QUALITY ASSURANCE AND CONTROL OF CONVENTIONAL X-RAY MACHINES AT DIFFERENT HOSPITALS AND CLINICS IN EASTERN ETHIOPIA

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Abstract. The aim of this study was to assess the quality assurance of conventional X-ray machines installed in two towns from Eastern Ethiopia, Dire Dawa and Harar, at different hospitals, clinics and health centers. Data collection took place with the collaboration of the Ethiopian Radiation Protection Authority's (ERPA) inspection team using the check lists, interviews with the owners of the facilities, radiographers and radiation safety officers. In this study, the test beam alignment, beam collimator, X-ray tube peak voltage (*kVp*) accuracy, timer accuracy, and half-value layer (*HVL*) were evaluated for each X-ray machine, in order to obtain quality control measuring device according to designed methods. The results indicate that out of 31 X-ray machines tube voltage accuracy was 90.32, 93.55, 96.77 and 93.55 percent for peak tube voltage settings of 90, 80, 70 and 60 kV, respectively. Timer accuracy was 93.10, 89.66, 93.10 and 86.20 % for timer settings of 0.4, 0.2, 0.125 and 0.08 s, respectively. Test results revealed that all machines were in the normal range in what concerns collimator and alignment. Output consistency and *HVL* were in acceptable limits for 96.77 % of the investigated machines. Our study suggests that X-ray equipment performance can be improved by radiation protection training, establishing a quality assurance program.

Key words: quality control, X-ray machine, quality assurance.

INTRODUCTION

Quality control (QC) in diagnostic radiology is essential to insure accurate diagnostic information at optimal radiation doses [4], thereby making it possible to get highest image quality and reduce unnecessary radiation hazard to patients, workers and the public [14]. A quality assurance (QA) program needs to be applied to diagnostic imaging equipment to provide quality assurance for a diagnostic radiology facility [15, 16]. The nature and extent of this program will vary with the size and type of the facility, the type of examinations conducted, and other factors [1]. The QA program must cover the entire X-ray system from the machine to the processor and the view box [12]. The program is used to obtain the best diagnostic image with fewer hazards and distress to the patients. It includes periodic quality test, and continuous assessment of the efficacy of the imaging service by initiating corrective factor as it was mentioned in reference [1].

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The main goal of X-ray machine QA is the minimization of radiation exposure and maximization of image quality [11]. This can be assured by an X-ray machine working at optimum operating parameters such as reproducibility of tube voltage, dose output, time, X-ray tube efficiency. It is also important to assure the accuracy of the peak tube voltage (*kVp*) and tube current (mA) [1, 2, 5–8, 14].

Regular implementation of QC in diagnostic X-ray facilities is essential to provide good quality images, which lead to proper diagnoses with minimum hazard and distress [1].

Important performance tests in diagnostic radiology in Ethiopia are carried out according to a QC protocol and the measured parameter values are compared to the relevant acceptance limits [7]. The regulating body responsible for this in Ethiopia is the Ethiopian Radiation Protection Authority.

The main purpose of this work is to assess the quality assurance of conventional radiography machines used in Dire Dawa and Harar Hospitals and clinics in collaboration with ERPA.

MATERIALS AND METHODS

STUDY AREA

Radiographic measurements were done in thirteen general hospitals (GH), nine Medium Clinics (MC), three Primary Hospitals (PH), two Specialty Clinics (SC), two Higher Clinics (HC), and one Diagnostic Centre (DC). All these health facilities were located in the Eastern part of Ethiopia, in Dire Dawa and Harar towns. There were 40 X-ray machines found at 32 facilities considered under the study.

DATA COLLECTION METHODS

Data was collected with the collaboration of Ionizing Radiation Regulatory Control Directorate's Inspection Team of ERPA, with the check lists and focus group discussion, with radiographers and radiation safety officers. ERPA is regulatory body and responsible for implementing the power given by the proclamation, Ethiopian Radiation Protection Authority Proclamation [3].

In this study, seven parameters were tested: peak tube voltage (*kVp*) accuracy, timer accuracy, reproducibility, collimation, alignment, half-value layer (*HVL*) and output consistence. Timer accuracy and *kVp* measurements were done using an X-ray quality control measurement device Magic Max Universal.

