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Quality Control Monitoring of Medical Diagnostic X-Ray Units in Southern Tanzania

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ABSTRACT

Introduction: The study focused on the assessment of quality control tests in X-ray units from the southern regions of Tanzania to yield the data required to create and implement quality control policies and strategies.
Material and Methods: Quality control tests were conducted on twenty-six diagnostic X-ray units in private and government hospitals in the southern regions of Tanzania during 2020 – 2021. The tests focused on the reproducibility of accelerating tube potential, time reproducibility, the accuracy of accelerating tube potential, half-value layer, beam alignment, and collimation. The statistical analyses were done using the Microsoft Excel spreadsheet of 2013. The results were compared with the tolerance limits.
Results: Of all X-ray units evaluated, 92.31% had kVp accuracy within the tolerance limit of 5% and 92% of the X-ray units had acceptable HVL values ≥ 2.3 mm Al at 80 kVp. Moreover, results have shown that 86.96% and 82.61% of X-ray units had acceptable beam collimation (≤ ±2 cm) and beam alignment (≤3% of the X-ray source and X-ray table), respectively.
Conclusion: Comprehensive regulatory inspections and equipment maintenance plans in southern Tanzania are significantly required due to the high patient workload which attributes to frequent breakdowns of X-ray units. Moreover, radiographers need to be trained on how to minimize and detect beam misalignment and collimation failure since the most unacceptable results were observed from these tests.

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Introduction

Globally, the use of ionizing radiation in diagnostic imaging has significantly increased over the past few decades [1]. Despite its clinical advantage, this modality is one of the main sources of man-made radiation exposure to the world population. Prolonged exposure to ionizing radiation due to diagnostic imaging has been known to cause various health effects including acute radiation injury and risk of cancer [2]. Various studies have shown that the problem of prolonged radiation exposure to patients is primarily caused by inadequate quality control (QC) programs, a lack of preventive maintenance, and non-adherence to radiological protection principles during practices [3-5]. Failure to provide an accurate QC program and maintenance to the X-ray machines may also affect the image quality and therefore minimize the amount of diagnostic information obtained from the X-ray image [3, 6-9]. These challenges of significant radiation exposure to the patients and poor image quality can be early detected and prevented by frequently performing the QC programs or at least once a year. All diagnostic X-ray machines need to be justified and optimized to avoid unnecessary occupational or patient radiation exposure. The primary goals of QC programs are to obtain high image quality and reduce radiation exposure to patients and workers [6, 10-13]. Based on the International Commission on Radiological Protection (ICRP) recommendations [14-16], various countries including Tanzania have been introducing QC programs for their radiological facilities to maintain image quality and minimize patient radiation exposure. The QC program is achieved by performing routine testing and maintenance on the X-ray units to verify the optimal status of imaging systems and high image quality while minimizing radiation exposure to patients and radiographers. Currently, the QC program in Tanzania is routinely conducted in all X-ray units as required by the Tanzania Atomic Energy Act number 7 of 2003 and its associated regulations [17]. However, the efficiency of conducting QC programs routine-wise for medical facilities in the southern part of Tanzania with high patient loads is still unknown.

The regions of Mtwara, Lindi, and Ruvuma in the southern part of Tanzania have an insufficient number

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of medical facilities which provide diagnostic X-ray services. Most of these facilities have a significantly high patient load who needs various X-ray examinations. Moreover, some of these X-ray units are old and have a high risk of failures, breakdowns, and safety problems for both patients and radiographers. Therefore, the need to perform frequent QC tests of X-ray units is highly required to overcome the stated problems which are mainly caused by the ionizing radiation in the course of diagnosis. Although previous studies have reported non-compliance with X-ray machines, limited information is available regarding some factors affecting the QC of X-ray machines. Recently, no studies have reported the QC status of diagnostic X-ray units in the southern part of Tanzania. This study aimed to assess the QC in diagnostic X-ray units in the southern regions of Tanzania over the period 2020-2021. The QC tests were based on basic safety standards and the use of international tolerance limits established by the National Council on Radiation Protection and Measurement Report No. 99 [18] and the American Association of Physicists in Medicine (AAPM) Report No. 31 [19].

