

Quality Control and Diagnostic Image Integrity In Radiography; an Evaluation of Some Selected Diagnostic Centers In Zaria Nigeria

¹Maryam Auwal Tureta, ¹Abdulrahman Umaru, ¹Mohammed Yusuf Mohammed, ²Abdulrazaq Bamanga, ³Falmata Baba Kasheem, ³Moshood Salawu

¹Department of medical radiography, Ahmadu Bello University, Zaria, Kaduna, Nigeria.

²Department of Radiography, National Tuberculosis and Leprosy Training Centre, Zaria, Nigeria.

³Department of Physics, ModibboAdama University, Yola

Corresponding Author's Email: abdulumaru08@gmail.com

ABSTRACT

Maintaining optimal image quality and radiation safety in diagnostic radiography relies heavily on regular quality control (QC) testing of radiographic equipment. However, in many developing regions, QC practices are inconsistent and often poorly documented. This study evaluated the adequacy and compliance of QC testing in diagnostic radiography units across selected public hospitals in Zaria, identifying deviations from standard regulatory requirements and highlighting areas needing improvement. A cross-sectional descriptive study was conducted in radiology departments of public hospital in Zaria, Nigeria. Standard QC parameters including exposure reproducibility, kVp accuracy, half value layer (HVL) and beam alignment and collimation were evaluated using established QC kit. Two of the three machines (M2 and M3) performed within acceptable international standards, while one machine (M1) showed significant deviations. The kVp accuracy test revealed a mean percentage error of 27.62%, 2.41%, and 4.16% for M1, M2, and M3 respectively. Exposure reproducibility tests showed coefficient of variation values of 5.93%, 3.25%, and 4.37%. HVL values were 1.55 mmAl(M1), 3.0 mmAl(M2), and 2.9 mmAl(M3), indicating insufficient filtration in M1. Beam alignment and collimation results for M2 and M3 were within $\pm 1\%$ and $\pm 2\%$ tolerance, respectively. Due to M1's instability, the full collimation test could not be completed. Machine M2 and M3 met QC standards, while M1 failed most tests, reflecting possible calibration or maintenance issues. Recommendations are provided to ensure optimal equipment performance and minimize unnecessary radiation exposure.

Keywords: Quality control, Radiation safety, equipment performance, Diagnostic imaging, Image quality.

1.0 INTRODUCTION

X-ray imaging remains one of the most essential diagnosing tools in modern medicine, providing rapid and non-invasive visualization of internal structures for accurate diagnosis and treatment planning (Almutairiet al., 2024; Mohammed et al., 2023). However, the diagnostic value of radiographic imaging depends greatly on the technical performance and calibration of equipment, as well as strict adherence to control (QC) protocols (Sezdi, 2011). Inadequate maintenance or poor calibration can lead to suboptimal image quality, repeated exposure, and unnecessary increase in radiation dose to both patients and operators (Carroll et al. 2023).

Quality control testing is a critical component of radiation protection and diagnostic reliability. It involves systematic evaluations of equipment parameters such as kilovoltage peak (kVp) accuracy, exposure reproducibility, beam alignment, and half value layer (HVL) to ensure compliance with international standards (Carroll et al., 2023). Regular QC procedures help maintain image consistency, detect equipment faults early, and minimize unnecessary radiation exposure. Conversely, facilities with poor QC practices often report high repeat rates, equipment malfunctions, and increase patient doses (Almutairi et al., 2024; Sezdi 2011). A major goal of QC testing in radiography is radiation dose optimization. Sezdi (2011) emphasized that optimizing radiation dose is crucial for minimizing patient exposure while maintaining diagnostic image quality. The study found that improper use and lack of dose monitoring contribute to excessive radiation exposure. Implementing the ALARA (As Low As Reasonably Achievable)

principle, proper calibration, and routine QC testing identified as effective strategies for dose optimization. Similarly, Alnafeet et al. (2023) examined QC procedures for digital X-ray machines in Riyadh hospitals and reported that while most machines met the acceptable limits for kVp accuracy, exposure reproducibility, and HVL, regular annual testing and immediate servicing of non-compliant units were strongly recommended.

