Greener Journal of Biomedical and Health Sciences
Vol. 9(1), pp. 220-225, 2026
ISSN: 2672-4529
Copyright ©2026, Creative Commons Attribution 4.0 International.
https://gjournals.org/GJBHS
DOI: https://doi.org/10.15580/gjbhs.2026.1.111626184

Quality Control Assessment of X-ray Tube Output Reproducibility and Linearity at Jos University Teaching Hospital, Nigeria

Awodi Ochoyodya Peter[1*], **Umaru Ibrahim**[1], **Abdullahi Mundi**[1]

[1] Department of Physics (Radiation and Medical Physics), Nasarawa State University, Keffi, Nigeria.

ABSTRACT

Quality control of diagnostic X-ray equipment is essential for consistent image quality and patient dose optimisation in line with the ALARA principle, yet no recent performance data were available for the X-ray tubes at Jos University Teaching Hospital (JUTH), Nigeria. This study assessed the output reproducibility and output linearity of all four functional general radiography units in the department (Siemens Multix Fusion, Philips Digital Diagnost, Shimadzu RADspeed Pro and GE Definium 6000) and compared the results with international acceptance criteria. A calibrated dosimeter with an ionization chamber was used at a focus-to-chamber distance of 100 cm with a 10 cm phantom. Ten consecutive exposures at 70 kVp and 20 mAs were made on each unit to determine the coefficient of variation (CV), and exposures at 5, 10, 20, 40 and 80 mAs at 80 kVp were used to determine the linearity ratio. All units showed acceptable reproducibility, with CV values from 0.30% to 3.21%, below the 5% limit. Three of the four units (75%) showed acceptable linearity, with ratios of 1.004 to 1.014 against a limit of 1.10; Unit B (chest unit) failed, with a ratio of 1.147, its normalized output rising from 0.190 to 0.218 mGy/mAs between 5 and 80 mAs. Output at identical exposure factors differed by about 10% between units. Unit B needs investigation and corrective action, unit-specific technique charts should be adopted, and a routine QC programme should be established.

ARTICLE'S INFO

Article No.: *112126189*
Type*: *Research
Full Text: *PDF, PHP, HTML, EPUB, MP3*
DOI: ***10.15580/gjbhs.2026.1.111626184***

Accepted: *21/11/2026*
Published: *26/11/2026*

Keywords: *quality control; X-ray tube output; reproducibility; linearity; diagnostic radiology; Nigeria*

Corresponding Author

Awodi Ochoyodya Peter

E-mail: *awodipeter2@gmail.com*

Article's QR code

1. INTRODUCTION

The X-ray tube and its generator determine the radiation quantity that forms every radiographic image. Two properties of that output are central to quality control (QC): reproducibility, the ability to give the same output when identical exposure factors are repeated, and linearity, the proportionality of output to the selected mAs at fixed tube potential (kVp) (Bushberg et al., 2020). Poor reproducibility causes images of varying density and complicates follow-up comparison (Seeram and Brennan, 2021). Poor linearity means the delivered dose no longer matches the technique selected, which can produce either unnecessary exposure or underexposed, noisy images (IAEA, 2014).

For a fixed tube and kVp, air kerma (K) is expected to be directly proportional to mAs, so the normalized output K/mAs should be constant across stations. Reproducibility is quantified through the coefficient of variation (CV) of repeated exposures. International protocols set a CV tolerance of 5% and a linearity tolerance of about 10% (IAEA, 2014; AAPM, 2002). Testing against these limits is a core component of any radiation protection programme and supports the ALARA principle (ICRP, 2007).

Published work from Nigeria shows that QC compliance is uneven. Studies have reported output discrepancies of more than 30% in some facilities (Afolabi et al., 2017), inadequate beam filtration in a considerable proportion of units in Lagos (Ehiedu et al., 2020), and variable generator stability in conventional units in Abuja (Sule et al., 2018). Unstable mains power, limited funding and a lack of trained personnel are recurrent barriers (Ajayi et al., 2021; Okoye et al., 2016). Jos University Teaching Hospital (JUTH) is a leading referral and training centre for north-central Nigeria, yet no recent systematic evaluation of its X-ray tube performance was available.

This study therefore aimed to assess the output reproducibility and linearity of the diagnostic X-ray tubes at JUTH and to determine their compliance with international acceptance criteria. The specific objectives were to measure tube output at fixed kVp across several mAs stations, to calculate the CV from repeated exposures, to evaluate linearity from the relationship between output and mAs, and to compare the results with international tolerance limits.