Materials and Methods

In the present study, quality control measurements on twenty-six diagnostic X-ray machines were conducted in Mtwara, Lindi, and Ruvuma regions during 2020 – 2021. The names of the hospitals were coded in the alphabet for anonymity. The quality control measurements were focused on the reproducibility of accelerating tube potential and time reproducibility which were tested on twenty-six X-ray units, the accuracy of accelerating tube potential which was tested on twenty-six X-ray units, half-value layer (HVL) which was tested on twenty-three X-ray units, beam alignment and, collimation which were tested on twenty-three X-ray units. The measurements of accelerating tube potential and time reproducibility, the accuracy of accelerating tube potential, and HVL were done by using Unfors non–invasive X-ray test instruments comprising of χi classic with serial number 231096 coupled to a detector with serial number 233989. The Unfors test instrument is made in Sweden by a company called Raysafe. Beam alignment and collimation measurements were done using RMI beam alignment and collimator test tools manufactured by Radiation Measurements inc from the United States of America.
All statistical analyses were done using the Microsoft Excel spreadsheet software program of 2013. The detailed explanations of each test are given independently below.

Quality control tests in selected X-ray units

Reproducibility of output kVp and time

The X-ray machine can produce the same radiation exposure even though in short intervals [9, 20]. The assessment of kVp ensures that the delivered kVp is close to that set on the equipment by the operator. In this test, the detector of the Unfors was placed on the X-ray table. The X-ray tube was positioned perpendicular to the Unfors detector at a distance of 100 cm from the Unfors detector and the optical field was collimated at the Unfors case. In the control console, the electric current and time exposure parameters were selected and remained fixed during all exposures. The selected exposure parameters were 80 kVp and 10 mAs. The exposure was allowed and measurements of kVp and time in milliseconds (ms) were obtained and recorded from the Unfors reader. This particular, test was repeated three times to ascertain reproducibility. The coefficient of variation (CV) was then obtained from the recorded readings using Equation 1 [21-23].

$$CV = {}^{\sigma}/_{\bar{x}} = \frac{1}{\bar{x}}\left[\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}\right]^{1/2} \quad (1)$$

Where; σ is the standard deviation of a series of measurement results, $\bar{x}$ is the mean value, x_i is ith exposure measurement and n is the number of exposure measurements. The coefficient of variation of any three consecutive irradiation measurements should be no greater than 0.05, and each of the kVp and time (ms) measurements variation should be within 5% of the mean value of the three measurements [7, 9, 20, 22, 24].

kVp Accuracy

The penetrating power of the X-ray beam is determined by the appropriate kVp during X-ray production. kVp accuracy test is the one used to measure the precision of peak electric potential across the X-ray tube [20, 24]. In this test, kVp accuracy measurements were done by using Unfors test instruments where the Unfors detector was placed on the X-ray table. Then the X-ray tube was positioned perpendicular to the Unfors detector at a distance of 100 cm from the Unfors detector and the optical field was collimated at the Unfors detector case. The Unfors detector wire was connected to its Unfors reader at cubical control. The exposures were made in six different kVp which ranged from 50 kVp to 100 kVp. Moreover, all exposures were done with fixed 10 mAs and the results of output kVp were recorded for each reading. The kVp tube accuracy was calculated using Equation (2) [20, 21, 23].

$$kVp\ accuracy = \left(\frac{v_m - v_s}{v_s}\right) x\ 100\% \quad (2)$$

Where; v_m is a measured value of accelerating tube potential in kV, v_s is the set value of accelerating potential in kV. The percentage value of kVp tube accuracy should be less than ±10% for a medical X-ray machine to pass [24].

Half-value layer (HVL)

Half-value layer is the thickness of a medium that will minimize the intensity of the X-ray beam to half of its original value [11].