In contrast, Almutairi et al., (2024) found widespread non-compliance in Bangladesh, with only 60% of diagnostic facilities meeting beam alignment standards and non-achieving the recommended HVL levels. The authors concluded that inadequate QC implementation increases patient dose and reduced diagnostic accuracy. Likewise, Mamma et al., (2023) conducted a large-scale study (196 X-ray units) on QC performances in Tanzania and reported that 59% failed the kVp accuracy tests, 57% failed timer accuracy test, and 60% failed beam alignment test, highlighting the urgent need for preventive maintenance programs and regulatory oversight.

Across Africa and Asia, several studies have reported similar deficiencies in QC implementation. In Nigeria, Ijaboret et al., (2021), Nworah et al., (2018), Osahon et al. (2019) and Umaru et al., (2020) observed that many X-ray machines failed to meet AAPM standards for kVp accuracy and reproducibility, largely due to irregular maintenance and lack of calibration. Such deficiencies not only compromise diagnostic image quality but also expose patients to unnecessary radiation doses, emphasizing the need for regular QC testing and equipment calibration. This study therefore aims to assess the quality control

performance of diagnostic X-ray equipment, focusing on key parameters such as kVp accuracy, exposure reproducibility, beam alignment, and half value layer, in order to determine compliance with established standards and identify areas requiring improvement.

2.0 MATERIALS AND METHOD

This descriptive cross-sectional study was conducted in two major public hospitals in Zaria, Kaduna State, Nigeria. Ahmadu Bello University Teaching Hospital, Shika and National Tuberculosis and Leprosy Training Centre (NTBLTC) Saye. The study included all functional diagnostic x-ray machines in these facilities, as they are routinely used for patient imaging and represent key centres of radiographic activity in the region.

Ethical approval was obtained from the health Research Ethics Committee of ABUTH. As the research involved only equipment performance testing without patients contact or access to confidential information, informed consent was not required.

2.1 Data Collection

Data were collected using a standardized data capture sheet and a quality control (QC) testing kit consisting of a kVp meter, multifunctional meter, thin Aluminum sheets, beam alignment and collimation test tools, and a digital (CR) cassette with a compatible image processor.

2.2 kVp accuracy

The kVp meter was positioned on the couch at 100 cm from the X-ray tube, aligned perpendicular with the beam as showed in Figure 1. Exposures were made at 50, 60, 70, 80, 90 and 100kVp using 40 mAs. Accuracy was determined using the formula:

$$\text{kVp accuracy} = \frac{\text{kVp measured} - \text{kVp set}}{\text{kVp set}} \times 100$$

2.3 Exposure reproducibility

Five exposures were made at 70 kV and 10 mAs under identical conditions. The variation in output readings was recorded using a RAD-Check multifunction meter (Figure 2) and analyzed using coefficient of variation (CV):

$$\text{Coefficient of variation (CV)} = \frac{SD}{mean} \times 100$$

2.4 Beam alignment and centering

The beam alignment and collimator test tools were placed on a CR cassette at 100 cm source to image distance (SID). The light beam was centered and collimated to the outer black line of the test tool, and an exposure was made at 70 kVp and 10 mAs to assess congruence between the x-ray and light field (Figure 3).

2.5 Half value layer (HVL)

The dosimeter was placed at 100cm SID and exposed at 70 kV and 30 mAs. Aluminum sheets of 1-5mm thickness were added incrementally until the exposure reading dropped below 50% of the unattenuated value. A graph of aluminium thickness versus exposure dose was plotted, and the corresponding thickness representing a 50% reduction in exposure was taken as the HVL.

2.6 Data analysis

Data were analyzed descriptively, with results presented as percentages, tables, and chart to illustrate equipment performance and compliance with QC standards.



Figure 1: Setup for kVp Accuracy.