For all set of voltage and timer the measurements were taken by putting the detector on the patient table at the distance of 100 cm from source to detector. The

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beam alignment and collimator test tools were placed on the examination table with the radiographic cassette in the bucky tray at 100 cm distance between source and detector. The exposures were made with the collimator shutters fully closed and X-ray tube pointed vertically downward. The exposure parameters for the leakage tests were as follows: tube voltage 80 kV, exposure of 100 mA·s and exposure time 20 ms [5].

DATA ANALYSIS

Accuracy of tube voltage

Tube voltage (peak kilovoltage, *kVp*) is the X-ray tube operating parameter that controls the quality of the generated X-ray beam. In this work, *kVp* accuracy was calculated using the following equation:

$$kVp_d = \frac{X_\mathrm{m} - X_\mathrm{n}}{X_\mathrm{n}} \tag{1}$$

where kVp_d is the voltage deviation and it is a dimensionless quantity, X_m is the measured value of the peak tube kilovoltage and X_n is the nominal value of the voltage (kV) [9, 13].

Exposure Time

In radiology, a measure of the amount of ionizing radiation at the surface of the irradiated object, calculated by multiplying tube current (mA) and exposure time (s) is expressed in units of milliampere seconds (mA·s). Timer accuracy was calculated using equation (2).

$$t_\mathrm{d} = \frac{t_\mathrm{m} - t_\mathrm{s}}{t_s} \tag{2}$$

where: t_d is the time deviation and it is dimensionless quantity, t_m is the measured value of exposure time and t_s is the value of selected exposure time.

Reproducibility

The parameters of timer and *kVp* output of an X-ray machine at a given setting should be reproducible when all the other parameters are fixed. Perfect settings of the above parameters provide optimal dose to the patients and course to quality image. Reproducibility was assessed in terms of the coefficient of variation using the following equation [9, 13]:

$$CV = \frac{\sigma}{\mu} \tag{3}$$

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where σ is the standard deviation of a series of measurement results such as dose (mGy), time (ms) or voltage (kV), and μ is their mean value [14].

Beam Quality

Beam quality refers to the overall energy or wavelength of the beam and its penetrating power [13]. The beam quality is controlled by the peak tube voltage (kVp). Whenever there is an increase in kVp, the generating X-ray beam is of higher energy and increased penetrating ability. Table 1 lists the acceptance limits of the physical parameters that characterize the performance of X-ray imaging systems [9, 13].

Table 1

The accepted deviation limits of X-ray technical parameters [3, 10]

Parameters	International acceptance limits	ERPA acceptance limits
kVp deviation (kVp_d) (kV)	$\leq \pm 10$	$\leq \pm 10$
Timer deviation (t_d) (ms)	$\leq \pm 10$	$\leq \pm 10$
Output reproducibility (CV)	$\leq \pm 5$	$\leq \pm 5$
Tube leakage (mGy)	≤ 1	≤ 1
Half-value layer (HVL) (mm)	$\geq$ 2.5 Aluminium	$\geq$ 2.5 Aliminium

RESULTS

This study focused on the quality assurance of conventional radiography installed at hospitals and clinics found in Dire Dawa and Harar towns.

The overall percentage error of kVp out of X-ray machines considered under this study, 93.55 % was within acceptable range limit and 6.45 % was out of acceptable range limits. The percentage error of timer, out of X-ray machines considered under this study, 90.52 % was within acceptable range and 9.48 % was out of acceptable limits.

Table 2 presents the measurement results for time accuracy, timer reproducibility, peak voltage accuracy, and peak voltage reproducibility for the 31 X-ray machines tested during this study. Here GH is the acronym for General Hospital, SC is Specialty Clinic, PH is Primary Hospital, MC is Medium Clinic, HC

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is Higher Clinic, DC is Diagnostic Centre, GH(M1) and GH (M2) are machine 1 and 2 in the same facility.

The facilities found in Dire Dawa (DD) were coded by facility code F1 to F18 and the facilities found in Harar (HR) town were coded by Fa to Fn. The timer reproducibility ranged from 0 to 4.55 and *kVp* reproducibility ranged from 0 to 1.84.

