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Quality Control Assessment of Diagnostic X-Ray Units in Zanzibar, Tanzania

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SAS, SKS and EK proposed the concept, performed data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing - original draft, writing - review and editing. All authors read and approved the final manuscript.

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ABSTRACT

Regular execution of quality control (QC) tests in medical diagnostic X-ray units is primarily important to provide high-quality images and proper diagnoses with least hazard. The performance criteria in diagnostic radiology in Zanzibar Islands, Tanzania were followed in accordance with the QC guidelines, and the values of the measured parameters were compared with the tolerance limits. The study was designed to perform QC tests on the diagnostic X-ray units in governmental and private hospitals. In this study six QC tests (beam alignment, beam collimation, kV reproducibility, half-value layer (HVL), mAs linearity and kV accuracy) were carried out by using beam alignment tool and Unfors non-invasive X-ray test device (Xi R/F&MAM detector). The measured parameters were conducted in two periods, from 2017 to 2018 (14 X-ray units were considered) and from 2019 to 2020 (16 X-ray units were considered). In both periods, the QC test results indicated that 100% of the X-ray units had acceptable HVL≥ 2.3 mm Al at 80 kVp. In the first period (2017−2018), the QC results showed that 78.57% and 85.71% had acceptable beam alignment (≤3% of the focus to image distance) and beam collimation (≤ ± 2 cm). Of the X-ray units

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evaluated, 85.71% had tolerable kV reproducibility of 5%, and 71.43% had mAs linearity within the tolerance limit of 10%, whereas 85.71% had acceptable kV accuracy within the tolerance limit of 5%. In the second period (2019−2020), the tolerance limits of X-ray units exceeded by 8.04% for kV reproducibility, 8.04% for kV accuracy, 16.07% for mAs linearity, 8.93% for beam alignment and 8.04% for beam collimation. The exceeded tolerance limits could be attributed to the new X-ray units which have full support of service agreements signed during the second period and increase of the compliances with the Tanzania Atomic Energy Act. No 7 of 2003 and its regulations. Results obtained highlight the need to regularly carry out comprehensive QC tests together with routine equipment maintenance.

Keywords: Diagnostic X-ray unit; quality control; image quality; diagnostic image.

1. INTRODUCTION

The use of medical X-ray equipment for diagnostic purpose began soon after the discovery of X-rays in 1895. Since then, many patients benefited from the X-ray services; however, the larger contribution to the man-made radiation exposure originates from diagnostic medical exposure and has been reported to continuously grow [1-3]. The 2010 report of the United Nations Scientific Committee on the effects of Atomic Radiation showed that diagnostic radiology contributes 20% to the global level of the total annual per caput effective dose [4]. In the study of Zontar et al. [5], the total collective effective dose to the population from radiological procedures in 2011 was reported to be approximately 1300 mSv in Solvenia. Visweswaran et al. [6] found that the annual caput dose increased from 0.35 mSv to 0.62 mSv by the worldwide usage of diagnostic examinations. Therefore, the problem of radiation exposures from the radiation diagnostic equipment has been persisted for quite a while and was related with the neglect of radiological safety and protection consideration. Numerous studies showed that the diagnostic X-ray units were operated without a proper quality control (QC) programme [7-9]. Failure to appropriately perform a QC programme may result in a large contribution of patient’s absorb dose and affects the image quality which may not provide accurate diagnostic information.

The QC checks in medical X-ray units are important for ensuring precise diagnostic information at optimal radiation doses [8, 10, 11] in this manner making it conceivable to minimize the excessive effect of radiation dose to patients, public and workers. The ALARA principle must also be adhered to, which provides that radiation dose should be kept as low as reasonably achievable. The QC programme aims to have a high image quality with minimum radiation exposure to patients. This goal can be achieved by testing various technical parameters, such as half-value layer (HVL), beam collimation, beam alignment, reproducibility, kVp accuracy and mAs linearity. Many studies have reported their efforts related to QC assessment in medical X-ray units [12-15]. Although the reference studies have reported the QC tests of diagnostic X-ray units, sufficient information on the compliance and QC monitoring of medical X-ray units is insufficient in many countries, including Tanzania particularly in the Zanzibar Islands. No studies to date have been reported on the compliance and QC tests of medical X-ray units in Zanzibar. This work aimed to assess the QC in diagnostic X-ray units in Zanzibar Islands over two periods: 2017-2018 and 2019-2020. The assessment was based on the basic safety standards and the use of international tolerance limits established by the American Association Physics Medicine Report No. 31 [16] and National Council on Radiation Protection and Measurement Report No. 99 [17].