Figure 2: Setup for Exposure Reproducibility

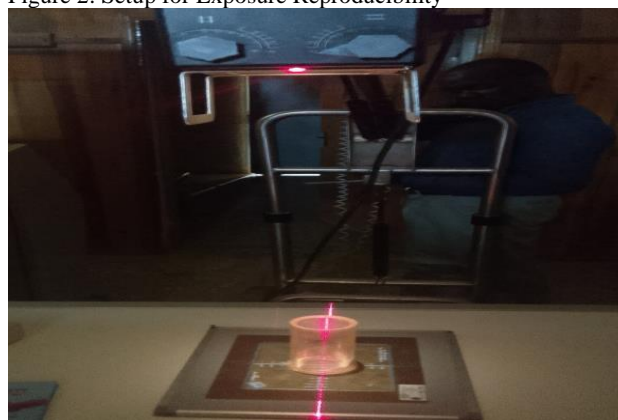


Figure 3: Setup for X-ray light beam alignment and centering.

3.0 RESULTS

A total of three diagnostic x-ray machines two fixed and one mobile units across two public hospitals in Zaria were evaluated for key quality control (QC) parameters, including kVp accuracy, exposure reproducibility, half value layer (HVL), and beam alignment and collimation.

Table 1 summarizes the specifications of the machine assessed. The systems were manufactured between 2008 to 2014 and installed between 2010 and 2016.

Table 1: Specifications of Various Machines in the Facilities

S/NO	MODEL	TYPE OF MACHINE	FILTRATION	MODEL NO	YEAR OF MANUFACTURE	DATE INSTALLED
M1	Toshiba	Fixed	1.3Al/75cm	MN-E7299X	2008	2010
M2	MinXray HF120/60 HPPWY powerplus™	Mobile	3.3Al/75cm	MXRSLW	2009	2016
M3	GEBE Private Limited	Fixed	1.3Al/75cm	5331186	2014	2016

3.1 kVp Accuracy

kVp accuracy was assessed using five exposures (10 mAs) at varying tube voltages between 50-90kVp. Due to technical limitations, exposure for Machines 1 and 2 began at 60 kVp. The measure and set kVp are presented in table 2.

Machine 1 demonstrated significant deviations, with percentage errors exceeding 24% across all tested kVp

levels. Indicating poor calibration. Machine 2 showed good performance, with percentage errors below 7%, while Machine 3 exhibited deviation ranging from 2.5% to 9.2%. Overall, the mean percentage error was highest for machine 1 (27.62%), followed by machine 3 (4.1.6%) and machine 2 (2.41%).

Table 2: kVp Accuracy Parameters (10 mAs)

Dial kVp	Machine 1		Machine 2		Machine 3	
	Actual kVp	Percentage error	Actual kVp	Percentage error	Actual kVp	Percentage error
50	-	-	-	-	54.6	9.2
60	81.1	31.17	60.1	0.17	61.5	2.5
70	90.7	29.57	69.8	-0.28	72.4	3.43
80	102.8	28.5	81.4	1.75	83.6	4.5
90	112.2	24.67	93.9	4.33	95.1	5.67
100	124.2	24.2	106.1	6.1	-	-

3.2 Exposure reproducibility

Exposure reproducibility was evaluated using five exposures at 70 kVp and 10 mAs (Table 3). Machine 1 showed an average exposure reading of 0.142 mGy and a coefficient of variations (CV) of 5.93%. Machine 2 showed a higher average output (1.21 mGy) with a CV of 3.25%, while Machine 3 produced 0.338 mGy with a CV of 4.37%. Machine 2 and 3 maintained acceptable reproducibility level (<5%), whereas Machine 1 showed slightly higher variability.