2. MATERIALS AND METHODS

2.1 Study setting and units tested

The study was carried out in the Radiology Department of JUTH, Plateau State, Nigeria. A census approach was used: all functional, fixed general radiography X-ray units in clinical service during data collection were included. Four units were tested (Table 1). Data were collected in May 2026.

Table 1. Characteristics of the X-ray units assessed

Unit	Designated use	Manufacturer and model	Year installed	Location
A	General radiography	Siemens Multix Fusion	2018	General X-ray Room 1
B	Chest radiography	Philips Digital Diagnost	2015	Chest Clinic
C	Trauma/emergency	Shimadzu RADspeed Pro	2019	Accident & Emergency
D	Mobile radiography	GE Definium 6000	2012	General X-ray Room 2

2.2 Instrumentation

Output was measured with a RadCal Accu-Gold+ electrometer and a 10×5-6 ionization chamber (6 cm^3). The specific model used was the Infors Mult-O-Meter. A stack of 30 cm × 30 cm PMMA slabs (total thickness 10 cm) provided attenuation and backscatter conditions. A non-metallic stand, a non-stretch measuring tape (1 mm graduations) and a spirit level were used for positioning. Personal protective equipment and dosimeters were worn by the operators.

2.3 Experimental setup

The electrometer and chamber were assembled per the manufacturer's instructions and warmed up for 15 minutes. For each unit, the tube was positioned vertically over the table and levelled. The phantom was placed centrally beneath the collimator, and the chamber was placed on top of it on the central beam axis with the chamber centre at a focus-to-chamber distance (FCD) of 100 cm. The collimator was opened only enough to cover the sensitive volume of the chamber.

2.4 Output reproducibility

Ten consecutive exposures were made at 70 kVp and 20 mAs on each of the four units, with an interval of at least 2 seconds between exposures to avoid tube overheating. The output (mGy) was recorded after each exposure.

2.5 Output linearity

The tube potential was fixed at 80 kVp and the FCD at 100 cm. A single exposure was made at each of 5, 10, 20, 40 and 80 mAs on each unit, and the output was recorded.

2.6 Data analysis

For each unit, the mean ($\bar{x}$) and sample standard deviation (s) of the ten readings were calculated, and reproducibility was expressed as the coefficient of variation:

$$CV\ (\%) = \frac{s}{\bar{x}} \times 100 \qquad (1)$$

Reproducibility was deemed acceptable when CV ≤ 5% (IAEA, 2014; AAPM, 2002).

For linearity, the normalized output (linearity coefficient, mGy/mAs) was calculated at each station, and the linearity ratio was defined as:

$$LR = \frac{(K/mAs)_{max}}{(K/mAs)_{min}} \qquad (2)$$

Linearity was deemed acceptable when LR ≤ 1.10. Output was also regressed against mAs by least squares (K = a·mAs + b), and the slope, intercept and coefficient of determination (R^2) were obtained. Calculations were performed using SPSS Version 28.0.

3. RESULTS

3.1 Output reproducibility

Raw readings and summary statistics are given in Table 2. Mean outputs were 4.21 mGy (Unit A), 3.98 mGy (Unit B), 4.44 mGy (Unit C) and 4.72 mGy (Unit D). All four units passed, with CV values between 0.30% and 3.21% (mean 1.12%). Units A, C and D were very stable (CV 0.30% to 0.55%). Unit B was the least repeatable (CV 3.21%; range 3.78 to 4.18 mGy) and showed an alternating high-low pattern between exposures, although it remained inside the 5% tolerance.

Table 2. Output reproducibility at 70 kVp and 20 mAs (n = 10 exposures per unit)

Unit	Range (mGy)	Mean (mGy)	SD (mGy)	CV (%)	Status (CV ≤ 5%)
A	4.18 – 4.24	4.21	0.018	0.43	Pass
B	3.78 – 4.18	3.98	0.128	3.21	Pass
C	4.42 – 4.46	4.44	0.013	0.30	Pass
D	4.68 – 4.76	4.72	0.026	0.55	Pass

3.2 Output linearity

Measured output and normalized output at each mAs station are shown in Table 3. Units A, C and D delivered an almost constant output per mAs (0.213 to 0.216, 0.222 to 0.224 and 0.235 to 0.236 mGy/mAs respectively). In Unit B, normalized output rose progressively with mAs, from 0.190 mGy/mAs at 5 mAs to 0.218 mGy/mAs at 80 mAs, so that doubling the mAs from 5 to 10 raised output by a factor of 2.13 (0.95 to 2.02 mGy) instead of 2.0, and successive ratios approached 2.0 only at the higher stations (2.10, 2.04 and 2.01).

