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Assessment of kVp accuracy and reproducibility of X-ray machines as a quality control measure in selected hospitals in Abuja, Nigeria

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Abstract

Background: The accuracy and reproducibility of the tube potential (kVp) affect image contrast, patient dose and repeat examinations. Published kVp quality control data from Abuja, Nigeria, are limited.

Objective: To evaluate kVp accuracy and reproducibility in X-ray units in selected hospitals in Abuja, Federal Capital Territory.

Methods: In this cross-sectional study, five X-ray units (XM-1 to XM-5) in five hospitals authorised by the Nigerian Nuclear Regulatory Authority were tested using a Cobia Smart R/F solid-state kVp meter. Accuracy was measured at 60, 70, 80, 90, and 100 kVp at 20 mAs and expressed as the percentage deviation from the set value. Reproducibility was assessed from five readings at 70 kVp across mAs stations of 16–40 mAs and expressed as the coefficient of variation (CoV). The accuracy tolerance was ±5% at each setting, based on American Association of Physicists in Medicine (AAPM) and International Atomic Energy Agency (IAEA) standards.

Results: The mean absolute kVp errors were 1.83%, 2.03%, 3.20%, 1.29%, and 2.40% for XM-1 to XM-5. Twenty-four of 25 measurements (96%) were within ±5%; the exception was XM-3 at 60 kVp (−6.25%). Measured kVp was below the set value in 23 of 25 measurements (mean deviation −1.92%). The CoV was 0.35%, 0.33%, 1.21%, 0.09%, and 0.05%, all within the limit. Four units met the criteria at every setting.

Conclusion: Four of five units were compliant, and one (XM-3) needs recalibration. Measured kVp was slightly below the set value in most measurements. Routine per-setting kVp testing, including after repairs, is recommended, and larger studies that include unregulated facilities are needed.

Introduction

Diagnostic radiography remains the most widely used imaging modality worldwide, and its benefits depend on keeping patient exposure as low as reasonably achievable while preserving diagnostic image quality [1]. The International Commission on Radiological Protection (ICRP) frames this through the principles of justification and optimisation [2],

and the IAEA's basic safety standards require verifying equipment performance through a quality control (QC) programme [3].

Equipment performance matters because retakes add dose without adding diagnostic information. Reject analysis in digital radiography still reports substantial retake rates: one Belgian department reported a digital radiography reject rate of 8.3% [4], and a Kenyan department reported an overall reject-and-repeat rate of 25.7%, with only 27% of radiographers carrying out reject analysis periodically [5]. Most rejects in modern digital systems stem from positioning and other operator factors [4,6], making machine-related causes easy to overlook. Exposure errors, including wrong beam quality, nonetheless still reduce image contrast and can trigger repeat exposures [6,7].

The tube potential (kVp) is central to both image contrast and patient dose. If the delivered kVp departs from the selected value, beam penetration and contrast change, and the exposure technique no longer produces the intended image. Two tests are used for this: kVp accuracy (agreement between set and measured kVp) and kVp reproducibility (consistency of repeated exposures at the same settings). Both are routine components of a diagnostic X-ray QC programme [3,8].

Nigerian studies show that kVp performance cannot be assumed. In Jos North, 16 of 23 X-ray machines passed the kVp accuracy test and 15 of 23 passed reproducibility, and machine age was significantly associated with performance [9]. In Lagos, a quarter of the 40 kVp accuracy results from ten units exceeded the tolerance, with two units (10 and 11 years old) outside it at every setting, although machine age was not significantly associated with the mean error [10]. Earlier work in Zaria [11] and Yola [12] similarly documented deviations that called for calibration. More recently, a study of ten tertiary hospitals in north-eastern Nigeria found that six units met the QC standards while four failed, with performance related to machine lifespan [13]. Comparable monitoring programmes have been reported in other African countries [14,15]. These findings come mainly from the north and south-west, and from mixed public and private facilities with varying regulatory oversight.

Abuja has a large concentration of regulated diagnostic facilities, but it is unclear whether facilities under active NNRA regulatory oversight, where QC is performed routinely, perform better than the wider Nigerian picture suggests.

This study therefore assessed kVp accuracy and reproducibility of five X-ray units in five NNRA-authorized hospitals in Abuja, compared the results with the applicable regulatory tolerances of ±5% by IAEA and AAPM, and identified units needing corrective action.