Table 3: Exposure Reproducibility

Exposure	mAs	KVp	M1 Output	M2 Output	M3 Output
1	10	70	0.16	1.19	0.33
2	10	70	0.15	1.16	0.36
3	10	70	0.14	1.2	0.34
4	10	70	0.14	1.25	0.32
5	10	70	0.15	1.25	0.34
Average Exposure Reading			0.142	1.21	0.338
COV (%)			5.93	3.25	4.37

3.3 X-ray light beam alignment and centering

Beam alignment and collimation tests were successfully performed on Machine M2 and M3 (Table 4). Due to unstable exposure settings, Machine 1 could not undergo collimation testing, although beam alignment was assessable. Machine 2 and 3 showed alignment deviations within acceptable limits (1cm or 3°) and collimation errors below 2 cm ($\leq 2\%$), consistent with international standards. The highest recorded deviation was 1.2 cm in Machine 2 and 2.0 cm in Machine 3 (Figure 4).

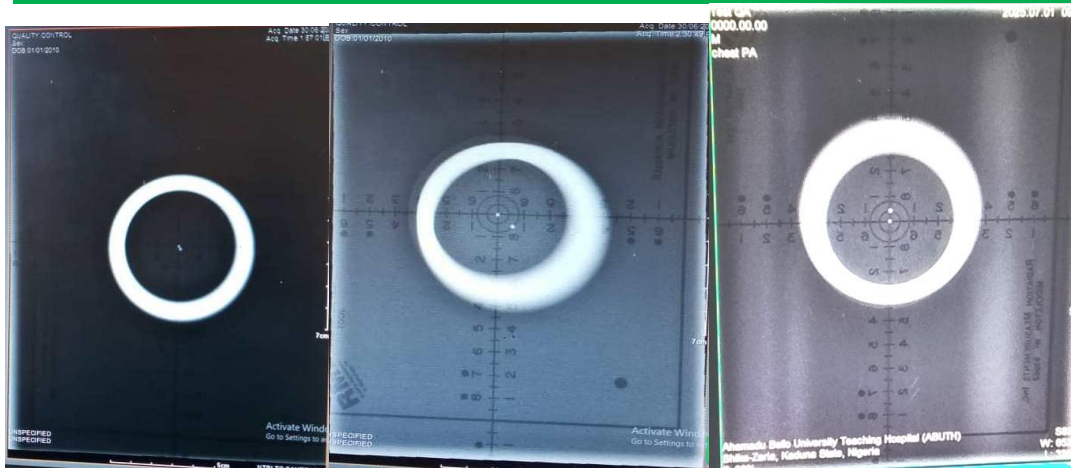


Figure 4: Radiograph of X-ray light beam alignment and centering

Table 4: X-ray light beam alignment and centering

Machine	Right		Left		Up		Down	
	In	Out	In	Out	In	Out	In	Out
M2	0.1	0.0	0.0	0.7	0.1	0.0	0.0	1.2
M3	2	0.0	0.0	0.9	1.0	0.0	0.0	1.0

3.4 Half Value Layer (HVL)

HVL measurements were obtained using incremental aluminum filters (1–5 mm) at 70 kVp and 30 mAs. As the filter thickness increased, the dose decreased progressively (Table 5). The HVL was determined as 1.55 mmAl for Machine 1, 3.0 mmAl for Machine 2, and 2.9 mmAl for Machine 3. Machines 2 and 3 produced harder (better filtered) X-ray beams, while the lower HVL of machine 1 suggested inadequate inherent filtration and suboptimal beam quality (Figure 5).

Table 4.5: Half Value Layer Parameters

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Al Thickness (mm)	mAs	kVp	M1 Output	M2 Output	M3 Output
0.1	30	70	0.39	1.25	0.39
0.2	30	70	0.31	0.98	0.32
0.3	30	70	0.28	0.72	0.22
0.4	30	70	0.23	0.51	0.17
0.5	30	70	0.19	0.38	0.12
Half of Average Dose with Al (mmGy)			0.34	0.69	0.23