Table 1. The minimum half-value layer requirement for the X-ray machine

Measured accelerating tube potential (kVp)	30	40	50	51	60	70	71	80	90	100
Minimum HVL (mm of Al)	0.3	0.4	0.5	1.2	1.3	1.5	2.1	2.3	2.5	2.7

For this test, the Unfors detector in its case was placed on the X-ray table and the X-ray tube was directed perpendicular to the Unfors detector at a distance of 100 cm from the surface of the Unfors detector and the optical field was collimated at the Unfors detector case. At the control panel of the X-ray machine, the setting of exposure parameters was performed by selecting 10 mAs and 80 kVp as recommended by other literature [8, 20, 22, 25]. Then, the first exposure was done without an aluminium attenuator and the result of the dose in µGy was obtained in the Unfors reader and recorded. In the second exposure, a 0.5 mm thick of aluminium plate was placed at the top of the detector without distortion of the Unfors detector position on the X-ray table then the exposure was made with other parameters remaining unchanged and the dose result was recorded. In the third exposure, a 0.5 mm thick of aluminium plate was replaced by an aluminium plate of 1 mm thick then the exposure was made with other parameters remaining unchanged and the dose result was recorded. This procedure was repeated in the fourth exposure whereby a 2 mm thick of aluminium plate was used as an absorber and in the fifth exposure, a 3 mm thick of aluminium plate was used. The HVL values were calculated using Equation 3 in the following manner as reported earlier [11, 12].

$$I/I_o = 1/2 = e^{-\mu t}$$
$$In(1/2) = -0.693 = \mu t_{1/2}$$
$$HVL = t_{1/2} = \frac{0.693}{\mu} \qquad (3)$$

Where; HVL is the half-value layer in mm of Al and μ is the linear attenuation coefficient per mm.

Moreover, the linear attenuation coefficient (µ) of aluminium for corresponding accelerating tube potential was obtained by the following Equation (4).

$$I/I_o = e^{-\mu ŧ}$$
$$\mu = -\frac{1}{ŧ} ln\left(I/I_o\right) \qquad (4)$$

Where; $ŧ$ is the thickness of the aluminium plate in mm, ln is the natural logarithm, I_o is X-ray intensity at zero absorber thickness in µGy, I is the X-ray energy (in µGy) transmitted through the aluminium plate at thickness ŧ. The mean value of HVL in mm of AL for each X-ray unit was calculated from HVL values obtained from each aluminium plate. As recommended by the ICRP report [26], the minimum allowable HVL values for a given accelerating tube potential are shown in Table 1.

Beam alignment and collimation

X-ray units provide means of aligning the X-rays with the patient and image receptor and confining the beam to only the region of interest in the patient. To measure the concurrence and perpendicularity of the X-ray beam, the accuracy of the beam limiting device and beam alignment measurements were done using RMI beam alignment and collimation test devices. Initially, the collimator test tool was located on the X-ray table and positioned parallel to the X-ray detector or bulky tray with a radiographic cassette to orient the dimension of the cassette or detector. The X-ray tube was directed perpendicular to the collimator test tool at a 100 cm focal film distance. The optical field of the X-ray machine was collimated at the rectangular frame of the collimator test device. Without the distortion of the setup position of the collimator test tool at the X-ray table, the beam alignment test tool was then placed at the centre of the collimator test device as shown in Figure 1. Depending on the power rating of the X-ray machine, the exposure parameters ranged from 50 to 70 kVp with 10 mAs were used to obtain a quality image as shown in Figure 2.

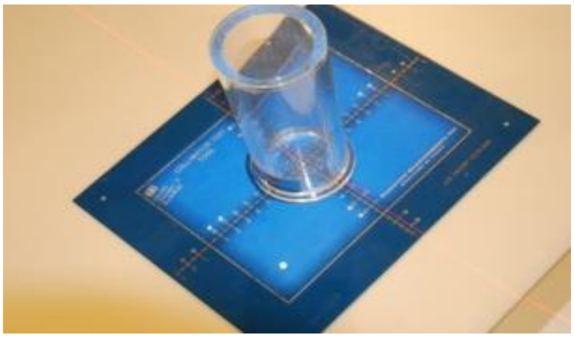

Figure 1. Beam alignment and collimator test tools positioned and collimated at the X-ray table