Table 2

Measured tube voltage and timer reproducibility, kVp accuracy, time accuracy and time reproducibility for 31 X-ray machines at 80 kV and 0.2 s

Facility code	Facility type	City	*KVp* accuracy (%)	*KVp* reproducibility (%)	Time accuracy (%)	Time reproducibility (%)
F1	GH	DD	–15.60	0.67	–3.10	0.52
F2	MC	DD	–4.60	0.41	–3.50	0.52
F3	MC	DD	–6.28	1.36	–3.00	0.59
F4	MC	DD	9.50	0.00	0.00	0.00
F5	GH	DD	–5.05	0.01	1.50	0.05
F6	HC	DD	1.47	0.32	1.00	4.55
F7	MC	DD	–4.60	0.00	–1.50	0.25
F8	MC	DD	6.31	1.19	NA	–
F9	HC	DD	1.25	0.00	2.00	0.00
F10	SC	DD	–8.36	1.84	22.8	1.13
F11	SC	DD	2.25	0.74	NA	–
F12	MC	DD	2.25	0.86	45.5	0.00
F13	MC	DD	–1.25	0.00	0.00	0.00
F14	GH	DD	–7.86	1.37	1.83	0.00
F15	PH	DD	–2.31	0.09	–5.65	0.79
F16	GH(M1)	DD	5.96	0.24	–2.47	0.00
F17	GH(M2)	DD	2.01	0.33	2.50	0.24
F18	GH	DD	–1.25	1.27	3.21	0.00
Fa	DC	HR	–3.88	1.63	–2.00	0.00
Fb	GH(M1)	HR	0.25	0.49	–3.00	0.00
Fc	GH(M2)	HR	–2.13	0.89	–3.00	0.26
Fd	MC	HR	9.56	0.03	1.50	0.49
Fe	GH	HR	–1.25	0.00	0.00	0.00
Fg	GH(M1)	HR	4.00	0.06	–11.21	0.53
Fh	GH(M2)	HR	–1.37	0.07	1.26	0.02
Fi	MC	HR	0.75	0.25	0.00	0.00
Fj	MC	HR	–0.38	0.19	–5.00	0.00
Fk	MC	HR	2.47	0.01	0.00	0.00
Fl	GH	HR	–9.20	0.01	8.45	2.31
Fm	GH	HR	5.64	0.05	4.51	0.24
Fn	GH	HR	12.78	0.14	3.64	0.44

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The peak tube voltage accuracy of X-ray machines was tested at different settings. The machine F1 failed accuracy at all *kVp* settings while Fn failed at 90 and 80 *kVp* high voltage settings. F8 and Fd failed at *kVp* accuracy 80 and 90 kVp high voltage settings, respectively.

Timer accuracy for different settings of the 31 X-ray machines was tested by setting the X-ray source to the detector at 1 m of exposure, 100 mA for 0.08, 0.125, 0.20 and 0.40 s shown in Table 4. For each setting, two measurements were taken, and the average value was calculated. The percentage error was calculated and compared with standard criteria specified in Table 1.

Table 3

X-ray accuracy for 31 machines operated at different peak tube potentials (*kVp*)

Designed operating potential (*kVp*)	Number of machines within normal range	Number of machines out of normal range
90	28 (90.32 %)	3 (9.68 %)
80	29 (93.54 %)	2 (6.46 %)
70	30 (96.77 %)	1 (3.23 %)
60	29 (93.54 %)	2 (6.46 %)

Out of 31 X-ray machines, 2 were not applicable for time setting. As shown in Table 4, timer accuracy was good for all machines except 6 machines which were out of the acceptance limit at 0.08, 0.125, 0.20 and 0.40 s. F10 failed at three timer settings 0.08, 0.2 and 0.4 while three other machines F12, Fl and Fn failed at two timer settings. F12 failed at 0.08 and 0.2, Fl failed at 0.08 and 0.125 and Fn failed at 0.125 and 0.4 seconds. The other two machines Fa and Ff failed at 0.08 and 0.2, respectively.

Table 4

Exposure time accuracy for 31 X-ray machines with its range of acceptability

Timer (s)	Normal range	Out of normal range
0.4	27	2
0.20	26	3
0.125	27	2
0.08	25	4

According to the results shown in Table 2, *kVp* accuracy was good for most of the tested machines; just 3 machines were out of the acceptable limit [3, 10]. F1

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deviated at all *kVp* settings for measurement by −13.6 %, −15.6 %, −13.3 % and –11.2 % for 90, 80, 70 and 60 *kVp* setting respectively. F2 and Fd deviated at one *kVp* setting at 60 and 90 kVp by 11.35 % and 11.83 % respectively. Fm deviated at 90 and 80 kVp by 11.6 % and 12.78 %, respectively.

