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Abstract

Radiographic imaging is central to modern medicine, providing essential diagnostic information that guides patient management. This study aimed to evaluate x-ray tube output in three diagnostic facilities in Jos, Plateau State, Nigeria, using a calibrated radiation dose meter, the Unfors Mult-O-Meter 710L. Tube output was measured along the central beam axis at a reference distance of 100 cm. Normalization was performed at 80 kVp and 10 mAs. The Unfors Mult-O-Meter 710L recorded air kerma in microgray (µGy) and milligray (mGy), from which tube output values in mGy/mAs were computed. Three clinical x-ray systems were assessed: Siemens Poly Mobile Plus (M1), Philips MCD-105 (M2), and EcoRay Ultra 200 Plus (M3). Measured air kerma values at the reference setup were 492 µGy (M1), 521 µGy (M2), and 469 µGy (M3), corresponding to tube outputs of 0.0492, 0.0521, and 0.0469 mGy/mAs, respectively. Facility M2 recorded the highest tube output, while M3 recorded the lowest. The findings revealed an approximate 11% variation in tube output across the three facilities. These differences are attributable to factors such as machine age, filtration, generator type, and calibration status. Reliable measurement of tube output is critical for patient dose estimation, establishment of diagnostic reference levels (DRLs), and optimisation of radiological practice in Nigeria.

Keywords: Tube output, Unfors Mult-O-Meter 710L, diagnostic radiology, air kerma, radiation safety, Jos

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Introduction

Radiographic examinations are among the most frequently used diagnostic tools in modern healthcare, playing an indispensable role in the detection, treatment, and monitoring of diseases. From chest imaging for pulmonary disorders to abdominal and skeletal radiographs for trauma and pathology, x-ray procedures save countless lives every year by enabling rapid and non-invasive medical assessment. The World Health Organisation (WHO, 2020) reports that medical imaging contributes significantly to healthcare delivery, particularly in developing countries where other advanced modalities such as magnetic resonance imaging (MRI) and computed tomography (CT) may not be readily accessible.

However, alongside these benefits comes the unavoidable challenge of radiation exposure. Unlike ultrasound or MRI, radiography involves ionising radiation, which has the potential to induce harmful biological effects if doses are excessive or improperly managed. The International Atomic Energy Agency (IAEA, 2021) emphasises that unnecessary or unoptimised x-ray exposures may increase lifetime cancer risks, particularly when cumulative exposures are considered. Thus, while radiography is essential, it must be carried out with careful attention to radiation protection principles, especially the ALARA principle (As Low as Reasonably Achievable).

Radiation Safety and Tube Output: One of the cornerstones of radiation safety in diagnostic radiology is the accurate evaluation of x-ray tube output, which is defined as the radiation dose delivered per unit tube current-time product (mAs) at a specified distance from the focal spot. Tube output reflects the performance of an x-ray system and directly influences the entrance skin dose (ESD) received by patients. In practice, tube output data are used in several ways to:

1. Estimate patient doses during radiographic procedures.
2. Compare performance of different machines.
3. Establish diagnostic reference levels (DRLs) that guide dose optimisation.
4. Monitor equipment functionality over time as part of quality assurance.

When reliable tube output data are unavailable, models such as those proposed by Faulkner, Davies, and Edmond are sometimes used to estimate patient doses indirectly. However, direct measurement using a calibrated dosimeter such as the Unfors Mult-O-Meter 710L is considered the gold standard because it provides machine-specific and site-specific data (Alex *et al.,* 2024).

In Nigeria, as in many low-resource settings, diagnostic radiology has expanded rapidly to meet growing healthcare needs. In Jos, Plateau State, radiographic examinations are increasingly common in both government and private facilities. Yet, there is limited published data on whether patient exposures remain within internationally recommended safety limits. Previous studies across Africa (e.g., Sidi *et al.,* 2022; Akinlade *et al.,* 2021) have shown that many facilities lack effective dose monitoring tools, calibration equipment, and comprehensive quality assurance programmes. Consequently, patients may unknowingly receive doses above the Diagnostic Reference Levels (ICRP, 2017). By evaluating tube output in selected facilities in Jos, this study seeks to generate baseline data that can inform future dose optimisation efforts, support the establishment of local DRLs, and improve overall patient safety.