Table 3. Measured output (mGy) and normalized output (mGy/mAs, in brackets) at 80 kVp

mAs	Unit A	Unit B	Unit C	Unit D
5	1.08 (0.216)	0.95 (0.190)	1.12 (0.224)	1.18 (0.236)
10	2.15 (0.215)	2.02 (0.202)	2.23 (0.223)	2.36 (0.236)
20	4.28 (0.214)	4.25 (0.213)	4.45 (0.223)	4.71 (0.236)
40	8.52 (0.213)	8.68 (0.217)	8.88 (0.222)	9.40 (0.235)
80	17.04 (0.213)	17.44 (0.218)	17.76 (0.222)	18.80 (0.235)

Linearity results are summarised in Table 4 and Figure 1. Linearity ratios were 1.014 (A), 1.009 (C) and 1.004 (D), all within the 1.10 limit. Unit B had a ratio of 1.147 and failed. The regression for Unit B also had a negative intercept of −0.155 mGy, compared with intercepts within ±0.02 mGy for the other three units, which reflects the same low-mAs shortfall. Because R^2 is dominated by the high-mAs points, it was at or near 1 for all units, including Unit B, and is therefore not a sensitive indicator of this fault.

Table 4. Summary of output linearity at 80 kVp

Unit	Normalized output range (mGy/mAs)	Linearity ratio	Slope (mGy/mAs)	Intercept (mGy)	R^2	Status (LR ≤ 1.10)
A	0.213 – 0.216	1.014	0.2127	0.020	0.99999	Pass
B	0.190 – 0.218	1.147	0.2201	−0.155	0.99999	Fail
C	0.222 – 0.224	1.009	0.2218	0.011	1.00000	Pass
D	0.235 – 0.236	1.004	0.2349	0.009	1.00000	Pass

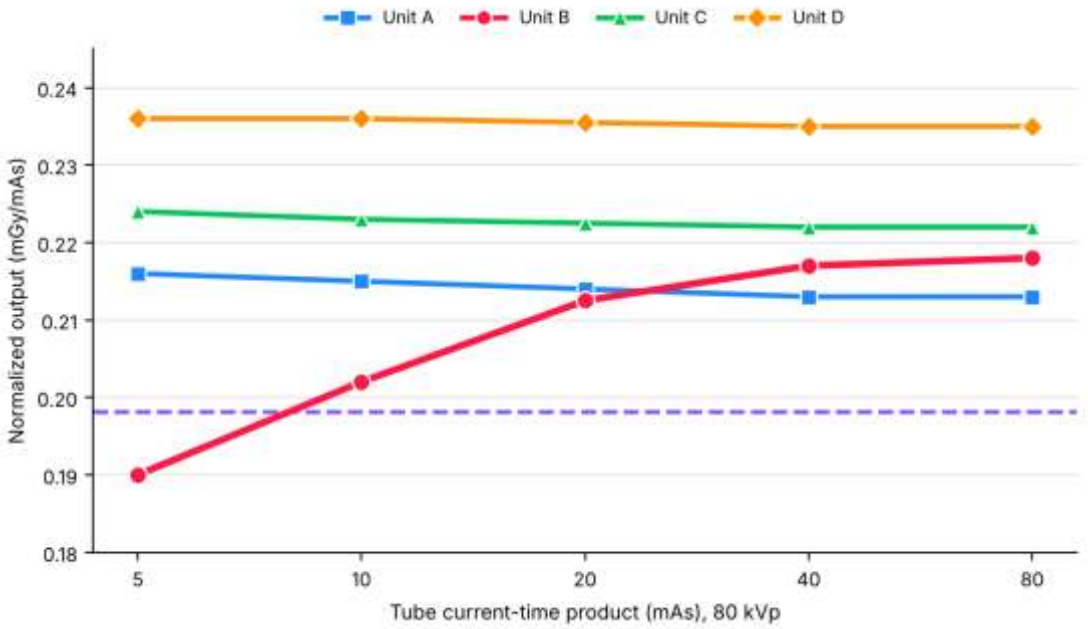


Figure 1. Normalized output (mGy/mAs) against mAs at 80 kVp for the four units. Units A, C and D are flat; Unit B rises from 5 to 80 mAs. The dashed line marks the lowest normalized output Unit B could have, given its maximum, and still meet a linearity ratio of 1.10.

