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Evaluation of diagnostic x-ray equipment performance in lindi and mtwara regions - Tanzania

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ABSTRACT

The purpose of the study was to evaluate the quality control (QC) tests results of general radiography x-ray equipment in order to assess the performance of the x-ray equipment in comparison to the acceptance limits, hence advise on measures to provide quality diagnostic imaging at optimized dose. QC tests results from health facilities in Mtwara and Lindi regions were evaluated. The QC results from 2015 to 2021 were analyzed for selected QC parameters which included kV accuracy, kV reproducibility, mAs linearity, beam quality, collimation and beam alignment. All x-ray units passed kV accuracy, kV reproducibility, and beam quality and beam alignment tests. It was noticed that the collimation test surfaced among the failed parameters, though the performance of all the tested parameters were within 76.9 %. to 100% of the acceptable limits. Furthermore, lack of QC and maintenance plan was noted. Generally, the performance of most of the x-ray units were in compliance with regulatory requirements. However, improvement is desirable especially in the areas of QC plan, preventive maintenance and repair. Managers of the facilities need to take heed that optimum equipment performance is vital if quality imaging at optimized radiation dose is to be realized.

***Keywords:* x-ray equipment, Quality Control, Optimization, Quality Imaging**

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1. INTRODUCTION

X-ray imaging is very useful in detection and diagnosis of various diseases as well as patient management [1, 2]. Though it is an efficient diagnostic method, x-ray imaging constitutes a major part of human exposure to manmade radiation and hence radiation risk [3, 4]. However, if the optimization principle is observed, diagnostic images can be obtained at as low as practicably achievable radiation dose [4, 5]. This can be done by limiting the radiation exposure to the optimum required level to create the clinical images needed to answer the medical problem [6]. To achieve the optimization goal, the performance of each component of the imaging chain has to be within the acceptable limits. Failure of one component affects the final image quality because the components are interlinked [7].

According to Njikip et al. [5], implementation of routine monitoring and correction of the equipment through quality control (QC) program is necessary if the optimum performance is to be realized. Examining the equipment output, the radiological image and the process used to create it, and making the needed corrections, ensures optimum performance of the imaging equipment, as well as timely and accurate diagnosis [8]. A comprehensive QC program consists of daily, weekly, monthly and annual assessments and should cover all the components of the imaging chain [5, 7, 9, 10].

Maintenance and repair program are also an important part of the QC plan, as it ensures that necessary corrective measures are taken in response to the monitoring results [11]. This is asserted by the U.S.FDA [12] which defines QC techniques as “those techniques used in the testing and maintenance of the components of an x-ray system”. Sungita et al. [13] insist that the implementation of preventive maintenance and repair plan enables timely and cost-effective correction of equipment errors, therefore enabling uninterrupted service provision. Furthermore, the authors point out that maintenance and repair plan become more effective when conducted by the staff of the facility.

In Tanzania, the Atomic Energy Act No.7 of 2003 requires radiology facilities to implement the QC program on routine basis [14]. However, implementation of the QC program in the country is inadequate [10, 13, 15]. The QC tests are mostly carried out by Tanzania Atomic Energy Commission (TAEC) during regulatory inspections. Njikip et al. [5] reported similar situation from Cameroon, where the QC tests are only carried out by the regulator in the country. Nevertheless, the regulatory tests are for verification purposes only, hence, does not cover all components of the imaging system. Besides, the regulatory tests are conducted once in two or more years, while routine QC requires testing on daily, monthly and annual basis [10]. Elsewhere, studies assessing the performance of medical x-ray equipment have been performed [5, 11, 16]. The studies revealed that routine equipment testing coupled with repair and maintenance improves image quality and reduce patient dose [5, 16]. The aim of this study therefore, was to evaluate the performance of conventional x-ray equipment in Lindi and Mtwara regions in terms of some factors affecting image quality and patient dose.

2. MATERIALS AND METHODS

The study used a longitudinal approach in analyzing retrospective data regarding performance status of the diagnostic radiology x-ray machines from 2015 to 2021. Using Excel spreadsheet, TAEC inspection reports were analyzed based on the QC measurements conducted in health facilities offering diagnostic radiology services in the two regions. The analyzed data included the test results of kilovoltage (kV) accuracy, kV reproducibility, milliampere seconds (mAs) linearity, congruence of light field with x-ray field (collimation), beam alignment and half value layer (HVL).

The following test tools were used for the measurements analysed:

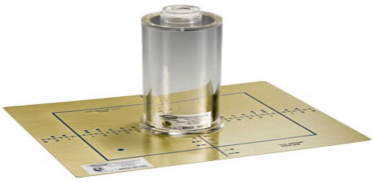
- Unfors χi base unit, Model No. 8201013-C and χi Classic R/F & MAM Detector Model No. 82022031-H, manufactured by Unfors in in 2011- used to evaluate the kV accuracy, kV reproducibility, mAs linearity and the HVL.
- RMI aluminium filters Model no. 163A manufactured by Radiation Measurements, Inc. – used to evaluate the HVL.