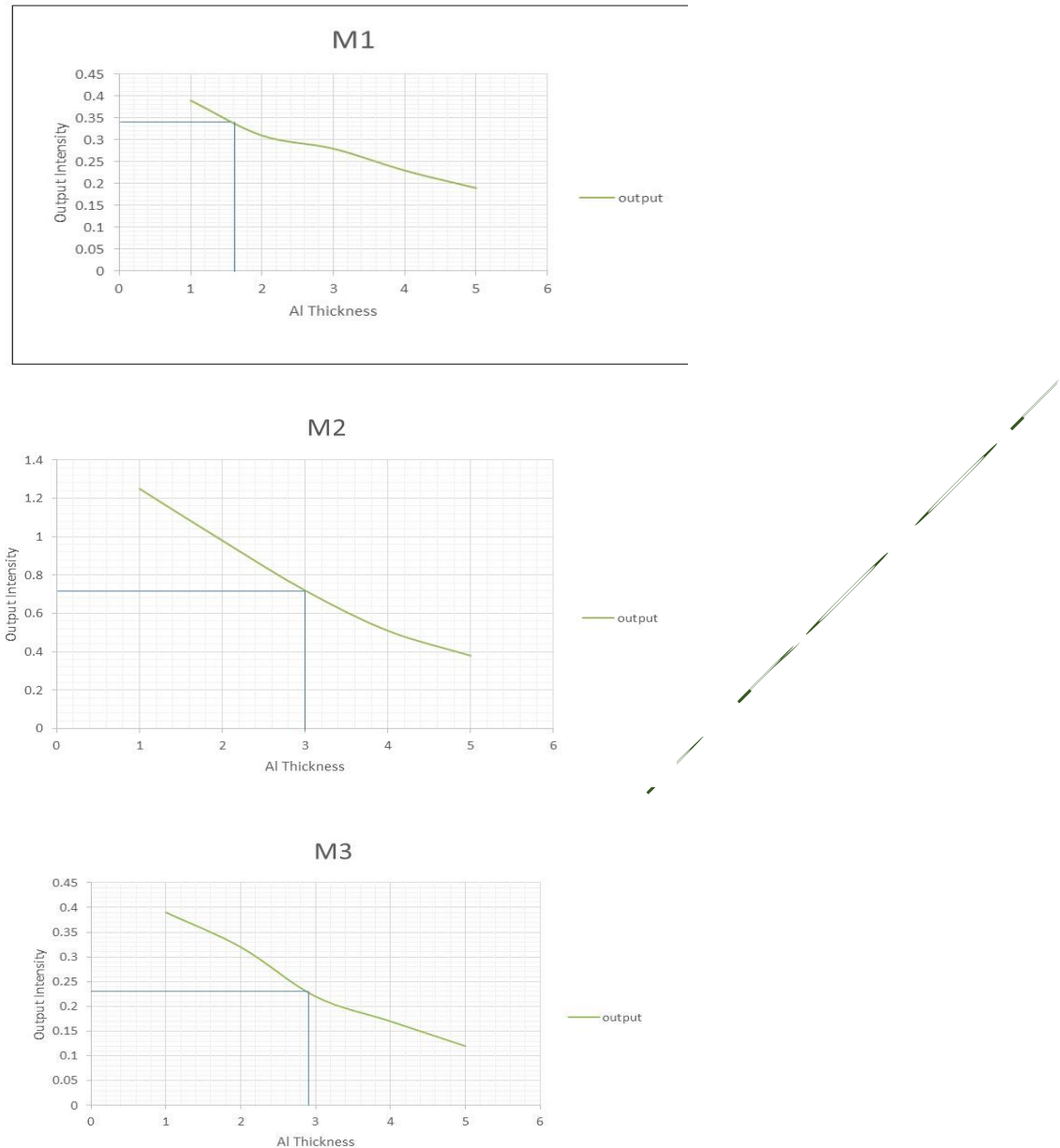


Figure 5: Line Graph for Half Value Layer of the machines

4.0 DISCUSSION

This study provides a comprehensive evaluation of the performance and safety status of diagnostic X-ray machines in selected public hospitals in Zaria, focusing on four essential quality control (QC) parameters: kVp accuracy, exposure reproducibility, beam alignment and collimation, and half value layer (HVL). Overall, the result revealed variable performance across the machines, reflecting difference in equipment age, maintenance history, and calibration practices. These findings emphasize the crucial role of regular QC programs in maintaining image quality and minimizing unnecessary radiation exposure, in line with international standard (IAEA, 2023).