3.3 Output differences between units

At identical settings (80 kVp, 20 mAs, 100 cm FCD), output ranged from 4.25 mGy (Unit B) to 4.71 mGy (Unit D); Unit D delivered about 10% more than Unit A (4.28 mGy). Per-mAs output at 80 kVp differed correspondingly (0.213 to 0.236 mGy/mAs).

4. DISCUSSION

4.1 Reproducibility

Every unit met the 5% CV limit, indicating that the generators deliver consistent output when the same technique is repeated. This supports predictable image density and reduces the likelihood of repeat exposures (Seeram and Brennan, 2021). The very low CV of Units A, C and D is in keeping with modern high-frequency generators with closed-loop control (Bushberg et al., 2020). Unit B's higher CV and alternating pattern suggest less stable generator behaviour, for example in filament current or high-voltage regulation, but the present data cannot identify the cause and the unit remained compliant. These results are comparable with the acceptable reproducibility reported for most units in south-west Nigeria (Afolabi et al., 2017). They differ from the greater variability reported for older conventional units in Abuja (Sule et al., 2018), which is plausibly explained by the digital, high-frequency equipment tested here, although equipment type was not compared directly.

4.2 Linearity and the Unit B finding

The main finding is that Unit B passed reproducibility but failed linearity. This is the pattern expected from a calibration error at particular mAs stations rather than from random instability: the unit repeated its output reliably, but the output did not scale in proportion to the selected mAs. The shortfall at 5 and 10 mAs (normalized output 12.8% and 7.3% below the 80 mAs value) means that low-mAs techniques, typical of small patients, may be underexposed, whereas the high-mAs end is comparatively accurate. Possible causes include inaccurate mA station calibration, timer error at short exposure times, or filament emission or feedback control faults; the present measurements cannot distinguish between these. The negative regression intercept is consistent with a timing or current offset at low mAs, and diagnosis would require dedicated timer and tube-current measurements. In practice, a radiographer adjusting mAs for patient size would not obtain the expected dose change on this unit, which undermines technique charts and, on AEC-equipped systems, the calibration of the exposure termination (Ilori et al., 2015).

The 25% failure rate is lower than rates reported in some Nigerian surveys, but the number of units here is too small to treat as a prevalence estimate. This study is consistent with the concern raised by Ehiedu et al. (2020) that some Nigerian units do not meet international criteria, and shows that a unit can be consistent yet inaccurate, which is why both tests are needed.

4.3 Dependence on the linearity criterion

The linearity criterion deserves attention when comparing studies. Defined as maximum over minimum normalized output, Unit B's ratio is 1.147 and fails the 1.10 limit. However, the maximum deviation of any Unit B station from its own mean normalized output was 8.6%, which would pass a mean-referenced ±10% criterion. Criteria expressed in other ways (for example, the difference between paired stations

relative to their sum) give different pass thresholds. We therefore applied the stricter extreme-to-extreme criterion, report the full normalized data, and regard Unit B's failure as criterion-dependent but clinically relevant, since the largest single-station departure (−8.6%) occurs at the low mAs values used for paediatric and small-patient imaging. Future QC reports should state the exact criterion used.

4.4 Differences between units

Output at identical settings varied by about 10% across units. Such differences arise naturally from variations in anode angle, inherent filtration, generator waveform and tube efficiency (Bushberg et al., 2020) and do not by themselves indicate a fault. Their practical importance is that using one technique chart for every room means patients receive different doses and images differ in density depending on the room used. This supports unit-specific technique charts based on measured output. The variation is also relevant to follow-up studies, where image differences may reflect equipment and not disease.

4.5 Context and implications

The findings show that a small, structured QC programme can be run at a Nigerian tertiary hospital with a single calibrated chamber, despite the funding and staffing barriers described by Okoye et al. (2016). The data are a baseline against which future tests can detect drift, which is the main benefit of routine monitoring. Because unstable mains supply can affect generators (Ajayi et al., 2021), repeating the tests under different supply conditions would be informative.