Materials and Methods

Study design and setting

A cross-sectional, quantitative quality control (QC) study was conducted on diagnostic X-ray units in Abuja, Federal Capital Territory, Nigeria. The study assessed two X-ray generator performance parameters: kVp accuracy and kVp reproducibility. Measurements were taken over eight months, from January 2026 to August 2026.

Five hospitals holding valid authorisation from the Nigerian Nuclear Regulatory Authority (NNRA) were purposively selected from the client list of a licensed QC service provider (Fezika Logistics Ltd). One general-purpose radiographic unit was tested in each hospital (coded XM-1 to XM-5). Facilities were selected because they had a high routine examination workload. Because the sample was purposive and small, the findings describe these units and are not representative of all facilities in Abuja. The manufacturer, type (mobile or floor-mounted), serial number, model, year and country of manufacture of each unit are given in Table 1. high-frequency), with CR image receptor type.

Table 1. Specification of the X-ray units in the selected centres

Unit	Manufacturer	Type of machine	Serial no.	Model	Year of manufacture	Country of manufacture
XM-1	GE General Electric	Mobile X-ray	20897ED5	AMX4	07/1995	USA
XM-2	Philips	Mobile X-ray	SN11000060	Practix 360	02/2011	Germany
XM-3	Gulfex Medical & Scientific	Floor mounted	20043006	XM-300	04/2020	China
XM-4	GE Haulun Medical System	Floor mounted	143603BC9	AMX4	10/2018	China
XM-5	Toshiba Digital Japan	Floor mounted	8H01410	Toshiba Rotanode	08/2018	Japan

Tube potential was measured with a Cobia Smart R/F solid-state (semiconductor) kVp meter (model CB3-19098461) with a stated working range of 50–200 kV. The meter was used in non-invasive mode and was reset to zero after every exposure.

Procedures

For each unit the meter was placed at the centre of the table, with the central ray directed perpendicular to the detector at a focus-to-detector distance of 100 cm. The beam was collimated to just exceed the detector area, covering its marked sensitive region. The same set-up was used for all five units. The tube current–time product was fixed at 20 mAs. The kVp was set on the control panel at 60, 70, 80, 90 and 100 kVp, and the measured kVp was recorded at each setting. Exposure was made twice, and the average reading was recorded.

The kVp was fixed at 70 kVp. Five consecutive exposures were made at mAs stations of 16, 20, 25, 32 and 40 mAs, and the measured kVp was recorded for each (Table 4).

The kVp accuracy was expressed as the percentage deviation of the measured value from the set value at each setting:

$$Percentage\ error\ (\%) = \frac{V_m - V_s}{V_s}\ X\ 100\ \ldots\ldots\ Eq\ 1$$

where Vm is the measured kVp and Vs is the set (dial) kVp. The signed deviation, (Vm − Vs) / Vs × 100, was also calculated to show the direction of any bias. The mean percentage error for each unit was calculated across the five settings.

kVp reproducibility was expressed as the coefficient of variation (CoV) of the repeated measurements at 70 kVp:

$$CoV(\%) = \frac{SD}{mean}\ X\ 100\ \ldots\ldots\ldots\ Eq2$$

where SD is the sample standard deviation (n − 1) of the five measured values, and the mean is their arithmetic mean.

Results were compared with the tolerances of IAEA guidelines. kVp accuracy was considered acceptable if the error did not exceed ±5% at each tested setting, and reproducibility was considered acceptable if the CoV did not exceed the ±5% tolerance limit. A unit was classed as failing if any single setting exceeded the tolerance, even if its mean error was within it.

Data quality and Management

The measurements were carried out by a NNRA-licensed Radiation Safety Adviser (RSA) with over 20 years of experience in Quality Control. The measurements were taken during routine QC visits to the facilities and were subsequently made available for analysis in this study. The data were collected prospectively from QC records, where administrative approval was obtained from each facility administration. The same meter was used for all units. The meter was checked and uncertainty was considered.

Descriptive statistics (mean, range, SD and CoV) were calculated for each unit and for each set kVp. To examine linearity between set and measured values, a linear regression of measured kVp on set kVp was fitted for each unit, and the slope, intercept and coefficient of determination (R^2) are reported. The proportion of units and of individual settings within tolerance was calculated. Descriptive and inferential statistics were performed in R stats v.4.5.1.

Ethical considerations

No patients or human participants were involved, and all measurements were made on unloaded X-ray units using a detector. Facility and unit identities are anonymised as XM-1 to XM-5.