Statement of the Problem

Accurate evaluation of patient radiation dose in diagnostic radiology begins with knowledge of the x-ray tube output, which is the radiation dose delivered per unit mAs at a fixed distance and kVp. Tube output is fundamental for estimating patient entrance skin dose (ESD), establishing diagnostic reference levels (DRLs), and ensuring compliance with international safety standards. However, in many medical centres in Jos, tube output is not routinely measured, and quality assurance programmes are limited. This creates uncertainty in patient dose assessments and makes it difficult to monitor trends or detect variations in equipment performance. Since factors such as machine age, generator type, and filtration can cause differences in output, the absence of reliable, facility-specific measurements means that patient exposures may not be optimised according to the ALARA principle. The lack of baseline tube output data for Jos therefore represents a critical gap that this study seeks to address.

Literature Review

Simo *et al.,* 2021, conducted research on the discovery of radiation output of three-phase X-ray machines based on mathematical models. This was done by proposing a mathematical model for estimating the tube output for three-phase x-ray machines. A total of three X-ray machines are used. The output of each x-ray machine was measured using a Diavolt. During measurements, three types of data were collected: the filtration, the fixed kV, and the charge (mAs). The x-ray tube output is estimated using a mathematical model derived from the survey data. When the estimated and measured outputs are compared, the difference between them is relatively small, typically falling below 6% and reaching a maximum of 14%. A dataset published by RadyAzzoz *et al.,* (2014 as cited in Abo-Madyan and El-Abyad 2020), was also used to test the model is also used to test the model, and the results indicate a small discrepancy (3% at 80 kV) between the measured and estimated values. Ultimately, the findings demonstrate that the model developed in this study outperformed the model developed by Kothan and Tungjai. In the event that dosimeters are unavailable, this model may serve as a substitute technique for calculating the output and, consequently, the radiation doses that patients receive during diagnostic x-ray exams.

Alex *et al.,* 2024, estimated the radiation output of an X-ray tube using a mathematical model: Case of high-frequency machines. The aim of this work was to develop a new mathematical model equation (NMME) for estimating the output of high-frequency X-ray tubes. In order to accomplish this, an initial model that does not account for the anode angle was constructed using data gathered from ten machines in various Cameroonian regions (for nine machines). The model was then tested on the tenth machine. A few simulations were run using the SpekCal program to assess the impact of the anode angle. This allowed the MME to be proposed. The output values obtained using the initial model were compared with the measured values to determine the deviation frequencies, which ranged from 0.65% to 19.61%. The statistical hypothesis test showed that the estimated values using the initial model and MME are in agreement with those measured, unlike the Kothan and Tungjai model. For the tenth machine, the percentage difference between estimated and measured values is less than 8 %. These findings demonstrate that the suggested model outperformed the earlier models. In the absence of a dosimeter, the NMME could be used to estimate the output of high-frequency X-ray machines and therefore the radiation doses received by patients during diagnostic X-ray examinations.

Simo *et al.,* 2021. Did comparison studies between different models Radiation dose from three-phase X-ray machines. By applying the Davies model to determine the entrance skin dose (ESD) of 731. Eight radiological procedures ,chest PA and LAT, lumbar spine AP and LAT, pelvis AP and LAT, skull PA and LAT and three-phase X-ray machines were considered. Based on the mathematical estimation of the radiation output of X-ray machines, a modified Davies model was proposed. The model was compared to others (Edmonds, Tung and Tsai) using their Mean Relative Errors (MRE) with respect to the reference Davies model and the Student's test of comparison of means. The 3rd quartile values were also compared to those found in Cameroon, Nigeria, Iran, France and the UK. The results showed that the MRE of the Edmonds model (55.0%) was significantly higher than the MRE of the Tung and Tsai model (7.1%), which was significantly lower than the MRE of the proposed model in this work (1.9%). Results also show that the 3rd quartile values were mostly higher than the reference level in the UK. Short Focus to Skin Distance (FSD) and high charge values are the causes of high dose values. In conclusion, the model put forth in this study is superior to the Davies model when a dosimeter is not present. An adjustment of technical parameters

