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Performance Characteristics of Radiographic equipment in Selected Healthcare Institutions in Southwest Nigeria

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Abstract

BACKGROUND: Evaluation of radiographic equipment performance is the recommended strategy for the verification of factors used in radiodiagnosis. Sometimes, the performance of the equipment is compromised due to the lack of adoption of the appropriate procedures and/or techniques.

AIM: The aim of this study was to determine the performance quality of the radiographic equipment in the study area in order to optimize the radiation dose delivered to the patients using these facilities and enhance their safety.

METHODS: The performance characteristic of selected radiographic equipment was determined using MagicMax quality control kits and test object. Radiographic equipment in eight selected radiodiagnostic centers designated as C1-C8 was assessed.

RESULTS: The results showed that all the radiography units in the studied centers passed the kVp reproducibility and mAs linearity tests with the exception of center C2. The kVp deviation for the centers varied between 2.0 and 7.7%, with the highest deviation in center C5 and lowest value in center C6. Center C7 has the highest deviation (–13%) of mAs, while the lowest value was obtained in center C6 (0%). The dose was lowest in center C1 and highest in center C3. The half-value layer, mAs, and filtration values had a stronger correlation with the incident air kerma dose compared to the other parameters. In addition, 50% of the equipment passed all the performance tests.

CONCLUSION: The study revealed that the performance characteristics of radiographic equipment in the studied area require improvement. Periodic monitoring of the equipment performance is recommended for adoption and enforcement to enhance quality practices and radiation safety.

Introduction

Radiographic equipment is widely in use globally. It has the highest frequency of imaging examinations as compared to other imaging modalities [1], [2], [3], [4], [5], [6]. Approximately 64% of all medical diagnostic examinations are from radiographic equipment [3]. Performance assessment of this equipment is therefore important to achieve its desired goal. Internationally, the radiation regulatory authorities recommended that imaging equipment be subjected to comprehensive quality assurance and quality control tests [7], [8], of which equipment performance assessment is a significant part. However, equipment performance assessment is still a challenge in many developing countries, where the equipment is known as old, poorly serviced, lacking good maintenance, and periodic quality control program [9].

Imaging equipment must be assessed regularly to enhance continued and reliable performance. This will ensure the proper functioning of the X-ray facility in accordance with international standards. According to the International Atomic Energy Agency (IAEA), the outcome of any imaging procedure depends on the performance of the equipment and its usage by the operators [7]. The study conducted by Wambani *et al*. specified the performance of the x-ray equipment as a key factor that influences patient dose [10]. Optimization of radiological protection is impossible without the evaluation of imaging equipment. It is a recommendation for newly installed x-ray diagnostic equipment to be subjected to standard safety operations before commissioning. This will enhance diagnostic quality and reduce patient dose [11].

Compliance surveys of x-ray equipment in Manitoba resulted in a patient dose downward trend [12]. The researchers reported that the downward trend is sustainable with quality control measures maintained. The study of Korir *et al.* noted an x-ray machine with failed generator exposure reproducibility and beam alignment test [9]. The consequences were high patient dose, image distortion, clipping of important anatomy, and grid cut-off among others [9]. A similar study reported patient dose reduction in the range of 31–77% for equipment having quality control assessment, while

none calibrated equipment increased patient dose up to a factor of 1–5 times more than IAEA guidance level [13]. The study by Ngaile *et al*. confirmed that the lowering of mAs is suitable for x-ray equipment with higher timer reproducibility, while an increase in tube potential works well in equipment with high accuracy and voltage consistency [14].

Performance assessment of radiographic equipment cannot be over-emphasized. A little shift in any radiographic parameter has a significant impact on the patient absorbed dose [15], especially due to the incidence of cancer induction from radiographic examinations [6], [16]. It is therefore important that radiographic units be assessed before usage and periodically to ensure proper functioning. Hence, this study desired to determine the output quality of the radiographic equipment in the selected centers to optimize the radiation dose delivered to the patients.

Materials and Methods

This study was conducted using radiographic units from eight healthcare institutions spread across the states in Southwest Nigeria. The study centers were designated C1-C8 for confidentiality. Institutional Ethical Clearance certificates were obtained before the commencement of the study. The specifications of the radiographic units are as presented in Table 1. Equipment performance assessment was conducted using MagicMax quality control kits (IBA Dosimetry, Germany) and test object (Orion France, Paris). The MagicMax quality control kits consist of the universal basic unit, XR multi-detector (for radiography quality), XM multi-detector (for mammography quality), current probe, and other accessories. The multi-detector measures the dose, dose rate, time, practical peak voltage, peak kilovoltage (kVp), average kilovoltage (kV), half-value layer (HVL), and total filtration. The current probe measures the current and current-time product, while the contrast and resolution were determined using the test objects.