Results

Table 2 shows the measured and set kVp values for the five units at 20 mAs, with the signed deviation from the set value shown in parentheses. Of the 25 measurements (five units at five settings), 24 (96%) were within ±5% of the set value. The only measurement outside the tolerance was XM-3 at 60 kVp, where the measured value of 56.25 kVp was 6.25% (3.75 kV) below the set value (Figure 1). All other absolute errors ranged from 0.37% (XM-4, 80 kVp) to 3.33% (XM-3, 90 kVp).

Across all 25 measurements, the measured kVp was below the set value in 23 cases (92%), with a mean signed deviation of −1.92%. The exceptions were XM-1 and XM-4 at 60 kVp, which read 2.17% (+1.30 kV) and 0.75% (+0.45 kV) above the set value, respectively. The mean absolute error of each unit was 1.83% (XM-1), 2.03% (XM-2), 3.20% (XM-3), 1.29% (XM-4) and 2.40% (XM-5) (Table 3). Based on mean error, all five units were within 5%. When assessed at each individual setting, XM-3 was not (Table 5).

The relationship between measured and set kVp was close to linear for every unit ($R^2 = 0.996–1.000$; Table 3, Figure 2a). The fitted slopes ranged from 0.928 to 1.030. XM-1 (slope 0.928) and XM-4 (0.946) had slopes below unity with positive intercepts, so that their deviation changed from over-reading at 60 kVp to under-reading at higher settings (Figure 2b). XM-3 had the steepest slope (1.030) with the largest negative intercept (−4.76 kV), consistent with its large under-reading at the lowest setting, which diminished towards 70 kVp (−1.93%). XM-2 and XM-5 under-read at all settings by a fairly constant amount (Figure 1). Because each regression is based on five points, the slope and intercept are reported descriptively.

Table 2. Measured kVp at each set kVp (20 mAs) for the five X-ray units. Values in parentheses are the signed percentage deviation from the set value. The measurement denoted by asterisk exceeds the ±5% tolerance limit.

Set kVp	XM-1	XM-2	XM-3	XM-4	XM-5
60	61.30 (+2.17)	58.35 (−2.75)	56.25 (−6.25)*	60.45 (+0.75)	58.45 (−2.58)
70	69.65 (−0.50)	68.35 (−2.36)	68.65 (−1.93)	68.95 (−1.50)	68.50 (−2.14)
80	77.95 (−2.56)	78.25 (−2.19)	77.55 (−3.06)	79.70 (−0.37)	78.10 (−2.38)
90	87.70 (−2.56)	88.50 (−1.67)	87.00 (−3.33)	88.25 (−1.94)	87.15 (−3.17)
100	98.65 (−1.35)	98.80 (−1.20)	98.55 (−1.45)	98.10 (−1.90)	98.25 (−1.75)

Table 3. Summary of kVp accuracy and linearity for each X-ray unit. |error| is the absolute percentage error; slope, intercept and R^2 are from linear regression of measured on set kVp (n = 5 settings per unit). The measurement denoted by an asterisk exceeds the ±5% tolerance.

Unit	Mean |error| (%)	Range of |error| (%)	Mean signed dev. (%)	Max |dev.| (Kv)	Slope	Intercept (Kv)	R^2	Settings outside ±5%
XM-1	1.83	0.50–2.56	−0.96	2.30	0.928	4.85	0.996	0 of 5
XM-2	2.03	1.20–2.75	−2.03	1.75	1.011	−2.39	1.000	0 of 5
XM-3	3.20	1.45–6.25	−3.20	3.75	1.030	−4.76	0.997	1 of 5 (60 kVp)*
XM-4	1.29	0.37–1.94	−0.99	1.90	0.946	3.41	0.999	0 of 5
XM-5	2.40	1.75–3.17	−2.40	2.85	0.983	−0.51	0.999	0 of 5

Figure 1. Deviation of measured from set kVp (%) for the five X-ray units at five kVp settings (20 mAs). The shaded band shows the ±5% tolerance. Only XM-3 at 60 kVp (−6.25%) lies outside the band.