Concept of Tube Output in Diagnostic Radiology

The concept of tube output is central to diagnostic radiology because it provides the baseline for evaluating patient radiation exposure. Tube output is defined as the air kerma per unit mAs measured at a fixed distance (usually 1 meter) along the central axis of the x-ray beam (Bushong, 2021). It is usually expressed in milligray per milliampere-second (mGy/mAs). Tube output serves as a key parameter in determining patient doses, equipment performance, and compliance with radiation safety standards.

The air kerma measured represents the kinetic energy released per unit mass of air by ionising radiation, and by normalising it to the mAs, it is possible to compare different machines under similar conditions. For instance, an older x-ray tube may exhibit lower output than a newer machine due to factors such as reduced tube efficiency, ageing components, or differences in inherent and added filtration (Zanganeh and Sharafi, 2021). Thus, measuring tube output is not only a technical requirement but also a radiation protection measure, as it directly influences patient entrance skin dose (ESD). High or inconsistent tube outputs may result in unnecessarily high patient doses, whereas low tube outputs can compromise image quality, potentially leading to repeat examinations and cumulative exposure (IAEA, 2021).

Methods of Measuring Tube Output

Tube output can be determined through direct measurement or mathematical modelling.

Direct Measurement:

i. This involves using calibrated radiation dose meters such as ionisation chambers, semiconductor detectors, or multipurpose devices like the Unfors Mult-O-Meter 710L.
ii. According to Martin and Sutton (2015), direct measurement remains the gold standard because it provides real-time, machine-specific, and accurate data.
iii. The IAEA (2021) recommends that tube output be routinely measured during quality assurance programs to monitor consistency in machine performance.

Materials and Methods

Study Design

This study was designed as a cross-sectional experimental evaluation of x-ray tube output across three diagnostic radiology facilities in Jos, Plateau State, Nigeria. The focus was to measure and compare tube output values under standardised conditions using a calibrated radiation dose meter. The choice of a cross-sectional design was appropriate because it allowed the assessment of tube output at a single point in time, providing a snapshot of equipment performance across facilities. This design has been commonly adopted in radiation protection studies aimed at establishing baseline values for diagnostic reference levels (Hart *et al.,* 2012). The three machines were relatively new, having been installed between 2020 and 2021, yet variations in tube output were expected due to differences in generator type, inherent filtration, and clinical usage patterns.

Instrument and setup

A calibrated Unfors Mult-O-Meter 710L was used to measure radiation output parameters. Measurements were taken at 100 cm from the focal spot along the central beam. Normalisation for output evaluation was set at 80 kVp and 10 mAs. The meter displayed air kerma in μGy and mGy, from which tube output (mGy/mAs) was calculated at the reference setup.

Data Collection Procedure

For each machine:

1. The x-ray tube was warmed up to avoid fluctuations associated with cold starts.
2. Three repeated exposures were made at 80 kVp and 10 mAs.
3. The Unfors Mult-O-Meter recorded the air kerma (μGy) for each exposure.
4. The mean of the three readings was taken as the measured output at the reference condition.

This procedure was repeated across the three facilities (M1–M3).

Calculation of Tube Output

Tube output was computed using the following relationship:

$$Tube\ Output\ (mGy/mAs) = \frac{Air\ Kerma\ (mGy)\ at\ 100\ cm}{mAs}$$

Where:

- Air Kerma is the dose measured by the Unfors Mult-O-Meter (converted from μGy to mGy).
- mAs is the product of tube current (mA) and exposure time (s).

