickness until the added filtration was 5 to 6 mm thickness, depending on the initial value taken with only inherent filter. The readings were recorded and tabulated.

kVp Reproducibility and Accuracy Measurements

While maintaining the same focus-detector distance setting of 100 cm, the kVp reproducibility was checked by taking three different exposures without changing the kVp and mAs settings and the values of kVpdisplayed on the dosimeter were recorded.This was to verify whether kVp set by the radiographer were the same from exposure to exposure. The coefficient of variation (CV) in equation 1 was used to determine the kVp reproducibility. The CV should be < 0.2 for good kVp reproducibility.

$$CV = \frac{SD}{M} X\ 100\% \qquad (1)$$

where SD is the Standard deviation and M is the mean of the values

The kVp accuracy was also checked by taking exposures with varying settings of kVp and constant mAs and recordedthe deviation between the kVp set on the control consoleagainst the kVp measured by the dosimeter. The accuracy should be within ±5%. All readings were recorded and mean values were tabulated.

$$\text{kVp accuracy} = \frac{kVp_{set} - kVp_{measured}}{kVp_{set}} X\ 100\% \qquad (2)$$

Machine Output Consistency Measurements (Linearity Test)

While the settings of Diavoltdosimeter and the tube voltage was kept at a fixed FDD of 100 cm and 80 kVprespectively, the tube loading (mAs) was varied from 20 to 80mAs in steps of 10 mAs. The tube loading was set to cover the range of mAs commonly used for patient's exposure at each diagnostic centre. The beam output (mGy/mAs) wasrecordedand tabulated. The maximum and minimum beam output was observed andequation 3 was used to calculate the machine output consistency. The value should be less than 0.1 for good machine output consistency.

Machine output consistency was further checked by maintaining the settings of Diavolt dosimeter and the tube loading at a fixed FDD of 100 cm and 20 mAs respectively, the tube voltage was varied from 40 kV to 80 kV in steps of 10 kV. The tube voltage was set to cover the range of kVp commonly used for patient's exposure at each diagnostic centre. The graph of tubeoutput was plotted against kVp for each centre and the linearity was assessed using the formula below.

$$\text{Linearity} = \frac{X_{max} - X_{min}}{X_{max} + X_{min}} \quad (3)$$

where X is the beam output in mGy/mAs.

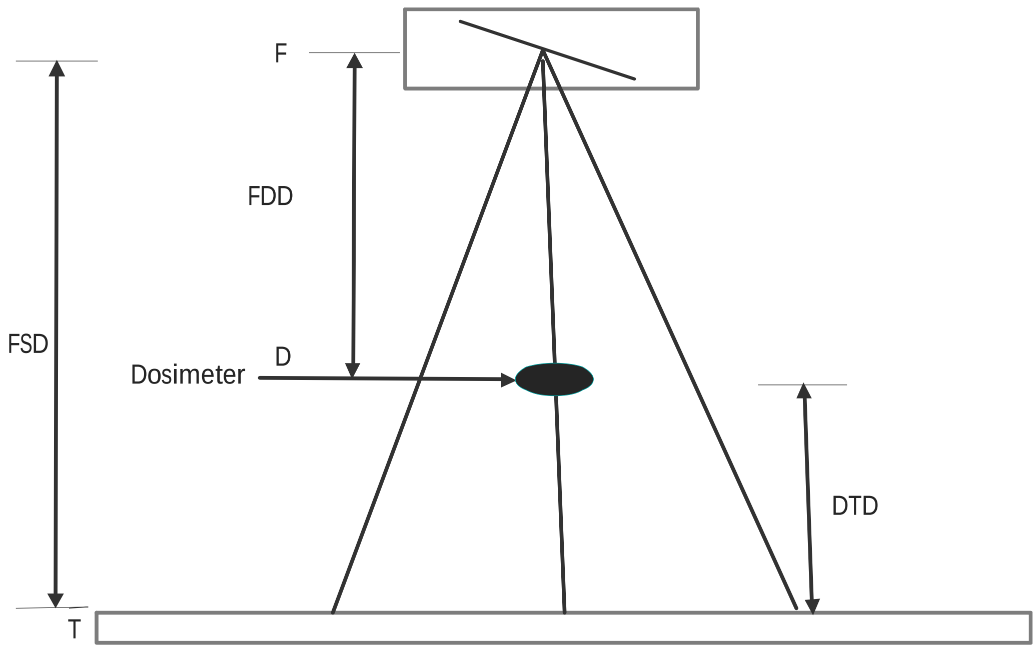

Fig. 1: Experimental Setup for all Measurements at Each Centre.