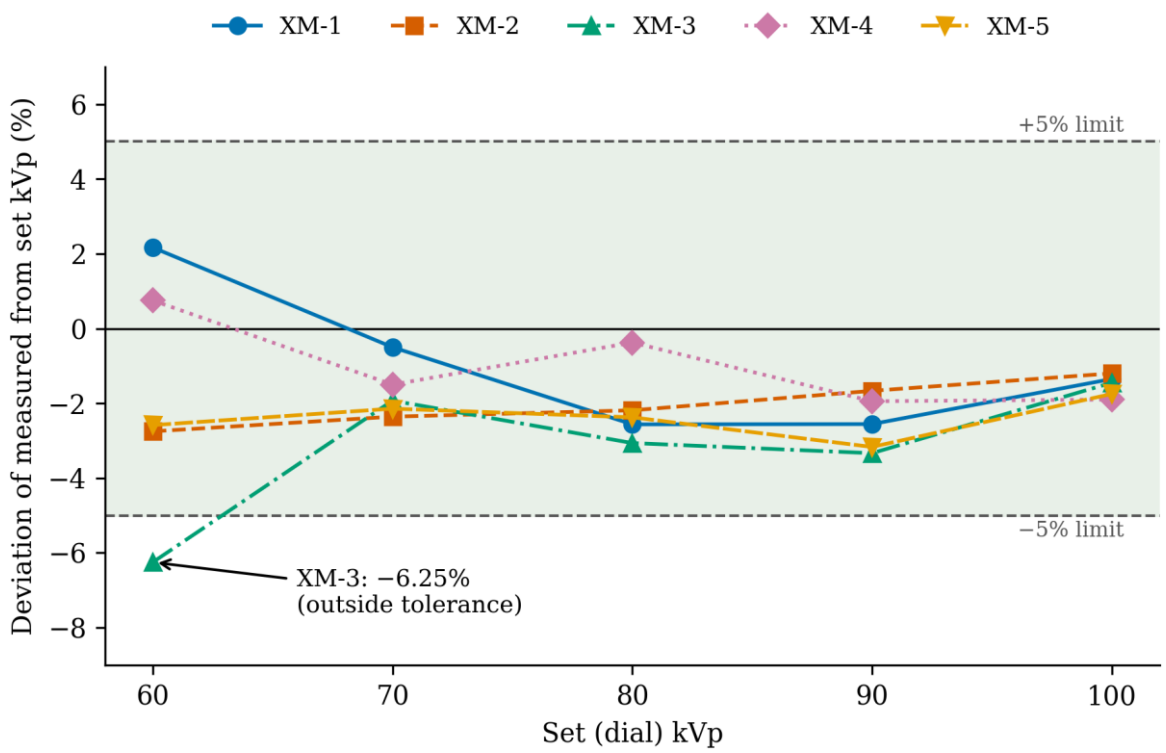
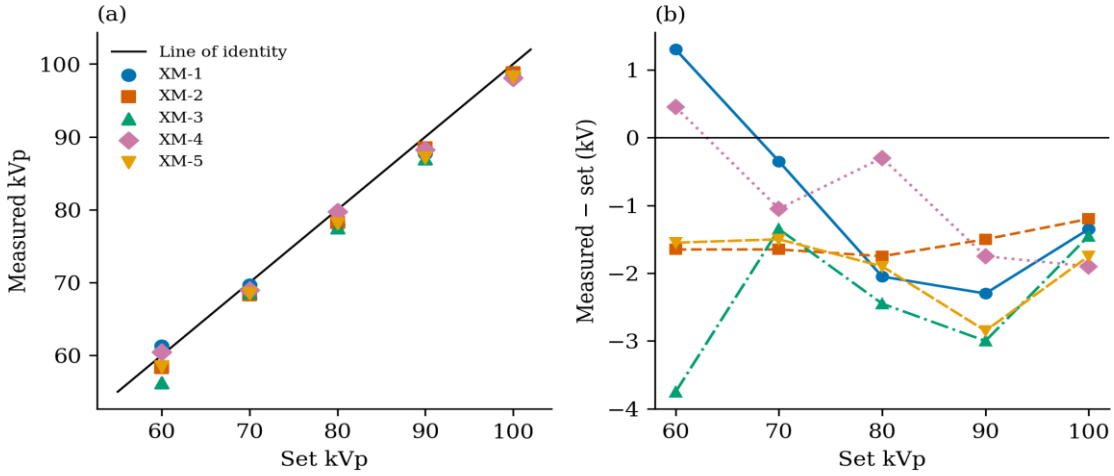


Figure 2. (a) Measured against set kVp for the five units, with the line of identity. (b) Difference between measured and set kVp (kV) at each setting