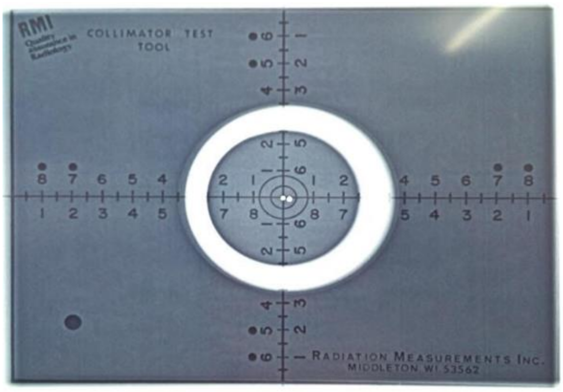

Figure 2. Typical radiograph from which beam limitation system is determined

Beam alignment was evaluated by measuring the distance between the centres of the two lead spots, and then obtaining the angle of X-ray beam misalignment using Equation 5 [27].

$$\theta = \tan^{-1}\left[\frac{dl}{h(h+l+y)}\right] \quad (5)$$

Where; h is the height of the alignment test tool in cm, l is the distance from the focal spot to the top of the beam alignment test device in cm, d is the distance between two lead spots in cm and y is the distance from the table surface to cassette or detector in cm.

From Figure 2, if the radiographic image of one lead ball is at the centre and the second ball intercepts the first cycle of the collimator test tool, then the beam is about 1.5° away from the perpendicular, if the image of one lead ball is at the centre while the other one intercept with the second cycle of collimator test tool, the misalignment is 3°. According to NCRP report number 99 of 1988, the X-ray beam misalignment should not exceed 3° [6, 18, 24].

Moreover, good collimation is considered if the X-ray beam in the radiographic image falls within the frame of the marked rectangle in the collimator test tool. For instance, if the radiographic image shows the X-ray beam falls within the first mark in the rectangular frame of the collimator test tool, ± 1 cm on either side of the rectangular frame of the collimator test tool, the X-ray beam and the optical field are misaligned by 1% of the distance between X-ray table and X-ray tube [7]. According to AAPM report number 74 of 2002, the maximum allowable collimator misalignment is ±2% of the image to source distance [24, 28].

Results

Reproducibility of output kVp and time

The calculated values of *CV* for studied X-ray machines are presented in Table 2. As can be seen from Table 2, *CV* values ranged from 0.0011 to 0.04 and 0 to 0.0276 for accelerating tube potential and time, respectively. The average values for accelerating tube potential and time were found to be 0.0064 $\pm 2.26x10^{-6}$ and $0.0047 \pm 3.31x10^{-4}$, respectively. The observed variation from this compliance test is also evident in the reproducibility values presented in Figure 3.

kVp Accuracy

Table 3 illustrates the kVp accuracy of medical diagnostic X-ray machines from the Mtwara, Lindi and Ruvuma regions. The results showed that 24 (92.31%) of the X-ray units had an acceptable tolerance limit of ±10% [24], and the remaining 2 (7.69%) X-ray units off limit. The off limit could be attributed to the line voltage supply (electric faults) and the age of the X-ray machines.

Table 2. The kVp and time reproducibility, kVp accuracy, HVL, collimation and beam alignment of medical diagnostic X-ray machines from Mtwara, Lindi and Ruvuma regions, Tanzania