FSD = Focus-to-Skin Distance, FDD = Focus-to-Detector Distance, DTD = Detector-to-Table Distance, T = Table, F = X-Ray Tube Focus, D = Detector

RESULTS AND DISCUSSION

Analysis of Data from Diagnostic Centres

A total number of 112 conventionaldiagnostic X-Raymachines were assessed from 106 diagnostic centresconsidered for this study. The classification of the diagnostic centres based on the ownership and the geo-political zone to which each belongs are presented in Table 1. Information onX-Raymachine with respect to their location (mobile or fixed) and generator types (single or 3-phase frequency) are presented in Table 2 (a) while the age of the various X-Raymachines wasgrouped and presented in Table 2 (b). The daily patient's workload on X-Raymachine at each centre is presented in Table 3.

The distribution of X-Rayunits considered in this study showed thatthe majority (36%) of the X-Rayunits were in the south western zone, most (71%) were owned by private institutions, 71% were fixed units and 63% were operated on 3-phase generator.

With respect to the age of the X-Raymachines, it was observed that, the year of manufacture of about 41% of the X-Raymachines were not available because they had faded away from the machines and could not be clearly seen. Of the remaining X-Raymachines, 31% were less than ten years of age, 17% were within ten to twenty years and twelve (12%) were above 20 years of age from the year of data acquisition.

Response of Diavolt Dosimeter against Ionization Chamber

The response, which is the degree of reliability, of Diavolt dosimeter (Field detector) to a known value of beam quality as against the response of the ionization chamber (Reference detector) operated under the same condition is presented in Table 4. The variation between the two detectors was found to range from 0.77 to 1.32.

Half Value Layer (HVL) of X-ray Machines

The Half Value Layer (HVL) measurement was carried out at each centre in order to determine the total filtration (inherent and added) in the X-Raytube assembly, thereby assessing the extent to which low energy X-Raybeam have been removed before reaching the patient during medical imaging at each centre. The analysis of the measured HVL of 112 diagnostic X-Ray machines at the six geopolitical zones showed that the HVL of the majority (97%) of the X-Raymachines were within the standard thickness of 2.3 mm Al at tube voltage of 80 kVp and focus to detector distance (FDD) of 100 cm[6]. The remaining x-ray machines (3%) have HVL that is less than 2.3 mm Al as seen in Table 5.

kVp Reproducibility

The coefficient of variation between three different exposuresof kVp at various diagnostic centres showed good reproducibility i.e. coefficient of variation < 0.2 (7,8) for 91% of the X-Ray unitsin the North central, 82% in the North East, 100% in the North West, 88% in the South-South, 88% in the South West and 80% in the South East. This implies that majority of the X-Ray machines in all the geopolitical zones had good kVp reproducibility as seenin Table 6. However, some centres had bad kVp reproducibility, which may be due to the age of the x-ray machines.

kVp Accuracy

The kVp accuracy for 112 X-Ray machines in the six geo-political zones was calculated and analyzed as presented in Table 7. Although, it is expected that the deviation between the kVp set by the operator and the kVp measured by detector is within ±5% [4]. However, it was observed that only 12 (36%) centres in the North Central zone, 6 (54%) in the North East, 7 (70%) in the North West, 5 (40%) in the SouthSouth, 18 (45%) in the South West and 3(30%) in the South East zones were within the ±5% limit. This means that only 45% of all the diagnostic units considered in this study produced kVp that is accurate within ±5%.

Tube Output Linearity

Tube output linearity test carried out on 112 diagnostic X-Ray machines in six geopolitical zones showed varied level of consistency and stability with respect to the applied power source/generator and is presented in Table 8. It was observed that the X-Rayunits operated on single phase generator produced X-Ray beam output that is characterized by inconsistency due to power interruption/ fluctuation.Some of the X-Ray units in this category were found in the state and private institutions. Whereas, most of the X-Ray machines at the Federal/teaching institutions were operated on 3-phase generator, which helped in stabilizing their X-Ray beam output.As seen in Table 8, only 64% of the X-Ray units considered in this study produced stable beam output.