.kVp reproducibility

The repeated measurements at 70 kVp across the five mAs stations (16–40 mAs) are given in Table 4 and Figure 3a. The coefficient of variation (CoV) was 0.35% for XM-1, 0.33% for XM-2, 1.21% for XM-3, 0.09% for XM-4 and 0.05% for XM-5, all below the acceptance limit of +5% (Figure 3b). XM-3 showed the greatest spread, with readings from 67.30 to 69.55 kVp (range 2.25 kV, SD 0.83 kV), whereas XM-4 and XM-5 varied by 0.15 kV and 0.10 kV, respectively. High reproducibility did not imply agreement with the set value. The mean measured value at the set 70 kVp was below 70 kVp in all five units (mean deviation −1.36% for XM-1, −2.49% for XM-2, −2.34% for XM-3, −0.16% for XM-4 and −2.57% for XM-5). XM-5, the most reproducible unit, had a mean of 68.20 kVp and was consistently about 1.8 kV below the set value. No individual reading deviated from 70 kVp by more than ±5%; the largest deviation was 3.86% (XM-3 at 16 mAs). The readings at the nominal setting of 70 kVp and 20 mAs in Table 2 and in Table 4 differed by 0.15 to 0.95 kV between the two tests (largest in XM-4). These two sets of readings were taken in the same session

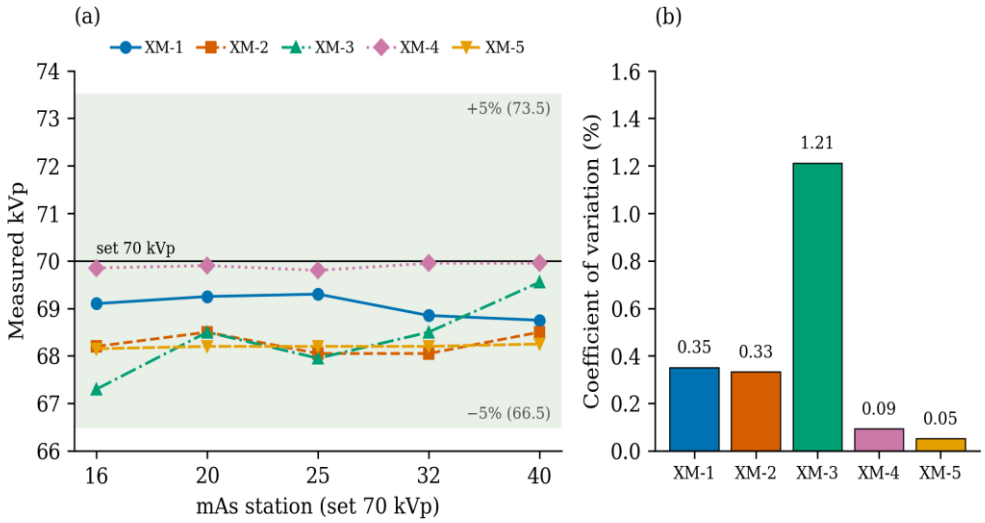


Figure 3. (a) Measured kVp at a set 70 kVp across the five mAs stations. The shaded band shows ±5% of the set value. (b) Coefficient of variation of the five readings for each unit.

Table 4. Measured kVp at a set 70 kVp across five mAs stations, with mean, standard deviation (SD, n − 1), coefficient of variation (CoV), range and the largest deviation of any reading from 70 kVp.

mAs station	XM-1	XM-2	XM-3	XM-4	XM-5
16	69.10	68.20	67.30	69.85	68.15
20	69.25	68.50	68.50	69.90	68.20
25	69.30	68.05	67.95	69.80	68.20
32	68.85	68.05	68.50	69.95	68.20
40	68.75	68.50	69.55	69.95	68.25
Mean	69.05	68.26	68.36	69.89	68.20
SD	0.242	0.227	0.829	0.065	0.035
CoV (%)	0.35	0.33	1.21	0.09	0.05
Range (kV)	0.55	0.45	2.25	0.15	0.10
Max |dev. from 70 kVp| (%)	1.79	2.79	3.86	0.29	2.64

Overall compliance

Four of the five units (XM-1, XM-2, XM-4 and XM-5) met both the accuracy and the reproducibility criteria at every tested setting (Table 5). XM-3 met the reproducibility criterion but did not meet the accuracy criterion at 60 kVp, and was therefore classed as non-compliant overall and was referred for recalibration

Table 5. Compliance of each X-ray unit with the accuracy and reproducibility criteria.