The assessment of kVp accuracy revealed notable variation among the machines. Machine M1 exhibited the highest

percentage deviation (27.62%), well beyond the acceptable limit of $\pm 5\%$, whereas Machine M2 (2.41%) and M3 (4.16%) remained within tolerance. This large deviation observed in M1 likely resulted from deterioration of the high voltage generator or miscalibration, problems commonly associated with aging or poorly serviced systems (Godfrey *et al.*, 2015 and Odoh *et al.* 2022). Such inaccuracies can compromise image contrast and increase patient dose, highlighting the need for recalibration or possible replacement.

Exposure reproducibility, which reflect output stability, also varied across machines. Machine M1 produced recorded a coefficient of variation (CV) of 5.93%, slightly exceeded the 5% tolerance limit, while Machines M2 (3.25%) and M3 (4.37%) were within acceptable limits. Variability above tolerance may be linked to unstable

power supply, a malfunctioning exposure timer, or inadequate preventive maintenance (Code 2024; IAEA, 2023). Inconsistent exposure can lead to unpredictable image densities, repeat examinations, and unnecessary radiation exposure in facilities with limited QC monitoring as reported by Inyang *et al.*, (2015).

Beam alignment and collimation results indicated satisfactory performance across all testable units. Alignment for all machines were below 1cm (1% at 100 cm FFD), consistent with international tolerance (IAEA, 2023). Collimation deviations for M2 (1.2 cm) and M3 (2 cm) were within the 2% limit, suggesting adequate congruence between the X-ray field and light field. These findings align with reports of Sezdi (2011) and Umaru *et al.*, (2020), who observed similar results. Proper beam alignment and collimation are critical for patient protection, ensuring that only target anatomy is irradiated, and unnecessary exposure is minimized (Saidu *et al.*, 2020). However, M1 could not complete the collimation test due to noise and unstable exposure output, suggesting severe performance degradation that warrants immediate technical intervention. The HVL result confirmed this pattern. Machines M2 (3.0 mm Al) and M3 (2.9 mm Al) met the expected filtration levels for 70kVp (Mamma *et al.*, 2023). While M1 showed a lower HVL (1.55mmAl), indicating poor beam quality and inadequate filtration. Insufficient filtration allows more low energy photons to reach the patient, increasing skin dose and reducing image contrast (Nouchi *et al.*, 2023; Ike-ogbonna *et al.*, 2020). Difference in HVL performance reflect variations in machines design, filtration materials and maintenance practice (Sezdi, 2011; Ngoye *et al.*, 2022). Taken together, these findings show that only two of the three machines operated within acceptable QC limits, the results highlight how irregular maintenance and calibration contribute to poor machine performance. This reinforces the urgent need for structured QC programs supported by preventive maintenance schedules, dedicated budgets, and technical oversight (Ike-ogbonna *et al.*, 2020; Misokefalou *et al.*, 2022). Establishing regional or national QC monitoring ideally under regulatory supervision would help standards and strengthen compliance across facilities. This study was limited to functional X-ray units in two major public hospitals, which were selected because they serve as the main referral and training centers in the region and account for the majority of radiographic workload. Therefore, the findings may not represent all diagnostic facilities in the region. Nonetheless, they provide valuable baseline data for improving QC practice in similar settings. Future studies should expand to include private facilities and assess trends over time to better inform equipment management policies.

5.0 Conclusion

Most X-ray units in the study met acceptable QC standards, except one (M1), which showed significant deviations in kVp accuracy, exposure reproducibility, and half-value layer. These deficiencies can compromise image quality, increase patient dose, and lead to repeated exposures. Regular QC testing, timely maintenance, and calibration are essential to sustain diagnosis reliability and radiation safety.

Implementing standardized QC programs and enforcing regulatory oversight would enhance the safety and effectiveness of diagnostic radiology services in the region.

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