2. MATERIALS AND METHODS

2.1 Technical Parameter in Diagnostic X-Ray Units

The evaluation of diagnostic X-ray units has been carried out by checking and examining the equipment’s performance wherein several technical and physical parameters were selected including the beam alignment, collimation, kVp reproducibility, kVp accuracy and linearity (Table 1). These parameters were checked with the Unfors non-invasive X-ray test device (Xi R/F&MAM detector with serial no. 223522). The total beam filtration was also found by using the HVL measurement method at 80kVp where different thicknesses of aluminium sheets are placed between the X-ray tube and the test detector. This test is essential because it shows how the low energy photons are removed from the primary beam.

Table 1. **Medical X-ray machine assessment criteria**

Parameter	Tolerance limits
Collimation	≤ ± 2 cm
Beam alignment	≤ 3% of focus to image distance FID
kV accuracy	± 5%
kV reproducibility	± 5%
mAs linearity	± 10%
Beam quality (HVL)	≥ 2.3 mm Al

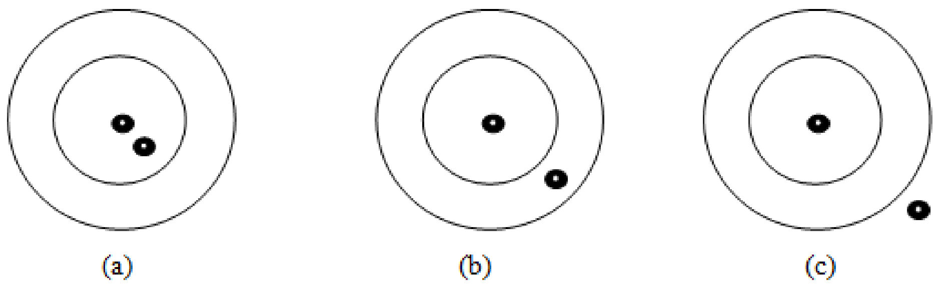

Fig. 1. Beam alignment (a) alignment <1.5°; (b) 1.5° <alignment <3°; (c) alignment <3°

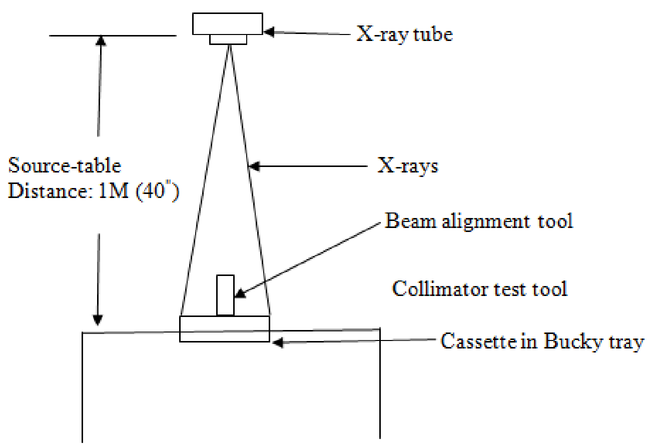

Fig. 2. Collimation/beam alignment setup

2.2 Beam Alignment and Collimation

The beam alignment and collimation tests were performed by using the beam alignment and collimator test tools, as previously described by [18] and [19]. The collimator test tool was placed above a radiographic film cassette, whilst the beam alignment test tool was kept at the centre of the collimator test tool. The X-ray tube was directed to the collimator test tool downward at a distance of 1 m from the focal spot, and the light field was collimated at the rectangular outline of the collimator test tool. The radiographs of the beam alignment and collimator test tools were performed on the 8 cm × 10 cm cassette with exposure parameters of 60 kVp and 10 mAs. The Fig. 1 shows the possible ways where beam alignment can occur. In this figure, if the X-ray beam alignment is less than 1.5° or in between 1.5° and 3°, then the alignment is within the acceptable limit. If the beam alignment is greater than 3°, then it is not in the acceptable limit.

Good collimation was assumed if the X-ray field falls just within the image of the rectangular frame in the test tools. For instance, if the edge of the X-ray field falls on the first spot (±1.0 cm on either side of the line), then the edges of the X-ray field were misaligned by 1%. The X-ray beam alignment was considered proper if the collimation test tool is perpendicular to the beam, and the image on the cassette must coincide with the field size of the collimation test tool (Fig. 2).