Unit	Accuracy (±5% at every setting)	Reproducibility (CoV ≤ [±)	Overall
XM-1	Pass	Pass	Pass
XM-2	Pass	Pass	Pass
XM-3	Fail (60 kVp: −6.25%)	Pass	Fail
XM-4	Pass	Pass	Pass
XM-5	Pass	Pass	Pass

Discussion

This study assessed the kVp accuracy and reproducibility of five X-ray units in five NNRA-authorized hospitals in Abuja. Four units met the tolerance at every tested setting. One of 25 measurements (4%) was outside it: XM-3 read 6.25% (3.75 kV) below the set value at 60 kVp (Table 2, Figure 1). Reproducibility was good in all units, with coefficients of variation of 0.05–1.21% (Table 4).

The proportion of failures was lower than in most earlier reports (Table 6). In Nigeria, 25% of kVp accuracy results in Lagos [10] and 30% of units in Jos North [9] exceeded ±5%, and a Zaria study, as reported in [10], found that 67% of results failed. A national survey in Tanzania found that 59% of the

units tested failed the kVp test [17]. Our findings are closer to those from Palestine, where 11 of 12 units passed accuracy testing [19], and from the Lindi and Mtwara regions of Tanzania, where all units passed [18]. One explanation is that all five facilities held NNRA authorisation and were visited routinely by a QC service provider, but we did not test this. The facilities were also selected from that provider's client list, which may favour better-maintained equipment, so the results should not be taken to represent all facilities in Abuja.

Measured kVp was below the set value in 23 of 25 measurements (mean deviation −1.92%), and XM-2, XM-3 and XM-5 under-read at every setting. This consistent offset points to a calibration problem rather than random error, and XM-5 shows that excellent reproducibility does not guarantee accuracy. We did not investigate the cause. Other studies in Nigeria have proposed line-voltage variation and faults in the kVp selection circuitry as causes of kVp errors [10]. The error pattern also differed from Yola, where errors were larger at higher settings [12]; here the largest deviation was at the lowest setting. Machine age has been associated with failure in several studies [9,10,13,19], but it did not predict performance here: the oldest unit (1995) was compliant and the newest (2020) had the single failure. With five units, no conclusion on age can be drawn.

Tube voltage influences both image contrast and patient dose [21], so systematic under-reading means the delivered exposure differs from the selected technique. The mean errors here (1.29–3.20%) are small, but the 6.25% deviation in XM-3 at 60 kVp exceeds the IAEA tolerance and warrants recalibration. We did not measure the effect on image quality or repeat rates. Because the Lagos authors linked poor kVp accuracy to a lack of checks after repairs [10], kVp should be retested after any repair or tube replacement, and compliance judged at each setting rather than on the mean error.

This study has limitations. The sample was small and purposive, measurements were made at a single visit with one meter whose uncertainty was not reported, and the reproducibility test varied mAs rather than repeating identical exposures. Only kVp was examined, not timer accuracy, mAs linearity, output or half-value layer. Comparison with other studies is limited by differences in sample size, kVp range, instruments, tolerances and how failures were counted. Larger studies with random selection across Abuja, including facilities without regulatory oversight, and repeated measurements over time are needed to establish how well these findings generalise.

Conclusion

Four of the five X-ray units tested in NNRA-authorized hospitals in Abuja met the kVp accuracy and reproducibility criteria at every tested setting. One unit (XM-3) under-read by 6.25% at 60 kVp and needs recalibration and retesting. Measured kVp was generally slightly below the set value (mean −1.92%), and reproducibility was good in all units. In this small, purposive sample, performance was better than reported in most earlier Nigerian studies, though we did not test the role of regulatory oversight. Routine per-setting kVp testing, including after repairs, should continue, and larger studies that include unregulated facilities are needed.

Table 6. Comparison of the present findings with published kVp accuracy and reproducibility studies.