4.6 Limitations

This was a single-centre, cross-sectional study of four units, so the results cannot be generalised to other facilities. Only reproducibility at one technique (70 kVp, 20 mAs) and linearity at one tube potential (80 kVp) were tested, and each linearity station was measured once, so random measurement error could not be separated from systematic deviation. A single dosimeter was used with no independent cross-check, and a PMMA phantom does not reproduce patient scatter, so absolute outputs should not be read as patient doses. Kilovoltage accuracy, exposure time accuracy, half-value layer, AEC performance and beam alignment were not assessed, and the units differ in age, workload and maintenance history, which were not recorded. The linearity result for Unit B depends on the criterion applied, as discussed above.

5. CONCLUSIONS AND RECOMMENDATIONS

All four X-ray units at JUTH showed acceptable output reproducibility (CV 0.30% to 3.21%). Three of four (75%) also showed acceptable linearity (LR 1.004 to 1.014). Unit B, the chest radiography unit, showed non-linear output (LR 1.147) with a shortfall at low mAs despite passing reproducibility, and its output also differed by about 10% from the highest-output unit at identical factors. Based on these findings we recommend that:

1. Unit B be investigated by a qualified medical physicist or service engineer and recalibrated, with its use restricted to the mAs range where output was proportional until corrected. Reproducibility and linearity should be re-tested after any repair.
2. Unit-specific technique charts be developed from measured output.
3. A documented QC schedule be established, with reproducibility and linearity tested at least annually and more often for older or high-use units, extended to kVp, timer, HVL and AEC tests.
4. Hospital management fund QC equipment, preventive maintenance and medical physics support.
5. Future work include multi-centre sampling, repeated measurements at each station, several kVp values, longitudinal tracking, and correlation with patient dose metrics.

Declarations

Ethics: This study involved equipment measurements only and did not involve patients.

Funding: None

Conflict of interest: The author declares no conflict of interest.

Acknowledgements: Supervisor(s), JUTH Radiology Department staff and others.

Data availability: All measured data are provided in Tables 2 to 4.

REFERENCES

AAPM (2002) *Quality Control in Diagnostic Radiology.* AAPM Report No. 74. American Association of Physicists in Medicine.

Afolabi OO, Oladipo IC, Adebayo AA (2017) Assessment of X-ray tube output reproducibility and linearity in selected diagnostic centers in South-West Nigeria. *Nigerian Journal of Medical Physics* 4(1): 12–21.

Ajayi PO, Adebayo OO, Owoeye OO (2021) Influence of electrical power instability on X-ray generator performance in Nigerian hospitals. *West African Journal of Radiology* 28(2): 89–96.

Bushberg JT, Seibert JA, Leidholdt EM, Boone JM (2020) *The Essential Physics of Medical Imaging.* 4th ed. Wolters Kluwer.

Ehiedu CC, Ogbonna NC, Onwu EO (2020) Half-value layer and tube output measurement in selected X-ray facilities in Lagos, Nigeria. *International Journal of Radiology and Imaging* 7(1): 33–41.

IAEA (2014) *Quality Assurance Programme for Diagnostic Radiology Facilities.* IAEA Human Health Series No. 19. International Atomic Energy Agency.

ICRP (2007) *The 2007 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 103. Elsevier.

Ilori TA, Olowookere CJ, Ogundare FO (2015) Performance audit of automatic exposure control systems in Nigerian radiology departments. *Journal of Applied Clinical Medical Physics* 16(4): 245–252.

Okoye IJ, Uzoigwe AC, Nnamdi PC (2016) Barriers to effective quality assurance implementation in Nigerian radiology departments. *Journal of Clinical Imaging Science* 6: 25.

Seeram E, Brennan PC (2021) *Radiation Protection in Diagnostic Radiography.* 3rd ed. Elsevier.

Sule IO, Adejoh T, Ogunjobi AS (2018) Implementation of a quality control protocol for conventional X-ray units in Abuja, Nigeria. *Nigerian Journal of Radiography* 5(2): 44–52.

Cite this Article: Awodi, OP; Umaru, I; Abdullahi, M (2026). Quality Control Assessment of X-ray Tube Output Reproducibility and Linearity at Jos University Teaching Hospital, Nigeria. *Greener Journal of Biomedical and Health Sciences*, 9(1): 220-225, **https://doi.org/10.15580/gjbhs.2026.1.112126189**.