2.3 Kilovoltage Reproducibility

Reproducibility is verified to find out how constant the output is when an X-ray exposure is repeated many times. The peak kilovoltage (kVp) reproducibility tests were conducted with the Unfors non-invasive X-ray test device (Xi R/F&MAM detector with serial no. 223522). In this compliance test, the timer and kVp output of an X-ray machine at a given clinical setting should be reproducible when all the other parameters are fixed. The perfect settings of the above-mentioned parameters provide optimal dose to the patients and course to a quality image. The coefficient of variation of kVp should be less than 2%. Meanwhile, the coefficient of variation of time and output should be less than 5%.

2.4 Kilovoltage Accuracy Test

In diagnostic radiology, kilovoltage (kV) is an important parameter of a diagnostic X-ray unit to consider when choosing the radiographic technique factors. This parameter is applied across an X-ray tube to determine the quantity and energies of an X-ray machine during an exposure. The strength and penetration power of the diagnostic X-ray units were found by using the kV settings. The kVp test provides a measurement of the peak electric potential across the X-ray tube during its operation [20, 21], and it is important in diagnostic imaging to control the optical density and contrast of the X-ray image and radiation dose to the patient. To evaluate the kVp accuracy, the average actual kV was measured with RaySafe Xi R/F&MAM detector with serial no. 223522 for six different dial kVp settings in the range between 50kVp and 100kVp at a recommended 10 mAs setting. The QC procedures require that the X-ray voltage variation is within ±4 kVp or ±5% of the normal value [19]. In this test, the kVp accuracy of the X-ray units was estimated as follows [9]:

$$kVp\ accuracy = \left|\frac{X_m - X_s}{X_s}\right| \times 100\% \qquad (1)$$

Where X_m denotes the measured value of *kVp* from the non-invasive meter and X_s is the value of the selected *kV* from the control panel of the diagnostic X-ray equipment. The results obtained were compared with the accuracy-test value of ±5% as recommended by the American Association of Physicists in Medicine [16, 22].

2.5 Linearity Test

Linearity concerning milliampere (mA) and exposure time in seconds (s) were carried out with Xi R/F&MAM detector. The detector was placed on the radiology bed along the beam central axis at 66 cm from the X-ray tube focus. At fixed kVp, the mAs was varied from 20 mAs to 320 mAs (five values at least), and the exposures in µGy were recorded. Then the linearity coefficient (LC) was calculated using the following equation [12]:

$$LC = \frac{|X_2 - X_1|}{|X_2 + X_1|} \leq 0.1 \qquad (2)$$

Where X_1 and X_2 are the doses per *mAs* for the first and second selected *mAs*, respectively.

3. RESULTS AND DISCUSSION

3.1 Brands of Diagnostic X-Ray Units

The current study focused on the QC tests of diagnostic X-ray units found in government and private hospitals in Zanzibar Islands from the (2017−2018 and 2019−2020) periods. Most diagnostic X-ray machines installed during these periods are Mindaray, Siemens and Philips (Table 2 and 3). The results from Table 2 indicated that 76.19% of the diagnostic X-ray machines are working, 14.29% are defective and 9.52% are out of order. The results in Table 3 showed that 73.68% of the X-units are working, 15.79% are defective and 10.52% are out of order.

3.2 Quality Control Test in the 2017−2018 Period

Table 4 illustrates the QC evaluations of the 14 working X-ray units for the 2017−2018 period. The results showed that 14 (73.69%) of the total X-ray units were tested for the beam alignment and collimation. In the beam alignment test, 78.57% of the 11 X-ray units tested are within acceptable limits (≤ 3%) of FID, whilst 3(21.43%) of the X-ray units failed to meet the criteria. The misalignment may be caused by shifts in the relative positions of the anode focal spot or light bulb [23]. In the beam collimation tests, 85.71% of the 12 X-ray units tested are within the acceptable limits (≤ ± 2 cm), whilst 2(14.29%) of the X-ray units fall outside the limits. The un-acceptable limit of beam collimation may reduce the diagnostic image quality and lead to non-targeted exposure [23].

The test on kV accuracy, kV reproducibility and mAs linearity of the X-rays units were performed in the 2017−2018 period. The QC results showed that 85.71% of the 12 X-ray units had acceptable deviation between the measured and the normal values of kV accuracy within the tolerance limit of ±5% [24], whilst 14.29% of the 2 X-ray units failed. In the kV reproducibility test, 12 (85.71%) of the X-ray units were within the acceptable limit of ±5% [24, 25], whilst 2 (14.29%) of the X-ray units were higher than the tolerance limit. In the mAs linearity test, 71.43% of the 10 X-ray units had acceptable tolerance limits of ±10% [26], and the remaining 4(28.57%) X-ray units failed.