Study	Setting and sample	Instrument; kVp settings; tolerance	kVp accuracy	kVp reproducibility	Machine age and other findings
Nigerian studies					
Godfrey et al., 2015 [11]	Zaria, Kaduna State; 5 hospitals	60–100 kVp	67% of accuracy tests failed the ±5% limit; largest error 51.5% (as summarised in [10])	Reproducibility fell outside the ±10% limit at Hospital B (20.5% at 60 kVp, 12.9% at 70 kVp) and Hospital D (10.4% at 80 kVp), which the authors attributed to fluctuating generator voltage.	Some machines were described as "over-aged," though no ages were given, and none of the five hospitals fully complied with NNRA guidelines. Some rooms were below the 16 m² minimum, lacked lead lining or a protective cubicle, and kVp accuracy exceeded ±5% at Hospitals A and B, causing over- and underexposure.
Akpochafor et al., 2016 [10]	Lagos; 10 units, one per centre	Unfors ThinX RAD; 50–120 kVp at 20 mAs; 100 cm FID; ±5%	10 of 40 results (25%) outside ±5%. Units D3 and D10 failed at every setting (errors up to 17.5%); D4 and D9 failed at one setting each	Not assessed	Mean error not significantly related to age ($P = 0.770$). The two units failing at every setting were 10–11 years old, but two units under 5 years also failed at one setting.
Akpochafor et al., 2018 [9]	Jos North, Plateau State; 23 units	Unfors Thinx RAD; SID 100 cm; fixed tube current; ±5%	16 of 23 units (69.6%) passed; 7 (30.4%) failed	15 of 23 units (65.2%) passed; 8 (34.8%) failed	Machine age is significantly related to accuracy and reproducibility ($P < 0.05$). Accuracy and reproducibility were not correlated ($P = 0.916$).
Ike-Ogbonna et al., 2020 [16]	Jos; 6 units (2 government, 2 mission, 2 private)	Gammex 330 digital kV meter; ±5%	Four units (G1, G2, M2, P1) had errors of 2.30–3.14%	Not assessed	Every facility failed at least one of the four QC tests performed (kVp accuracy, field congruence, beam alignment, filtration).
Odoh et al., 2022 [12]	Yola, North-East; 3 tertiary hospitals	RMI 245 kV meter	High percentage errors at the higher exposure settings in all machines, requiring kVp calibration	kVp reproducibility was within the ±5% tolerance for M-1 (2.28%) and M-3 (4.47%), but M-2 was deficient at 10.35% and needed urgent calibration.	The machines were 10–16 years old, but age did not predict performance. All three over-delivered kVp at higher settings, so all needed calibration.
Barau et al., 2025 [13]	North-East Nigeria; 10 tertiary hospitals	70–120 kVp, three exposures per setting; ±5%	Six units had error and CoV below 2%	Four units (2, 4, 6, 9) exceeded the 5% limit	Performance related to machine lifespan. The same four units also failed mAs linearity and beam alignment limits.

Studies from other countries					
Sungita et al., 2006 [17]	Tanzania (19 regions); 196 units in the survey	RMI handbook methods; three kVp settings, repeated three times	59% of the units tested failed the kVp test	kVp accuracy and reproducibility were assessed together, and 59% of the 120 units tested failed, with errors of 4–20 kVp.	Only 13% of units passed the preventive-maintenance test; 53% were defective and 34% out of order.
Ngoye et al., 2022 [18]	Lindi and Mtwara regions, Tanzania; QC records 2015–2021	Routine QC results compared with acceptance limits	All units passed	All units passed	Lack of a QC and maintenance plan was noted. Collimation was the main failing parameter.
Budeiri et al., 2022 [19]	Palestine (3 cities); 12 units	Radcal Accu-Pro; AAPM limits	11 of 12 units (91%) passed	All units passed	Weak but significant association with age (P = 0.008); none with daily workload (P = 0.238).
Mehrdad et al., 2015 (as cited in [10]) [20]	Lorestan, Iran; 7 hospitals	—	35% of results failed; the two oldest units (installed 1982 and 1990) had errors of 7.29–20.34%	—	Failures concentrated in the oldest machines.
This study					
Present study	Abuja; 5 units, one per NNRA-authorised hospital	Cobia Smart R/F; 60–100 kVp at 20 mAs; 100 cm FFD; ±5% IAEA limits	1 of 25 results (4%) outside ±5% (XM-3 at 60 kVp, −6.25%). Four of five units compliant at every setting; mean absolute errors 1.29–3.20%	CoV 0.05–1.21% across five mAs stations at 70 kVp; all units within the limit	Units manufactured 1995–2020; the oldest (XM-1, 1995) was compliant and the newest (XM-3, 2020) had the single failure. Age not analysed (n = 5).

Declarations

Funding. None.

Conflicts of interest. The authors declare no conflict of interest.

Data availability. The underlying measurement data are available upon request.

