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Examination of Quality Control Parameters in some Diagnostic X-ray Units

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ABSTRACT

Periodical performance of quality control in diagnostic x-ray machines is important to provide minimum dose delivered to patients and high image quality. The current study is aimed to assure the quality control of conventional X-ray machines over some Makkah city hospitals according to quality control protocol and the measured parameters values are compared to the international acceptance limits. Some factors affecting on quality assurance of conventional X-ray machines such as reproducibility of time, applied high voltage, kilo-voltage accuracy, time accuracy, linearity and half value layer of X-ray machines over four hospitals in Makkah city are investigated. These parameters are measured by using the RaySafe solid-state detector connected with suitable ionization chambers located at 100 cm source to image detector**.** Time Reproducibility ranged from 0.05% to 0.07% and high voltage reproducibility ranged from 0.09% to 0.14 %. Kilo-voltage accuracy ranged from 0.22 to 3.5 % and time accuracy ranged from 0.02 to 4.1% respectively. Coefficients of linearity of diagnostic X-ray units in four hospitals in KSA were 0.02, 0.004, 0.02 and 0.24. This study concluded that quality control examinations are within the tolerance limit of the American Association of Physicist in Medicine, *"(AAPM)"*. It assists in the optimization of a dose delivered to patients.

KEYWORDS

Quality Control, Reproducibility, Accuracy, Linearity and Diagnostic X-ray, RaySafe.

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INTRODUCTION

The main objectives of quality assurance of an X-ray machine are to obtain high accuracy of the operating diagnostic X-ray and to optimize of the radiation dose delivered to patient. Quality control tests that are routinely carried out include: reproducibility of tube voltage, dose output, time, kVp accuracy, time accuracy, half value layer, the relationship between incidence air kerma and *X*-ray tube current**,** in addition to the linearity test (a relationship between X -ray tube output and kVp). The quality control test methods used in the present research are in agreement with the American Association of Physics in Medicine **(AAPM, 1981)** published quality control protocol for radiological equipment . The quality of X-rays in terms of the half value layer is considered as a part of quality assurance **(Stephen *et al*., 2001** and **Begum *et al*., 2011)**. The dose output reproducibility is studied based on the procedures for measuring entrance skin exposure (ESE) following American Association of Physics in Medicine (**AAPM, 1991)** report. Quality control tests for X-ray are studied based on the American Association of Physics in Medicine report **(AAPM, 1981** and **Plotti, 1995).**

Our aim in this study is to investigate some factors affecting the quality assurance of four radiographic *X* -ray units in Makkah city. These factors include reproducibility for dose output, time and applied high voltage, the accuracy of kilo-voltage, tube current, time accuracy, the relationship between *X*-ray tube output and kV.

MATERIALS AND METHODS

The RaySafe Xi, Fluke Corporation*,* The USA (America) manufacturer is used to perform the quality control tests for four radiographic x-ray equipments. Reproducibility for dose output, time and applied high voltage, the accuracy of kilo-voltage, tube current, time accuracy, linearity, the relationship between X-ray tube output and kV are explained as follows:

The Reproducibility

Reproducibility for dose output applied kV and exposure time of radiographic X-ray machine in four hospitals, King Abdullah Medical City Hospital KAMCH, Hera General Hospital (HGH), King Faisal Hospital (KFH) and Maternity & Children Hospital (MCH) is measured using Unfors RaySafe meter connected ***to a*** solid state detector. *Measurements are carried on* the position of a phantom for the desired field size and for three different exposures are made.

The coefficient of variation is calculated using the next equation 1 **(FDA,1999)**

$$COV = \frac{\sigma}{\text{avg}} X\, 100 \qquad (1)$$

Where: Calculated value of standard deviation [σ], of dose [mGy], time [ms] or voltage [kV]. Calculated value of mean, avg of dose [mGy], time[ms] or voltage [kV] .

Accuracy

The accuracy or relative percentage error of tube voltage and time setting is examined for each machine. Three exposures are recorded for tube voltage and irradiated time. The relative percentage error is calculated using the equation 2.

$$Relative\ \%\ error = \frac{Measured\ kV - Accepted\ kV}{Accepted\ kV}\ x\,100 \qquad (2)$$

Where: Accepted or assigned a value of the value of time [ms] or voltage [kV], that is entered digitally into a control panel. The measured value of time [ms] or voltage [kV] that is recorded using Ray Safe meter. The acceptance tolerance limit of the American Association of Physicist in Medicine recommendation (**AAPM, 2002**) and National New Zealand Laboratory, **(Plotti, 1995).**

The dose output linearity

The dose output linearity is calculated by using the equation (3) **(FDA, 1999).**

$$\frac{X2 - X1}{X2 + X1} < 0.1 \qquad (3)$$

Where X_1 and X_2 are two successive readings of dose output in the unit of µGy/mAs. A relation chip between applied kilo-voltage and the dose output is studied for four radiographic x-ray units in four hospitals in Makkah city. The physical X-ray machine is adjusted at 10 mAs and 500 msec. The source to image distance (SID) is adjusted at 100 cm where the ionization chamber of the Unfors Ray Safe is located in center beam axis to avoid heel effect. The dose output factors for each x-ray machine is generated and used for dose estimation **(Taha *et al.*, 2014).**

RESULTS

Reproducibility

Reproducibility for dose output applied kV and exposure time for x-ray machine in King Abdullah Medical City Hospital KAMCH, GE X-ray machines in three hospitals, Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) were presented as shown in (table 1).