Table 1: Distribution of Diagnostic Centres based on Ownership and Geographical Location

Geo-political zone	Private	State Government	Federal Government	Total
North Central	24	2	7	33
North West	8	-	2	10
North East	3	3	5	11
South South	7	-	1	8
South West	30	5	5	40
South East	8	-	2	10
Total	80	8	22	112

Table 2 (a): Information on Diagnostic X-Ray Machines at Various Diagnostic Centres

Geo-political zone	No of Mobile X-Ray Unit	No of Fixed X-ray Unit	No with Single phase Generator	No with 3-phase Generator
North Central	11	22	17	16
North West	5	6	7	4
North East	3	7	2	8
South South	1	7	1	7
South West	12	28	14	26
South East	1	9	1	9
Total	33	79	42	70

Table 2 (b): Age of X-Ray Machines at Various Diagnostic Centres

Geo-political zone	**≤ 5 years**	**> 5 ≤ 10 years**	**> 10 ≤ 15 years**	**> 15 ≤ 20 years**	**> 20years**	***NA**
North Central	6	5	2	3	6	11
North West	3	NA	2	NA	1	5
North East	NA	1	4	1	2	2
South South	NA	3	1	1	NA	3
South West	6	7	1	3	3	20
South East	2	2	1	NA	NA	5
Total	17	18	11	8	12	46

**NA – Not Available*

Table 3: Daily Patient's Workload on X-Ray machine at Various Diagnostic Centres

Geo-political zone	< 10 Patients	> 10 < 20 Patients	> 20 < 30 Patients	> 30 patients
North Central	2	17	4	10
North West	1	5	1	4
North East	2	3	2	3
South South	1	2	2	3
South West	5	16	9	10
South East	2	3	3	2
Total	13	46	21	32

Table 4: Response of Diavolt Detector and Ion Chamber during Calibration at SSDL

Tube Loading (mAs)	**Air Kerma (μGy)**		
	Diavolt	**Ion Chamber**	**% Variation**
12.5	731.9±1.6	723.5	1.16
25.0	1460.0±1.8	1441.0	1.32
50.0	2905.0±1.9	2881.0	0.83
75.0	4345.0±2.0	4312.0	0.77

Table 5: Analysis of HVL (80 kVp & 100cm FDD) at Various Diagnostic Centres

Geo-political Zone	**Number of X-Ray machine with filter < 2.3 mm Al**	**Number of X-Ray machine with filter ≥ 2.3 mm Al**
North Central	1	32
North West	1	10
North East	Nil	10
South South	Nil	8
South West	1	39
South East	Nil	10
Total	3	109

Table 6: kVp Reproducibility at Various Diagnostic Centres

Geo-political Zone	≤ 2% (Good Reproducibility)	X-Ray machine with good reproducibility (%)	> 2% (Bad Reproducibility)
North Central	30	91	3
North West	9	82	2
North East	10	100	*NA
South South	7	88	1
South West	35	88	5
South East	8	80	2
Total	99	88	13

**NA – Not Available*

Table 7: kVp Accuracy at Various Diagnostic Centres

Geo-political Zone	Machine setting within ±5%	Machine setting within ±10%	Machine setting > ±10%
North Central	12	11	10
North West	6	4	1
North East	7	1	2
South South	5	2	1
South West	18	15	7
South East	3	2	5
Total	51	35	26

Table 8:X-Ray Beam Linearity at Various Diagnostic Centres

Geopolitical Zone (No of x-ray Unit)	≤ 0.1 (stable)	> 0.1 (unstable)
North Central (33)	21 (64%)	12 (36%)
North West (11)	5 (45%)	6 (55%)
North East (10)	8 (80%)	2 (20%)
South South (40)	20 (50%)	20 (50%)
South West (8)	6 (75%)	2 (25%)
South East (10)	4 (40%)	6 (60%)
Total (112)	64 (57%)	48 (43%)

CONCLUSION

X-Ray machines' mechanical parameters at some selected diagnostic centres in Nigeria have been assessed with a multi-purpose Diavolt dosimeter. The results showed that almost half of thediagnostic centres considered in this study were faced with inconsistent quality assurance checks of their X-Ray units and non-compliant with regulatory requirements.These may affect the image quality produced by the X-Ray system and the overall effect could be excessive radiation exposure.In order to obtain good quality diagnostic images at optimal radiation exposure to patients in Nigeria, the regulatory authority should putin placestrict measures, that will make all diagnostic centres in the country to comply withregulatory requirements for peaceful radiation practices. Further study is aim at quantify the absorbed dose received by patients at these diagnostic centres.

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