Determination of X-ray tube output

The X-ray outputs (mGy/mAs) were determined at a focus detector distance (FDD) of 100 cm with a tube potential setting of 80 kVp and tube loading of 10/15 mAs [17], [18].

Reproducibility test for kVp

The kVp reproducibility test was conducted according to Taha [19] using the relation given by equation (1):

$$R = \frac{SD}{Z_{av}} \times 100\% \quad (1)$$

where R is the reproducibility, SD is the standard deviation of series of measurements, and Z_{av} is the mean value of the parameter measured. For this study, five exposures were made at a kVp of 80 and keeping FDD and tube loading constant at 100 cm and 10 mAs, respectively.

Accuracy test for kVp

The accuracy test for kVp was conducted according to standard using the relation given in equation (2) [19], [20]. Three exposures were made for this test at a kVp of 80 keeping FDD and tube loading constant at 100 cm and 10 mAs, respectively.

$$A = \left| \frac{V_m - V_s}{V_s} \right| \times 100\% \quad (2)$$

A represents the accuracy error, V_m is the measured mean kVp and V_s is the selected kVp.

Linearity test for mAs

The linearity test was determined using the relation given in equation (3)

$$L = \frac{|X_1 - X_2|}{X_1 + X_2} \quad (3)$$

X_1 and X_2 represents two successive readings [19].

Measurement of contrast sensitivity

The radiographic units contrast sensitivity was determined by scanning the test object (FL18) to obtain the best image that will enable counting the circular details that are visible. On average, three exposures were made using the appropriate exposure

Table 1: Specifications of the selected imaging facilities

Center	Type	Name	Manufacturer	Model	Filtration (mm)	Focal spot (mm)	Year of manufacture
C1	Digital	Varian	GE	RAD-21	0.7	NA	2016
C2	Computed	Philips	Philips	Optimus 50	2.5	NA	2007
C3	Computed	Allengers	Toshiba	E7237X	0.9	2.0/1.0	2013
C4	Conventional	Varian	GE	E7240FX	1.2	1.2/0.6	2008
C5	Conventional	GE	GE	2185226	0.23	0.8	2010
C6	Conventional	Varian	GE	RAD-12	1.6	1.2/0.6	2007
C7	Conventional	Toshiba	Toshiba	E7239X	0.9	2.0/1.0	2012
C8	Computed	BMI	Toshiba	E7252X	0.9	1.2/0.6	2012

NA indicates not available.

parameters according to the operation of each X-ray unit. The images with the best contrast were selected and compared with the calibration chart.

Measurement of limiting resolution

The limiting resolution test was conducted by exposing the test object using the lowest kVp and the appropriate mAs that gave the brightest image possible. Three exposures were made, and the best was chosen. Thereafter, the total number of spatial frequency groups that can be resolved was determined and compared with the standard chart.

Results

The measured radiographic output parameters are presented in Table 2. The deviations of the measured kVp and mAs from the nominal values are shown in Table 3. Figure 1 represents the plot of radiographic tube output with kV^2 and Table 4 displayed the Pearson correlations for the radiographic output parameters. The performance assessment tests conducted are kVp reproducibility, kVp accuracy, mAs linearity, contrast sensitivity, and limiting resolution. The results are shown in Table 5. All the radiography units in the study centers passed the kVp reproducibility and mAs linearity tests except in center C2. However, 62.5% passed the kVp accuracy test, 25% were within the acceptable limit, and 12.5% failed the test. For contrast sensitivity, 87.5% passed, and 12.5% failed the test, while for resolution test, 75% passed, 12.5% were within acceptable limits, and 12.5% failed the test. The equipment performance assessment from this study was compared with other studies, as shown in Table 6.

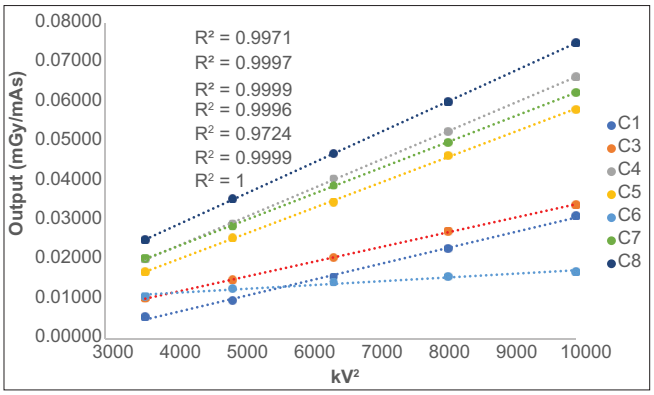

Figure 1: Tube output (mGy/mAs) variation with kV^2

Discussion

The kVp has the highest deviation in center C5 and lowest value in center C6, while mAs has the highest deviation in center C7 and lowest value in center C6. The deviation of kVp and mAs from the nominal values (Table 3) might be due to the conduction