X-ray Unit	Manf. Year	Reproducibility		HVL in mm Al			Collimation	Beam alignment
		kVp (%)	Time (%)	Min.	Max.	Avg.		
A	2019	0.0400	0.0030	3.14	3.79	3.56	Pass	Pass
B	2020	0.0011	0.0013	2.15	2.19	2.18	-	-
C	2020	0.0034	0.0060	2.49	2.89	2.61	Pass	Pass
D	1999	0.0059	0.0000	3.19	3.52	2.53	Pass	Pass
E	2020	0.0020	0.0010	2.32	2.82	2.53	Out of Limit	Pass
F	2020	0.0020	0.0000	2.5	3	2.69	Out of Limit	Out of Limit
G	1991	0.0060	0.0040	2.62	3.21	2.97	Pass	Pass
H	2020	0.0150	0.0090	2.3	2.5	2.4	Pass	Pass
I	1999	0.0020	0.0000	2.79	3.4	3.02	Pass	Pass
J	2014	0.0020	0.0020	2.68	2.82	2.74	Pass	Out of Limit
K	1999	0.0030	0.0010	2.98	3.55	3.09	Pass	Pass
L	2020	0.0030	0.0010	2.68	2.81	2.79	Pass	Pass
M	2006	0.0030	0.0000	3.12	3.34	3.25	Pass	Out of Limit
N	2009	0.0020	0.0000	2.9	3.36	3.12	Pass	Pass
O	2020	0.0150	0.0090	2.5	2.99	2.69	Pass	Pass
P	2019	0.0020	0.0010	2.89	3.21	3.2	Pass	Pass
Q	2000	0.0070	0.0058	2.62	3.99	3.09	Pass	Pass
R	2020	0.0011	0.0043	2.63	3.03	3.21	Pass	Pass
S	2020	0.0274	0.0109	3.2	3.83	3.65	Pass	Pass
T	2019	0.0041	0.0080	2.46	7.3	4.08	Pass	Pass
U	-	0.0057	0.0208	2.19	4.79	2.94	-	-
V	2018	0.0029	0.0276	1.72	2.41	1.95	Out of Limit	Out of Limit
W	2013	0.0040	0.0020	3	3.31	3.21	Pass	Pass
X	-	0.0024	0.0018	2.82	4.72	3.45	-	-
Y	2020	0.0018	0.0031	2.46	2.96	2.65	Pass	Pass
Z	2018	0.0023	0.0000	-	-	-	Pass	Pass

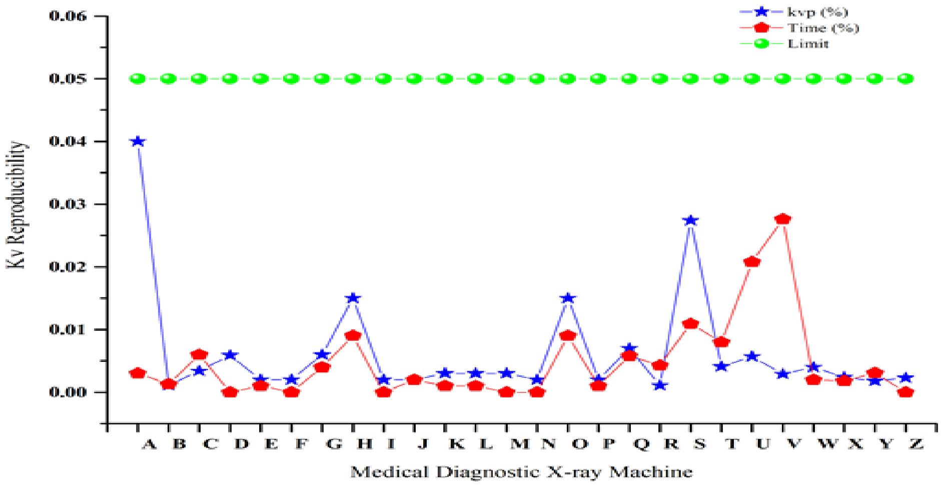

Figure 3. A plot of reproducibility against medical diagnostic X-ray machines from Mtwara, Lindi, and Ruvuma regions, Tanzania

Table 3. The percentage value of kVp accuracy of medical diagnostic X-ray machines from Mtwara, Lindi, and Ruvuma regions, Tanzania