The analysis of the entire results also showed that the number of satisfactory X-ray units has exceeded 81% of the total for the measurement of kV accuracy, kV reproducibility and beam collimation (Fig. 3). The number of unsatisfactory X-ray units did not exceed 15% of the total for most parameters, except for the measurements of mAs linearity (28.57%) and beam alignment (21.43%). This percentage may be attributed to the old X-ray units [18] or overuse of the machines in crowded hospitals. The issue of old machines has also been reported by various studies [27, 28]. In general, the average of the unsatisfactory parameters in the 2017−2018 period was 18.57%.

3.3 Quality Control Test in the 2019−2020 Period

The assessments of the performance of 16 X-ray units for the 2019−2020 period are shown in Table 5. In this period, the results showed substantial improvement (Fig. 3), and the overall average percentage of the unsatisfactory physical parameters diminished to 8.75%. The number of satisfactory X-ray units exceeded by 8.04% for kV reproducibility, 8.04% for kV accuracy, 16.07% for mAs linearity, 8.93% for beam alignment and 8.04% for beam collimation. In the kV reproducibility tests, 93.75% of the 15 X-ray units were within the acceptable limit of ±5% [24, 25], whilst the remaining unit (6.25%) failed. In terms of the kV accuracy, 15 (93.75%) of the X-ray units were within the tolerance limit of ±5% [24], and remaining unit (6.25%) failed. In the mAs linearity test, 87.50% of the 14 X-ray units had acceptable tolerance limits of ±10% [26], whilst 2 (12.5%) of the total X-ray units failed.

Table 2. Brands of diagnostic X-ray machines (2019−2020)

Brand	Number of machines	With defect	Out of order	Good working order
Mindray	4 (19.05%)	0	0	4
Philips	2 (9.52%)	0	0	2
Fujifilm	1 (4.76%)	0	0	1
Siemens	2 (9.52%)	0	0	2
No brand	12 (57.14%)	3	2	7
Total (%)	21 (100%)	3 (14.29%)	2 (9.52%)	16 (76.19%)

Table 3. Brands of diagnostic X-ray machines (2017−2018)

Brand	Number of machines	With defect	Out of order	Good working order
Mindray	3 (15.79%)	0	0	3
Philips	2 (10.53%)	0	0	2
Siemens	2 (10.53%)	0	0	2
No brand	12 (63.16%)	3	2	7
Total (%)	19 (100%)	3 (15.79%)	2 (10.53%)	14 (73.68%)

Table 4. QC assessment of the 14 X-ray units for the 2017−2018 period

Physical parameter	Total no. of units tested	No. of satisfactory units	No. of unsatisfactory units	No. of untested units
kV accuracy	14 (73.68%)	12 (85.71%)	2 (14.29%)	5 (26.32%)
kV reproducibility	14 (73.68%)	12 (85.71%)	2 (14.29%)	5 (26.32%)
mAs linearity	14 (73.68%)	10 (71.43%)	4(28.57%)	5 (26.32%)
Beam alignment	14 (73.68%)	11 (78.57%)	3 (21.43%)	5 (26.32%)
Beam collimation	14 (73.68%)	12 (85.71%)	2 (14.29%)	5 (26.32%)
HVL	14 (73.68%)	14 (100%)	0 (0%)	5 (26.32%)

Table 5. QC assessment of the 16 X-ray machines for the 2019−2020 period

Physical parameter	Total no. of units tested	No. of satisfactory units	No. of unsatisfactory units	No. of untested units
kV accuracy	16 (76.19%)	15 (93.75%)	1 (6.25%)	5 (23.8%)
kV reproducibility	16 (76.19%)	15 (93.75%)	1(6.25%)	5 (23.8%)
mAs linearity	16 (76.19%)	14 (87.50%)	2(12.5%)	5 (23.8%)
Beam alignment	16 (76.19%)	14 (87.50%)	2 (12.50%)	5 (23.8%)
Beam collimation	16 (76.19%)	15 (93.75%)	1 (6.25%)	5 (23.8%)
HVL	16 (76.19%)	16 (100%)	0 (0%)	5 (23.8%)