- Collimator test tool Model no. 07-661 manufactured by Nuclear Associates – used for testing the collimation.
- RMI Model 161A, manufactured by Radiation Measurements, Inc. – used for evaluation of the x-ray beam alignment or perpendicularity

Details of the evaluated x-ray equipment are shown in Table 1 while tolerance limits for the evaluated parameters are shown in table 2. Also, images of the QC test tools used in checking the parameters are shown in Figure 1.

UNFORS test device for kV, mAs linearity and HVL test tool

Collimator & Beam Alignment test tool



Aluminium Plates for HVL test

Figure 1: Quality Control Test Tools

Table 1: Details of the evaluated x-ray equipment

Manufacturer	**Model**	**Year manufactured**	**Tested Equipment**			
			2015	**2017**	**2019**	**2021**
Philips Medical Systems	MRS	1999	✓	X	✓	Replaced
Philips Medical Systems	MRS	1999	✓	✓	✓	Replaced
Philips Medical Systems	MRS	1999	✓	✓	✓	Replaced
Philips Medical Systems	MRS	1999	✓	✓	✓	Replaced
Philips Medical Systems	MRS	1999	✓	✓	✓	✓
Philips Medical systems	DUO Diagnost	1999	✓	X	✓	✓
Philips Medical Systems	MRS	1999	✓	X	X	✓
Philips Medical Systems	MRS	2009	✓	✓	✓	✓
Philips Medical Systems	Medio 50 CP	2011	✓	✓	✓	✓
Siemens Medical Company	1P 3848905 X2169	2000	X	✓	X	Replaced
Siemens Medical Company	WIZ RAD	2006	✓	✓	✓	✓
Siemens Medical Company	Multix Swing	2013	✓	✓	✓	✓
Siemens Medical Company	Mobilet II	-	✓	✓	✓	✓
Allengers Medical Systems	Allengers 525	2014	✓	✓	✓	✓
Allengers Medical Systems	Allengers 525	2017	-	-	✓	✓
FUJIFILM Corporation	FDR smart	2020				✓
Nanjing Perlove Medical	PLX101D	2020				✓
SITEC Medical Company	DigiRAD-FP	2020				✓

SITEC Medical Company	DigiRAD-FP	2020				✓
SITEC Medical Company	DigiRAD-FP	2020				✓
SITEC Medical Company	DigiRAD-FP	2020				✓
Total number of tested equipment			**13**	**11**	**13**	**16**

Key:

✓ = Tested x-ray equipment, X = Equipment not tested, MRS = Multi Radiography System

Table 2. Test parameters and tolerance limits [9, 17]

Measured Parameter	**Acceptable limits**
Collimation	≤ ± 2 cm
Beam alignment	≤ 3°
kV reproducibility	≤ ± 4 %.
kV accuracy	± 10 %
mAs Linearity	± 10 %
Beam quality (HVL)	≥ 2.3 mm Al

3. RESULTS

Table 3: Diagnostic x-ray equipment modalities as of July, 2021

Equipment Modality	**Number of Equipment per region**	
	Lindi Region	**Mtwara Region**
General Radiography	9	11
Fluoroscopy	1	1

According to the reports there was a total of 22 diagnostic radiography equipment in the two regions in the year 2021 (Table 3). However, the QC tests were performed on 16 x-ray units in the

year 2021. The TAEC reports further show that the tests were conducted on 13 x-ray units out of 15 in 2015, 11units out of 18 in 2017, and 13 units out of 19 in 2019 (Table 4). The reason is that x-ray equipment which were not functional during the TAEC inspections, were not tested.

Table 4: Performance of the x-ray equipment from 2015 to 2021

Tested Parameter	**2015**	**2017**	**2019**	**2021**
kV reproducibility	13 (100%)	11 (100%)	13 (100%)	16 (100%)
kV accuracy	13 (100%)	11 (100%)	13 (100%)	16 (100%)
mAs linearity	13 (100%)	11 (100%)	10 (76.9%)	15 (93.7%)
Beam quality (HVL)	13 (100%)	11 (100%)	13 (100%)	16 (100%)
Collimation	13 (100%)	11 (100%)	11 (84.6 %)	12 (75%)
Beam alignment	13 (100 %)	11 (100%)	13 (100%)	16 (100%)

The kV accuracy test was performed at the nominal settings of 50, 60, 70, 80, and 90 kV stations at fixed 10 mAs and 100 cm source detector distance (SDD). Deviation of the measured values ranged from -2.4% to +8.2% hence passed the tests as compared to the tolerance limits in Table 2. The reproducibility output values for kV, time and dose were obtained at the equipment setting of 80kV, 10 mAs and 100 cm SDD. Deviation of the measurements ranged from -0.8% to +3% which were within limit. With regard to the mAs Linearity test, the measurements analyzed were obtained at the mAs settings of 2, 4, 8, 16, 32, and 64, at fixed 60 kV and 100 cm SDD. The deviation of the output ranged from +1.4% to +7.8% for equipment that passed. For the equipment that failed, the deviation was - 15%.