Table 2: Radiography units output parameters at 80 kVp, 10/16 mAs, and 100 cm FDD

Centers	Dose (mGy)	PPV (kV)	mA	Dose rate (mGy/s)	Duration (s)	mAs	kV_{av}	HVL (mm)	Filtr (mm)	kVp
C1	0.153	82.59	193.4	3.040	0.0503	9.7	82.85	6.0	10.6	83.24
C2	0.282	83.68	NA	10.54	0.0267	NA	83.91	5.0	6.9	84.46
C3	0.839	77.04	85.9	1.769	0.4742	40.8	76.70	3.1	3.1	81.92
C4	0.396	83.63	97.1	3.965	0.0997	9.7	83.88	3.8	3.9	84.23
C5	0.530	72.68	113.5	3.936	0.1347	15.3	72.86	3.2	3.7	73.81
C6	0.730	81.02	259.3	19.02	0.0384	10.0	81.23	3.1	2.8	81.59
C7	0.342	82.15	86.3	3.406	0.1004	8.7	82.37	3.5	3.6	82.82
C8	0.431	82.26	166.4	7.828	0.0551	9.2	82.55	3.2	2.9	83.19

PPV: Practical peak voltage; kV_{av}: Average voltage; HVL: Half-value layer; Filtr: Filtration; NA: Not available.

Table 3: Comparison of selected and measured kVp and mAs for radiography units at 80 kVp, 10/16 mAs

Centers	Selected	kVp Measured	Deviation (%)	Selected	mAs Measured	Deviation (%)
C1	80.0	83.24	4.1	10.0	9.7	–3.0
C2	80.0	84.46	5.6	NA	NA	NA
C3	80.0	81.92	2.4	16.0	40.8*	155*
C4	80.0	84.23	5.3	10.0	9.7	–3.0
C5	80.0	73.81	–7.7	16.0	15.3	–7.0
C6	80.0	81.59	2.0	10.0	10.0	0.0
C7	80.0	82.82	3.5	10.0	8.7	–13
C8	80.0	83.19	4.0	10.0	9.2	–8.0

*The machine output differs from other equipment; NA: Not available.

Table 4: Pearson correlation of output parameters

Parameters	Dose (mGy)	PPV (kV)	mA	Dose rate (mGy/s)	Duration (s)	mAs	kV_{av}	HVL (mm)	Filtration (mm)	kVp
Dose (mGy)	1.000	–0.549	0.213	0.243	0.667	0.730	–0.572	–0.778	–0.725	–0.330
PPV (kV)		1.000	–0.018	0.243	–0.516	–0.582	0.999	0.470	0.331	0.925
mA			1.000	0.439	–0.239	–0.002	–0.006	–0.122	–0.041	–0.119
Dose rate (mGy/s)				1.000	–0.482	–0.412	0.254	–0.154	–0.202	0.112
Duration (s)					1.000	0.969	–0.554	–0.383	–0.317	–0.162
mAs						1.000	–0.616	–0.421	–0.327	–0.248
kV_{av}							1.000	0.475	0.336	0.907
HVL (mm)								1.000	0.983	0.391
Filtration (mm)									1.000	0.261
kVp										1.000

of incomprehensive equipment performance evaluation during the installation of the equipment. In addition, the lack of equipment performance evaluation after equipment maintenance might be responsible for some of the deviations observed. Newly installed imaging equipment is subjected to status and performance tests to establish the functional status of the equipment and generate the operational database [28]. The wide variation between the set factors and the actual output from x-ray machines has been reported by Nzotta and Chiaghanam [29]. The authors attributed the shortcomings to irregular quality control practices, poor equipment maintenance, and non-compliance to radiation protection rules and regulations. A small error in the selected kVp and mAs has a significant effect on the image quality. In addition, X-ray parameters are interdependent; a fault in any parameter has much influence on the final image quality [30]. Therefore, it is essential that the measured output parameters be in reasonable agreement with the nominal values to achieve the desired imaging goal.