X-ray machines	Accuracy of Accelerating Tube Potential						Status
	50 kVp	60 kVp	70 kVp	80 kVp	90 kVp	100 kVp	
A	-1.54	-7.9	-4.46	-5.3	-4.4	-	Pass
B	-4.14	-3.76	-2.19	-1.48	-0.67	-0.72	Pass
C	-0.92	-0.32	-0.01	-0.5	-0.32	-0.03	Pass
D	0.14	-0.02	0.9	1.7	0.87	2	Pass
E	-5.92	-0.73	-2.61	-4.43	-0.53	-2.12	Pass
F	0.38	-0.03	0.07	0.28	-0.62	-0.06	Pass
G	-1.82	0.15	-0.47	2.55	2.23	-	Pass
H	0.8	1.1	0.29	1.44	-0.24	1.2	Pass
I	2.69	-1.68	-0.89	-1.58	-1.58	8.4	Pass
J	-0.8	-5.07	-6.6	-7.46	4.91	3.69	Pass
K	7.1	0.28	1.36	2.33	1.28	-0.03	Pass
L	-1.96	-0.83	-0.63	0.16	-0.21	0	Pass
M	4.12	-1.23	-0.94	-0.63	-0.43	-0.22	Pass
N	4.26	-2.23	-2.08	-2.21	0.33	1.9	Pass
O	0.8	1.1	0.29	1.44	-0.24	1.2	Pass
P	0.8	1.17	0.29	1.5	-0.22	1.2	Pass
Q	-0.4	-6.83	-1.57	0.25	0.02	1.1	Pass
R	-0.31	-0.37	-0.92	-0.26	-0.08	-0.76	Pass
S	-0.9	-0.18	-0.26	-0.15	-0.88	-0.7	Pass
T	-0.2	0	0	1.75	1.78	-0.04	Pass
U	-10.32	-9.72	-10.27	-5.88	-6.64	-10.23	Off Limit
V	-0.98	-2.63	-2.61	-4.11	-10.44	-10.01	Off Limit
W	-5	-0.17	-2.71	-2.25	-2.11	-	Pass
X	1.21	1.45	-1.01	-1.47	-1.68	-3.21	Pass
Y	-0.6	-1.5	-0.28	0.375	-0.44	1.62	Pass
Z	1.32	1.02	0.06	0.01	1.21	1.97	Pass

Half-value layer (HVL)

The calculated minimum, maximum and average HVL values of the studied X-ray machines are shown in Table 2. The results revealed that the calculated mean value of HVL at 80 kVp ranged from 1.95 (equipment manufactured in 2018) to 4.08 mm Al (equipment manufactured in 2019). As can be seen from Figure 4, 92% of the X-ray units have adequate beam filtration (mean HVL values) greater than recommended minimum HVL value of 2.3 mm Al [29].

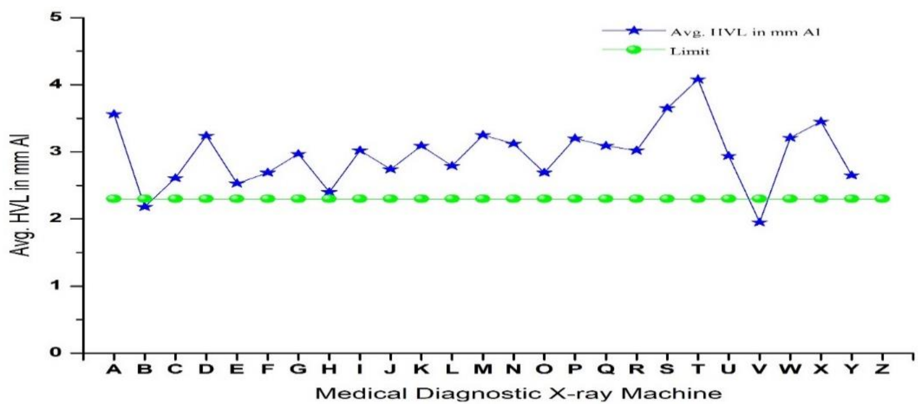

Figure 4. A plot of HVL measured at 80 kVp against medical diagnostic X-ray machines from Mtwara, Lindi, and Ruvuma regions, Tanzania

Beam alignment and collimation

The QC test results of beam alignment and collimation of the studied X-ray machines are shown in Table 2. The results revealed that 86.96% of X-ray machines had acceptable collimation within the maximum allowable limit of ±2 cm [24]. On the other hand, beam alignment test results showed that 82.61% of X-ray machines had acceptable alignment within the maximum allowable limit of 3^o [24].