The data for beam alignment and collimation tests were analyzed to check whether the congruency between light and x-ray beams, and the beam perpendicularity were within the tolerance limits. Deviation for collimation ranged from - 0.3cm to + 1.5cm for the equipment that passed the

test and – 3 cm, +3.2 cm and +3.4 cm for the equipment that failed. Deviation of the measured values of the beam alignment test ranged between 0.5° to 1.5°. For the HVL, the QC tests were performed using aluminium filters of 0.5, 1.0, 1.5, 2.0, and 2.5 mm thickness at 80 kV, 10 mAs and 100 cm SSD. Deviation of the measurements ranged from 2.8 mm Al to 3.9 mm Al which are within limits.

4. DISCUSSION

The findings on the x-ray equipment performance have been presented. As shown in Table 4, all the tested x-ray equipment passed the kV reproducibility, kV accuracy, HVL and beam alignment tests, while the collimation test seem to be the parameter that failed most. With regard to the mAs linearity test, the equipment performance was within limit except for the years 2019 and 2021 when 2 (23.1%) and 1 (6.1%) of the equipment failed the tests respectively. The results are discussed into three main categories: performance of x-ray equipment, lack of quality control program, and lack of preventive maintenance and repair program.

4.1 Performance of x-ray equipment

The performance of most of the x-ray units were within regulatory requirements as indicated in Table 2. It is noticed, however, that the collimation parameter surfaces as a most failed test. This indicates the necessity for regular checking of the collimation parameter in every three to six months because the collimator is much used and hence is vulnerable to often inaccuracy [18]. Failure of collimator setting can cause irradiation of unwanted area, or missing of area of interest [10]. Without regarding the number of x-ray equipment, the results of the current study are comparable to the previous study [9] conducted in another region in Tanzania. In the current study, 75% to 100% passed the various QC tests (Table 4), while in the study by Nkuba and Nyanda [9], 93% - 98% of the equipment passed the various tests. However, when compared to the study done more than 10 years back [13], the performance in the current study are much better. In the study by Sungita et al [13], only 41% – 60% of the tested equipment passed. Therefore, the findings of the current study suggest enhancements in radiation protection of workers and patients.

The improvement in performance of most x-ray units evaluated in this study were largely attributed to the enactment of the Atomic Energy Act of 2003 and its regulations which has increased the level of compliance. Also, the installation of new Philips x-ray machines in hospitals (especially in government hospitals) coupled with maintenance program, through a joint project (ORET Project) between the governments of Tanzania and the Netherlands has much contribution to the improvement [19]. Elsewhere, the work by Akpochafor et al. [20] and Ciraj et al. [21] in Nigeria and Serbia respectively, affirmed that the number of years an x-ray equipment has, impacts on the equipment performance.

4.2 Lack of quality control program

It was evident during the study that routine QC tests are not performed in the diagnostic x-ray facilities as previously reported [10, 13]. The lack of appropriate test tools and lack of enforcement are noted as reason for inadequacy of QC plan as reported in the previous study [15]. Similarly, Njikip et al. [5] reported the lack of test tools and enforcement as hindrances to the QC plan in Sudan and Cameroon. The AAPM [22] insists that the QC program is complementary to quality imaging and radiation protection procedures. Lack of QC program results into late detection of equipment failure, at a grave stage, which may require higher repair costs and can lead to disruptions of services. This results in inaccurate or delayed diagnosis, unnecessary dose to the patient, wastage of clients' time, and poor services [7, 10].

4.3 Lack of preventive maintenance and repair program

It was observed during the study that maintenance or repair of equipment is not timely performed. For example, in 2017, among the 7 machines that were excluded from the study, five x-ray machines were not working due to some faults for more than 4 months. Then again, three machines had problems with mAs setting. The main reason observed was the lack of in-house preventive maintenance and repair personnel. The ORET project covers maintenance and repair for government facilities, however, the contracted company may not perform repair promptly for abrupt errors as it is located far (around 500 km) from the regions and the process from requisition to implementation of the repair work takes some days. A previous study in Tanzania reported lack of preventive maintenance and repair program which resulted into poor performance of equipment,

and misplacement of equipment parts, manual/guides and records [13]. Elsewhere, Ekpo et al. [16] found that many facilities in Nigeria had poor plan for preventive maintenance and QC which caused equipment failures. The authors further emphasize that most equipment faults cannot be predicted, hence, planned procurement, QC, preventive maintenance and prompt repairs are indispensable if effective and efficient radiological practice is to be realized. It should be noted that maintenance and repair program is an important part of the QC program, and that the plan is most effective when implemented by trained in house staff [13]. In their study, Egbe et al. [23] recommended the establishment of a QC plan that goes beyond procurement and installation of x-ray equipment.

5. CONCLUSIONS

In general, the diagnostic x-ray machines tested showed satisfactory performance despite the lack of quality assurance program within the investigated facilities. However, regular checking of the collimator parameter and within a shorter interval need to be observed, as it is important for the image quality, the exam and for the correct dose received by the patient. It is crucial that the radiological facilities put in place a QC program combined with in house maintenance plan for consistent optimum performance of equipment. The facilities need to take heed that optimum equipment performance is fundamental if quality imaging at optimized radiation dose and cost are to be realized.

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