Table 5: Performance assessment results at the study centers

Centers	C1	C2	C3	C4	C5	C6	C7	C8
kVp reproducibility (5%)								
Assessment (%)	0.12	0.19	0.09	0.12	0.26	0.05	0.07	0.14
Comment	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
kVp accuracy (5%)								
Assessment (%)	4.13	5.36	2.25	5.20	7.86	2.02	3.52	4.08
Comment	Pass	AC	Pass	AC	Fail	Pass	Pass	Pass
mAs linearity (<0.1)								
Assessment	0.001	NA	0.051	0.011	0.006	0.002	0.003	0.007
Comment	Pass	NA	Pass	Pass	Pass	Pass	Pass	Pass
Contrast sensitivity (3%)								
Assessment	0.018	0.011	0.007	0.045	0.013	0.011	0.018	0.009
Comment	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass
Resolution (>1.80)								
Assessment	2.00	1.80	0.06	2.50	2.24	4.00	2.24	2.50
Comment	Pass	AC	Fail	Pass	Pass	Pass	Pass	Pass

AC: Acceptable; NA: Not available.

The radiography equipment in center C3 gave an output quite different from all the other x-ray machines. Parameters, such as pulse count, pulse frequency, and dose per pulse, among others, were captured by the MagicMax QC kit on the equipment. This might be responsible for the higher mAs values recorded. The output of C3 machine also confirms the variability of x-ray equipment due to different configurations [31]. The effect of variant X-ray equipment configurations was responsible for the choice of different mAs values in some centers. For center C2, the cathode and anode cables were sealed such that the current probe could not be attached. This was the reason why the mAs values were not measured at the center. The dose (Table 2) was lowest in center C1 and highest in center C3. The radiographic equipment in center C1 is fully digital. Digital equipment records a lower radiation dose compared to conventional equipment [15]. In addition, C1 equipment has the highest filtration value compared to equipment in other centers. Increasing filtration results in a reduction of dose up to a factor of 3 [32]. For C3, the high dose might be attributed to the higher mAs value. Tube current influences dose [15]. Although center C6 had the lowest deviations of exposure factors from the nominal value, yet the dose has the second-highest value. The high dose value observed is attributable to the low filtration value. The equipment has the lowest measured filtration value. However, all the equipment in the study centers have their filtration values within the recommend limits [18], [33]. In addition, the measured HVL values for all the equipment in the study centers are within the recommended specifications [33]. The impact of HVL, filtration, and mAs on incident air kerma dose was observed, as shown in Table 4. The Pearson correlation (Table 4) for the radiographic output parameters showed that the HVL, mAs, and filtration values had a stronger correlation with the dose compared to the other parameters.

The X-ray equipment in center C6 was above 10 years, yet it yielded better results compared to those within its age brackets and even newer equipment elsewhere. However, all the equipment in the study centers passed the kVp reproducibility test (Table 5). Similar observation has been reported by other studies [19], [20], [25], [27]. The effect of good kVp reproducibility was evident, as shown in Figure 1, in which the kV^2 has a very strong correlation with the tube output. In addition, equipment in centers C1, C6, C7, and C8 passed all the performance tests (Table 5). This shows that the equipment has better maintenance compared to others. Center C5 failed the kVp accuracy test; hence, there is a higher probability for a repeat of examination due to over-exposure and consequently high dose to the patient. The kVp accuracy failure is well documented in the literature [21], [22], [23], [24], [26]. Center C4 failed the contrast sensitivity test; this might result in poor image quality. More so, as the kVp accuracy value (5.20) of the equipment is a bit above the reference value (>5%). The equipment in the center C3 failed the resolution test. Resolution defects may result in the rejection of radiograph and poor diagnosis, thereby defeating the aim of the examination. The condition of equipment in center C2 is worrisome given that the mAs value could not be determined. In addition, the kVp accuracy and resolution values are above the reference values. Although within acceptable limits, this outcome indicates that the equipment is poorly maintained and lacks adequate quality control measures.

It is through performance assessment that radiographic equipment can be ascertained to function

Table 6: Comparison of equipment performance failure (%) with other studies

Authors	This study	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]
kVp Reproducibility	0.0	0.0	0.0	NR	NR	42.9	5.6	0.0	NR	0.0
kVp accuracy	12.5	16.7	21.7	38.6	25.0	42.9	11.1	6.7	27.0	29.5
mAs linearity	12.5	NR	NR	NR	NR	NR	NR	NR	NR	NR
Contrast Sensitivity	12.5	NR	NR	NR	NR	NR	NR	NR	NR	NR
Resolution	12.5	NR	NR	NR	NR	NR	NR	NR	NR	NR

NR: Not recorded.

optimally. Periodic and regular monitoring of the equipment performance is a continual obligation. This would enhance quality performance and promotes radiation safety for both patients and radiological staff.

Conclusion

The study revealed that the performance characteristics of radiographic equipment in the study area require improvement. Periodic and regular monitoring of the equipment performance parameters is recommended for adoption and enforcement, thereby preventing exposure error, film reject, misdiagnosis, and radiation risks. The study, therefore, concluded that monitoring of performance characteristics of the equipment will enhance quality practice and radiation safety for patients and staff.

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