Regarding timer accuracy, six machines failed the test (Table 5). F10 deviated at three timer settings, 0.08, 0.20 and 0.40 seconds by 19.5 %, 22.75 % and 26.62 % respectively. F12 deviated at 0.08 and 0.20 seconds by 23.75 % and 45.5 % respectively. Fa and Ff deviated at one timer settings each, 0.08 and 0.20 s by –11.21 % and –19.43 % respectively. Fm deviated at two timer settings, 0.125 and 0.40 seconds by 14.57 % and 12.21 % respectively. Fk deviated at 0.08 and 0.125 s by 11.4 % and 10.7 %, respectively.

Table 5

Failure and deviation of X-ray machines with four different time settings

Facility code	Timer (ms)			
	0.4	0.2	0.125	0.08
F10	26.62 %	22.75 %	–	19.5 %
F12	–	45.5 %	–	23.75 %
Fa	–	–19.43 %	–	–11.21 %
Ff	–	–19.43 %	–	–11.21 %
Fk	–	12.21 %	14.57 %	–
Fm	–		10.7 %	11.4 %

Collimator and alignment test was done using on average X-ray machines for tube voltage 80 kVp, X-ray beam intensity at 100 mA·s, 100 cm focal film distance (*FFD*), 20×20 cm field size (Table 6). The results indicate that the collimator and alignment was good for all machines.

Table 6

Beam axis of alignment for X-ray machines for peak tube voltage 80 kVp and beam intensity 100 mA·s

Parameter	Normal range	Out of normal range
Perpendicularly	31	0
Short axis	31	0
Long axis	31	0

Besides the results shown in Table 6, the collimator and alignment were in normal range for all machines and output consistency and half-value layer (*HVL*) were in acceptable limits in a proportion of 96.77 % [3, 10]. Regarding the peak

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voltage and timer reproducibility, our study demonstrated that all machines had passed the acceptable limits.

As shown in Table 7, *HVL* and output consistency were good for most machines; just one machine has got less *HVL* than acceptable and one machine has got greater coefficient of variation than the acceptable limit.

Table 7

Normal and out of normal range of output consistency and half-value layer of X-ray machines

Parameter	Normal range	Out of normal range
HVL	30	1
Output consistency	30	1

DISCUSSION

This study focused on the quality assurance of conventional radiography equipment installed at hospitals and clinics found in Dire Dawa and Harar towns. Our results indicate that most tested parameters of X-ray radiography devices were in compliance with the comparative standard criteria provided in Table 1.

Similar research was done by [9] on 120 units tested regarding *kVp* accuracy 40.83 % were acceptable and 59.17 % were deemed unacceptable according to [10, 16]. Timer accuracy out of 120 units tested 57.5 % were acceptable and 42.5 % were rejected according to the international limit. Beam alignment out of 80 units tested 60 % were acceptable and 40 % were rejected according to the international limit [7, 8].

The results of the current study demonstrated that a small percentage of the investigated facilities were out of the internationally acceptable limits.

CONCLUSIONS

This study indicates that the *kVp* and timer reproducibility were measured by setting peak voltage at 80 kV and timer at 0.2 s for all machines. The misalignment of the X-ray machine above the tolerance limit should be checked as it affects the patient's dose and image quality. Some of the X-ray machines may need manual adjustment for the X-ray beam to become perpendicular to the image receptor and regular quality control test to be implemented.

Effective patient protection can be achieved with optimally performing X-ray equipment, the application of good radiographic technique and continuous assessment of radiographic image quality. The overall X-ray equipment quality

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check results obtained in this study indicated proper functioning of the tube voltage, tube current, output consistence and total filtration for most of the investigated equipment. The machines that deviated from the acceptable limit by one or more measure should be taken for maintenance and calibration before being used to evaluate a patient's health status.

Moreover, ERPA should promote the development of national diagnostic reference levels for quality assurance and quality improvement tools in each type of examination for all health centers in the country.

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