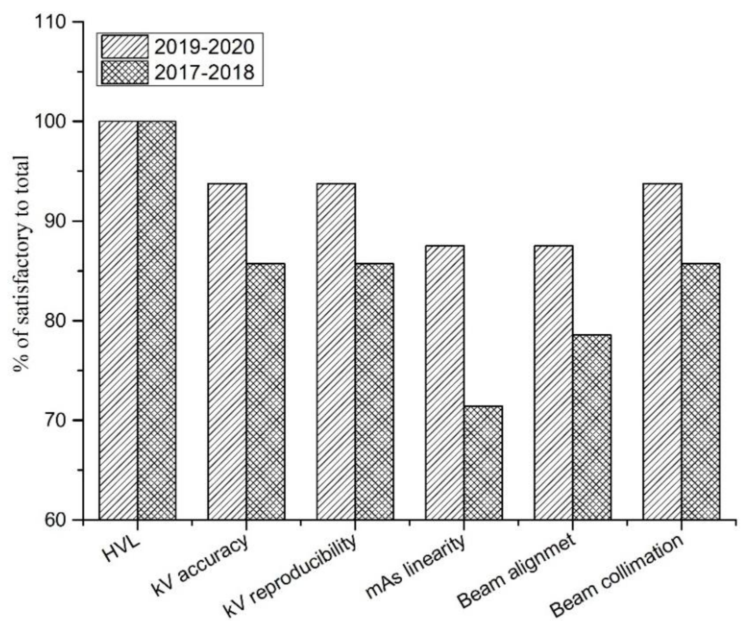

Fig. 3. Percentage of satisfactory units to total between periods 2017−2018 and 2019−2020

Table 6. Quality control performance for some X-ray units

Physical parameter	Percentage of unsatisfactory units		Difference	Improvement
	2017−2018	2019−2020		
kV accuracy	14.29	6.25	8.04	56.26
kV reproducibility	14.29	6.25	8.04	56.26
mAs linearity	28.57	12.5	16.07	56.25
Beam alignment	21.43	12.5	8.93	41.67
Beam collimation	14.29	6.25	8.04	56.26
Average	18.57	8.75	9.82	53.34

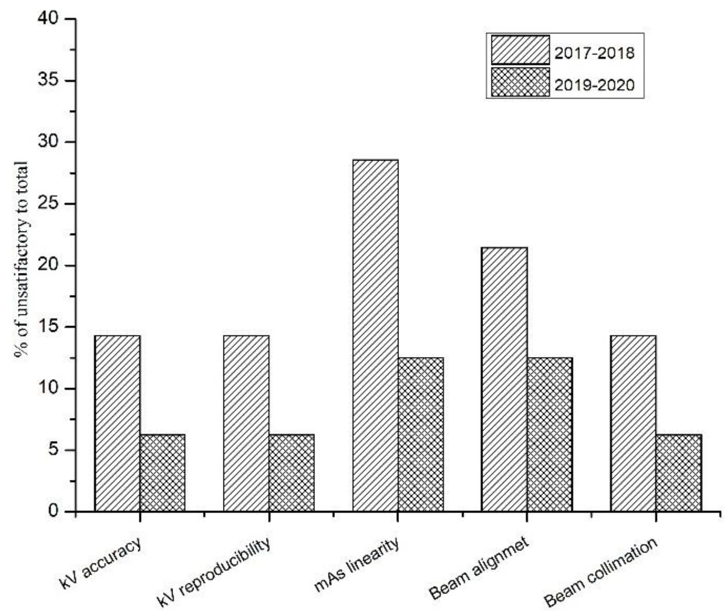

Fig. 4. Percentage of unsatisfactory units to total between periods 2017−2018 and 2019−2020

Table 6 and Fig. 4 demonstrate clear evidence that almost all parameters in the second period (2019−2020), including the beam alignment and collimation, have been improved in terms of the percentage of the number of unsatisfactory X-ray units to total. In all parameters, the maximum value (12%) of unsatisfactory X-ray units to the total was recorded in the second period. The average of the unsatisfactory physical parameters has improved from the first period (18.75%) to the second period (8.75%). These improvements might be attributed to the new X-ray units which have full support of service agreements signed during the second period and increase of the compliances with the Tanzania Atomic Energy Act. No 7 of 2003 and its regulations

4. CONCLUSION

Most diagnostic X-ray units assessed here have demonstrated an acceptable performance; however few of them needed recalibration for some parameters. In the first period (2017−2018), the analytical results on analysis showed that 81% of the 14 X-ray units were satisfactory when tested for QC tests, whilst 19% of the equipment were unsatisfactory. In the second period (2019−2020), the average of the satisfactory physical parameters has improved from the first period. These improvements might be attributed to new X-ray units which have full support of service agreements signed during the second period and increase of the compliances with the Tanzania Atomic Energy Act. No 7 of 2003 and its regulations. Therefore, the results in this article highlights the need to carry out comprehensive QC tests on a regular basis together with routine equipment maintenance. This work may lead to a substantial decline in the invariants from ordinary performance and faulty X-ray units.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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