Results and Discussion

The results of the tube output measurements obtained at the reference setup (100 cm, 80 kVp, 10 mAs) are presented in Table 2. The evaluation of tube output across the three diagnostic facilities in Jos provides important insight into the performance of the x-ray units and their compliance with radiation safety standards. As presented in Table 2, the tube output values obtained at 80 kVp and 10 mAs ranged from 0.0469 mGy/mAs in Facility M3 to 0.0521 mGy/mAs in Facility M2, with Facility M1 recording an intermediate value of 0.0492 mGy/mAs. The variation between the highest and lowest outputs was about 11%, which, although relatively small, is significant for patient dose estimation and highlights the natural differences that occur between machines in different facilities. Figure 1 further illustrates these variations, showing Facility M2 with the highest output, followed by M1, while M3 consistently produced the lowest output.

When compared with internationally reported values, the tube outputs obtained in this study are well within acceptable ranges. According to Hart *et al.,* (2012) and *Simi et al.,* (2020), the typical tube output for general radiography at 80 kVp lies between 0.045 mGy/mAs and 0.055 mGy/mAs. The values obtained in Jos, ranging from 0.0469 to 0.0521 mGy/mAs, are consistent with this international benchmark. This demonstrates that the x-ray units under evaluation are functioning adequately and that, from the perspective of tube output, patients are unlikely to be at risk of receiving unnecessarily high radiation doses.

The differences observed across facilities can be explained by factors such as generator efficiency, tube age, and filtration. For instance, Facility M3 had the lowest tube output, which may be due to its higher total filtration (3.2 mm Al), a factor that improves beam quality but reduces the measured output. On the other hand, the slightly higher tube output recorded in Facility M2 could be attributed to differences in generator calibration or the relative age of the machine. These findings highlight the importance of routine equipment performance evaluation, since variations in tube output, even within the acceptable range, directly influence entrance skin dose and overall patient safety.

The results of this study are consistent with findings from related works. Alex *et al.,* (2024) demonstrated that tube output varies across machines, proposing a mathematical model that can be applied when dosimeters are unavailable. Similarly, Simo *et al.* (2021) confirmed that measured and modelled tube outputs for three-phase machines showed close agreement, with differences of less than 6%. In Nigeria, Adamu *et al.* (2021) also integrated tube output into dose estimation at the University of Maiduguri Teaching Hospital, further underscoring the importance of this parameter in dose monitoring and optimisation. These studies collectively support the present findings by showing that tube output is both variable and crucial for accurate dose estimation.

Overall, the tube outputs measured in Jos facilities not only align with international safety guidelines but also provide valuable baseline data for the region. This is important for the future development of local Diagnostic Reference Levels (DRLs), which remain lacking in many parts of Nigeria. By establishing routine tube output monitoring using reliable instruments such as the Unfors Mult-O-Meter 710L, facilities can strengthen their quality assurance programmes, detect performance changes early, and optimise radiographic practice in accordance with the ALARA principle.

Summary of the Findings

1. Tube output across the three facilities ranged from 0.0469 to 0.0521 mGy/mAs, an 11% variation, yet all values fell within international safety limits (0.045–0.055 mGy/mAs).
2. Differences in output were linked to machine characteristics such as filtration, generator efficiency, calibration, and tube age.
3. The results provide baseline data for Jos, highlighting the need for routine tube output monitoring with tools like the Unfors Mult-O-Meter 710L to support DRL development and dose optimisation under the ALARA principle.
4. These values are within international ranges (0.045–0.055 mGy/mAs as reported by Hart *et al.,* 2012; Simo *et al.,* 2021), showing the machines are functioning adequately.

Conclusion and Recommendations

This study has shown that the tube outputs of the three diagnostic facilities in Jos ranged from 0.0469 to 0.0521 mGy/mAs, with an 11% variation across machines. These values fall within internationally accepted ranges, indicating that the units are functioning adequately. The observed differences are attributable to machine-specific factors such as filtration, calibration, generator efficiency, and tube age. Establishing routine tube output measurements using calibrated devices like the Unfors Mult-O-Meter 710L is therefore essential for quality assurance, accurate dose estimation, and the eventual development of local Diagnostic Reference Levels (DRLs). By maintaining this practice, radiological centres in Jos can strengthen patient safety.