Discussion

Reproducibility of output kVp and time

Appropriate reduction of radiation exposure to patients while optimizing image quality in diagnostic X-ray machines requires an adequate QC program including reproducibility tests of output kVp and time [1]. In the current study, all obtained reproducibility values of output kVp and time are within the tolerance limit of 5% [24]. This significant success may be caused by the widespread use of automatic voltage control systems in most of the studied X-ray machines. The challenge of using direct power from the mainline has been observed to cause significant variation in output kVp [22, 30].

Country-wise, a similar study conducted in 2006 by Sungita [7] showed that 59% of the units failed the output kVp reproducibility whereby most of the studied X-ray units were found to be more than 20 years old. When comparing these results with the current study, it showed that there is a significant improvement of 59% within 15 years. This noticeable improvement could be attributed to the fact that 48% of the X-ray unit in the current study were new, manufactured in 2020 and installed in 2021. Another study conducted in Nigeria by Akpochafor et al [31] showed that 34.78% of the studied X-ray units failed in kVp reproducibility by most of the failed X-ray units in this test were aged between 10 to 27 years. The results from this literature significantly agreed that the aged machine negatively affects kVp reproducibility. Thus, competent authorities should strategically plan to address the replacement of old X-ray machines or provide stringent preventive maintenance to those aged units.

kVp Accuracy

The results from the current study have shown that 92.31% of the studied X-ray machines were within the recommended criterion limit of ±10% at all selected kilovolt peaks from 50 to 110 kVp. According to medical personnel from the centres with X-ray units which failed kVp accuracy, declared to have no regular maintenance to their unit. Thus, the failure of kVp accuracy in these units could be attributed to a lack of preventive maintenance and frequent breakdown without calibration of kVp and mAs after repair. The continued use of X-ray units without maintenance and repair seems to be a common problem in most developing countries [4-7, 9, 20, 28]. Moreover, the study conducted by Resuli et al [23] revealed that two-thirds of X-ray units with single-phase generators did not have acceptable results for the kVp accuracy test, which can be due to high ripple voltage.

In 2020, a similar study conducted in Zanzibar by Suleiman [20] showed that 85.71% of X-ray units in Zanzibar, Tanzania had kVp accuracy within the recommended criterion limit. This slight difference of 6.6% could be caused by the presence large number of new X-ray units available in the Mtwara, Lindi, and Ruvuma regions. Moreover, another study conducted in Dar es Salaam city in 2017 by Nkuba and Nyanda [9] showed that 95% of the units studied had an acceptable deviation between normal and measured accelerating tube potential. This is the highest acceptable value compared to the current study and the study conducted in Zanzibar [20]. Noticeable reasons for such significant achievement in Dar es Salaam city is attributed to the fact that most reliable companies and experts who provide services to X-ray units are in Dar es Salaam city, most of the centres are well equipped themselves with modern and reliable equipment and can be easily accessed to win a competition, and well monitoring by the national regulatory body (TAEC). Moreover, Dar es Salaam city has the highest value of registered X-ray units in the Country. This achievement significantly lowers the patient’s workload and breakdown sequence [9].

Half-value layer (HVL)

The appropriate filtration of the X-ray beam removes low-energy photons unnecessary for the formation of the diagnostic image of interest. Consequently, the X-ray beam's filtration improves image quality while also lowering the patient's radiation dose [32, 33]. The effect of adding filtration to an X-ray beam often results in an increase in the beam's mean photon energy and HVL [29]. Because of this relationship, X-ray beam quality may be evaluated using a technique called HVL measurement [12, 34]. AAPM report No 74 recommended that the measurement of HVL should be done at least annually and whenever the X-ray tube or collimator is replaced or serviced [24].