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References

1. Malone J. X-rays for medical imaging: radiation protection, governance and ethics over 125 years. Phys Med. 2020;79:47–64.
2. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann ICRP. 2007;37(2–4).
3. IAEA. Radiation Protection and Safety in Medical Uses of Ionizing Radiation. IAEA Safety Standards Series No. SSG-46. Vienna: IAEA; 2018.
4. Haddad L, Saleme H, Howarth N, Tack D. Reject analysis in digital radiography and computed tomography: a belgian imaging department case study. Journal of the Belgian Society of Radiology. 2023 Dec 22;107(1):100-100
5. Afwande S. Reject and repeat analysis in digital radiography in a Kenyan radiology department. Journal of Medical Imaging and Radiation Sciences. 2024 Oct 1;55(3):101688.
6. Atkinson S, Neep M, Starkey D. Reject rate analysis in digital radiography: an Australian emergency imaging department case study. J Med Radiat Sci. 2020;67(1):72–79.
7. ICRP. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann ICRP. 2017;46(1).
8. IAEA. Diagnostic Radiology Physics: A Handbook for Teachers and Students. Vienna: IAEA; 2014.
9. Akpochafor MO, Adeneye SO, Daniel AF, Omojola AD, Aweda AM. Evaluation of kilovoltage failure in conventional X-ray machines among selected X-ray centers in Jos North LGA, Plateau State, Nigeria. Niger Q J Hosp Med. 2018;27(2):768–775.
10. Akpochafor MO, Omojola AD, Soyebi KO, Adeneye SO, Aweda MA, Ajayi HB. Assessment of peak kilovoltage accuracy in ten selected X-ray centers in Lagos metropolis, South-Western Nigeria: a quality control test to determine energy output accuracy of an X-ray generator. J Health Res Rev. 2016;3(2):60–65. doi:10.4103/2394-2010.184231.
11. Godfrey LD, Adeyemo DJ, Sadiq U. Radiological kVp accuracy, reproducibility and consistence assessment of some hospitals in Zaria environs of Kaduna State, Nigeria. Arch Appl Sci Res. 2015;7:27–31.
12. Odoh EO, Umaru A, Isa S, Muhammad I. Assessment of kVp accuracy and reproducibility as radiation protection measures in tertiary hospitals in Yola, North-East Nigeria. Niger J Med Imaging Radiat Ther. 2022;11.
13. Barau NI, Mangset WE, Ijeoma I-OM, Mohammed YB. Evaluation of quality control standards in medical diagnostic X-ray facilities in North-Eastern Nigeria. Niger J Phys. 2025;34(1):110–117.
14. Nkuba LL, Nyanda PB. Compliance and quality control monitoring of diagnostic X-ray facilities in Dar es Salaam city, Tanzania. Braz J Radiat Sci. 2017;5(2).

15. Mammba HP, Khamis FO, Suleiman SA, Edmund ED, Salum SK, Makoba A. Quality control monitoring of medical diagnostic X-ray units in Southern Tanzania. Iran J Med Phys. 2023;20(1).

16. Ike-Ogbonna MI, Mangset WE, Ike EE. Comparison of Quality Control Parameters of Diagnostic X-ray Machines in government, Mission and Private Owned Facilities in Jos, Nigeria. Open Journal of Medical Research (ISSN: 2734-2093). 2020 Apr 8;1(1):20-7.

17. Sungita YY, Mdoe SSL, Msaki P. Diagnostic X-ray facilities as per quality control performances in Tanzania. J Appl Clin Med Phys. 2006;7(4):66–73.

18. Ngoye WM, Balobegwa V, Kileo AA, Edmund E, Khamis FO, Mammba PH. Evaluation of diagnostic x-ray equipment performance in lindi and mtwara regions-Tanzania. Brazilian Journal of Radiation Sciences. 2022 Jun 13;10(2).

19. Hjouj M, Budeiri D, Rajabi A, Abu Khalaf S, Jghama D. Assessment of peak voltage accuracy and reproducibility of conventional X-radiography units in Palestine. InProceedings of the 2022 5th International Conference on Digital Medicine and Image Processing 2022 Nov 10 (pp. 50-57).

20. Gholami M, Nemati F, Karami V. The evaluation of conventional X-ray exposure parameters including tube voltage and exposure time in private and governmental hospitals of Lorestan Province, Iran.Iranian Journal of Medical Physics. 2015, 89-95

21. Brindhaban A, Al Khalifah K, Al Wathiqi G, Al Ostath H. Effect of x-ray tube potential on image quality and patient dose for lumbar spine computed radiography examinations. Australasian Physics & Engineering Sciences in Medicine. 2005 Dec;28(4):216-22.