Based on the findings of this study, the following recommendations were made.

I. Annual Quality Control (QC) tests should include systematic tube output evaluation for all x-ray machines, and checks should be repeated after major repairs or servicing.

II. Tube output measurements using calibrated devices such as the Unfors Mult-O-Meter 710L should be routinely conducted in facilities across Jos to provide baseline data for patient dose estimation and machine performance monitoring.

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Figures

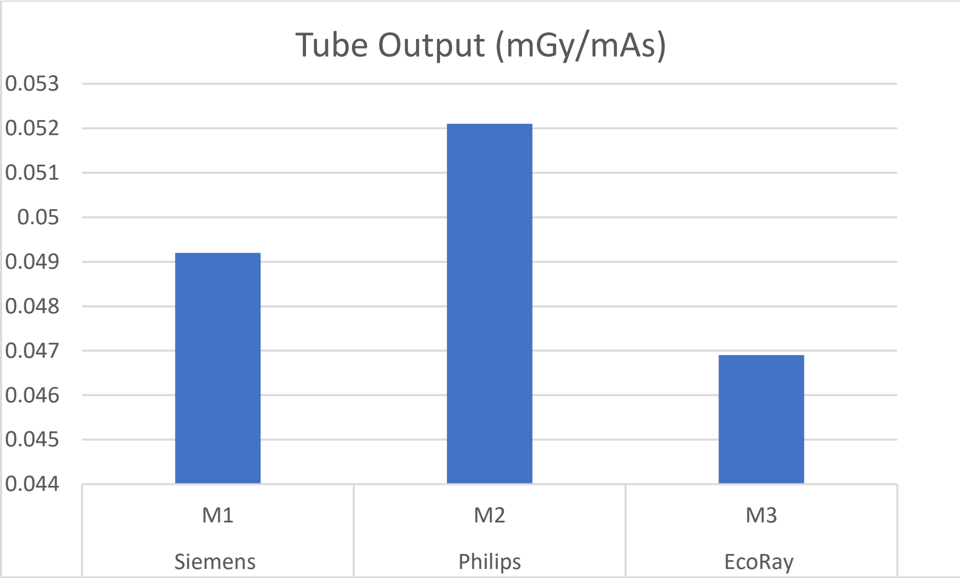

Figure 1: Bar chart showing tube output (mGy/mAs) of the three x-ray units

Table 1: Machine name and specifications at the study facility

Equipment/Device Name	Siemens	Philips	Ecoray
FACILITY CODE	M1	M2	M3
MODEL	POLY MOBILE PLUS	PHILIPS MCD-105	ULTRA 200 PLUS
SERIAL NUMBER	(240)05605022	30301	8B0139
TUBE TYPE	X22/13XI01	E7180	TOSHIBA E-7846
COMPANY	SIEMENS HEALTHCARE GERMANY	PHILIPS MADE IN JAPAN	ECORAY CO. LTD. KOREA
YEAR OF MANUFACTURE	FEBRUARY 2021	2020-09	SEPTEMBER 2019
YEAR OF INSTALLATION	OCTOBER 2021	2021	JULY 2020
MAXIMUM kVp	125	105	125
MAXIMUM mAs	160	100	206
INHERENT FILTERATION	1.1 mmAl	1.3 mmAl	0.8 mmAl
ADDED FILTERATION	1.6 mmAl	1.4 mmAl	2.4 mmAl
TOTAL FILTERATION	2.7 mmAl	2.7 mmAl	3.2 mmAl

Table 2: Machine name, code name, exposure parameters and corresponding machine tube output.

Machine name	Code name	KVp	MAs	Dose (µGy)	Dose (mGy)	Tube Output (mGy/mAs)
Siemens	M1	81	10	492	0.492	0.0492
Philips	M2	80	10	521	0.521	0.0521
EcoRay	M3	80	10	469	0.469	0.0469