The statistical values of HVL as presented in Table 2 show that 7.69% of the X-ray units have beam filtration less than the criterion minimum value of 2.3 mm Al [26]. The current findings of HVL values were less satisfactory than the HVL results obtained from Zanzibar which was reported by Suleiman et al [20]. In 2015, a study conducted in Iran by Rasuli et al [23] shows that 73.3% of the units had acceptable HVL values. This study revealed that X-ray units with more than ten years in operation had some problems with the HVL test which may be due to frequent repairs and displacement of filters. Centres are recommended to measure HVL at least yearly or after major maintenance of X-ray tube or housing, and should also use sufficient filtration to deliver quality diagnostic images with minimum radiation exposure to the patient [24].

Beam alignment and collimation

Misalignment distorts the image and may result in the deletion of information critical to the diagnosis of the patient's condition [6, 24]. Furthermore, extending the X-ray beam beyond the anatomical region of interest increases radiation exposure to the patient while decreasing image quality by introducing excessive scatter into the image [7, 35].

As presented in Table 2, 86.96% of X-ray units had acceptable collimation within the maximum allowable limit of $\pm 2\ cm$ [24]. The remaining 13.04% of the units fall outside the limits and are therefore characterized by increasing radiation exposure to non-targeted areas while minimizing the X-ray image quality. On the other hand, beam alignment test results showed that 17.39% of X-ray units had alignment out of the maximum allowable limit of 3^{o} [24]. Misalignment could be attributed to significant changes in the relative locations of the laser, light bulb, anode focal spot or reflecting mirror while collimation failure is caused by collimator system failure [6].

The collimation and beam alignment results in the current study are similar to that of a previous study conducted at Zanzibar by Suleiman [20] where 85.71% and 78.57% of the units had acceptable beam collimation and beam alignment. This implies that most of the collimation and beam alignment challenges face by X-ray machines in the regions from the southern zone of Tanzania might be similar to that of Zanzibar. Furthermore, another study conducted in Dar es Salaam, Tanzania by Nkuba and Nyanda [9] in 2017 showed that 93% of the studied units had acceptable beam alignment while 96.6% of the studied units had acceptable beam collimation. This shows that the compliance status in beam alignment and collimation at Dar es Salaam is significantly high compared to that of the current study and that of Zanzibar. Stringent strategies are required to increase compliance status for units in rural areas.

Furthermore, the study conducted by Rasuli et al [23] in Iran in 2015 showed that 60% of X-ray units had unacceptable performance in beam alignment tests which is significantly related to the high patient workload. This literature suggested that collimator field size should be adjusted for the patient since in some cases, patients may accidentally collide with the collimator assembly while sitting on the X-ray table.

To assess the impact of the age of X-ray units, the manufacturing dates of most studied X-ray machines were found to range from 1999 to 2020. However, the studied X-ray units that were out of the tolerance limit were manufactured between 2014 and 2020. Most of these failed machines were not given proper care by the operators.

The main limitation of the current study is only three regions of the southern zone of Tanzania were involved in the study. To perform a comprehensive study in the southern zone of Tanzania based on this subject, future studies should include Iringa, Njombe, and Mbeya regions. Moreover, the kVp and time reproducibility tests were only performed in this study at 80 kVp and 10 mAs while the HVL test was conducted at 80 kVp only due to time limitations. Therefore, further study is required to test kVp and time reproducibility and HVL in various input kVp.

Conclusion

The results presented here confirm that the majority of X-ray units evaluated in this study were within an acceptable tolerance limit; while a few of them with unacceptable tolerance levels require maintenance of beam collimation and alignment. These challenges can be mitigated by implementing comprehensive regulatory inspections and training practitioners on minimizing beam alignment and collimation failure. A comparison of the current study with literature from Tanzania has shown that the southern regions and Zanzibar face more compliance challenges than Dar es Salaam city. The challenge could lead to significant radiological health effects on a large population simply because the southern regions and Zanzibar have few X-ray machines with a high workload. Therefore, the results of the current study highlight the need to conduct regular QC tests together with maintenance services. The Tanzania Atomic Energy Commission, as a regulatory authority that controls all uses of ionizing radiation in the country, is required to modify its strategies and policies that will result in the effective and sufficient implementation of QC programs in rural and urban areas.

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