Table (1) : *Reproducibility of kV, time and dose output for four X-ray machines in four medical centers, KAMCH, MCH, HGH, and KFH Reproducibility of kV, time and dose output for four X-ray ma chines in four medical centers, KAMCH, MCH, HGH, and KFH***.**

Hospital.	FFD	Reproducibility (CV%)		
		kVp	Time (s)	Dose (mGy)
KAMC	100 cm	0.09	0.07	0.34
MCH	100 cm	0.07	0.05	0.14
HGH	100 cm	0.09	0.07	0.44
KFH	100 cm	0.14	0.06	1.29

Reproducibility for kilovoltage for x-ray machines was varied from 0.07% to 0.14%, of time was varied from 0.05% to 0.07 % and dose output was varied from 0.14 % to 1.29 % that is lower than the tolerance level (5%) **(FDA, 1999)**.

kV and Time accuracy

kVp Accuracy for King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) of different settings of four X-ray machines was determined. It examined for kilovoltage setting from 50-100 kV, 20 mAs. Time accuracy for King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) of four X-ray machines determined as presented in (Table 2).

Kilo-voltage accuracy and time accuracy for King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) were within the kilovoltage and time accuracy of 5% that issued by **(AAPM, 1991; Plotti, 1995)**. The obtained results were close to the data set published by **(Taha, 2015 and Ismail, 2015)** and was lower than tolerance (±10%) **(Plotti,1995).**

mAs Linearity

Coefficient of Linearity of X-ray machine in King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital

(KFH), Maternity & Children Hospital (MCH) was examined using 80 kVp and mAs vary from 2-32 mAs at 100 cm FFD and linearity coefficient is calculated for each machine as presented in (table 3).

Table (2) : *kVp Accuracy at source to image detector 100 cm and 12 mAs***.**

Hospital	Machine Manufacture	Mean KVp % Accuracy range	Mean time % Accuracy range
KAMC	Siemens	1.50-3.5	0.46-4.1
MCH	GE	0.22-1.02	1.44-2
HGH	GE	0.12-0.2	002-0.5
KFH	GE	0.6-194	0.02-0.11

Table (3) : *Coefficient of Linearity of X-ray machine in King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) at kV=81, SID=100, time=100 msec.*

Hospital/Machine No.	Linearity Coefficient
KAMCH	0.020
MCH	0.004
HGH	0.020
KFH	0.024

Coefficient of linearity of X-ray machine in King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) was 0.020, 0.004, 0.020 and 0.024 which lower than 0.1 that reported by **(Plotti, 1995).** It means that the mAs was directly proportional with the dose output at any setting points.

Half Value Layer (HVL).

The half value layer (HVL) of the x-ray beam was calculated by plotting relative attenuation percentage with and without lead sheet layer versus thickness (mm) for the lead. it was measured at 70 kV and 32 mAs and source to detector distance 66 cm. Half value layers were calculated as shown in (table 4).

Table (4) : *Minimum HVL requirement for an X-ray unit.*

Machine No.	Half Value Layer, mm
KAMCH	2.9
HCM	2.9
HGH	2.9
KFH	3.0

All half value layers are exceeding the minimum value, 2.3 mm Al at 70 kV as an accepted value of (FDA, 1999). The tube voltage and tube output for a diagnostic X-ray machine.

The relationship between X-ray Air kerma μGy/mAs and applied tube voltages from 40 to 130 kV at 10 mAs and 500 million seconds of the X-ray machines in the KAMC, HGH, MCH, and KFH was plotted in figures (1-4).

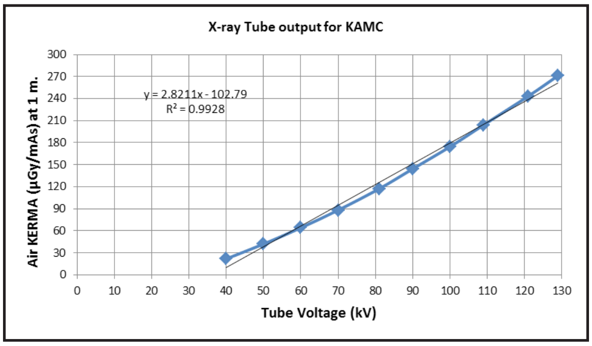

Fig. (1): Tube voltage and tube output for a diagnostic X-ray machine in KAMC.

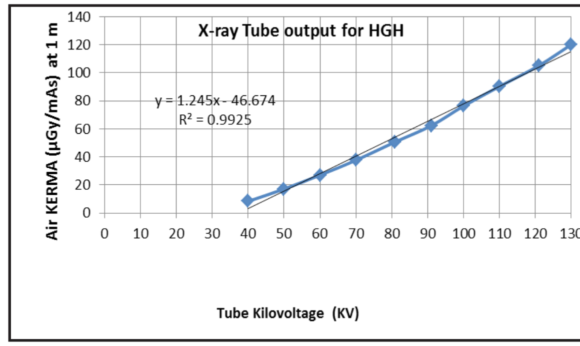

Fig. (2): Tube Voltage (kV) against Air KERMA in the HGH.

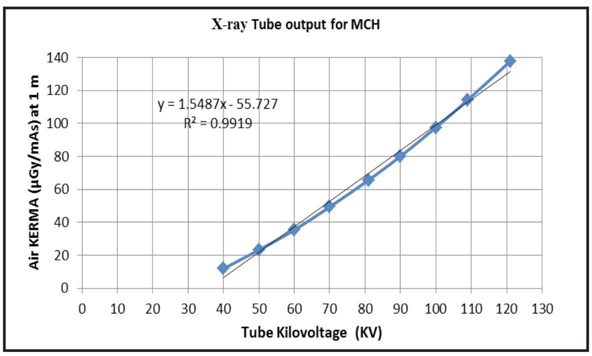

Fig. (3): Tube Voltage (kV) against Air KERMA in the MCH.

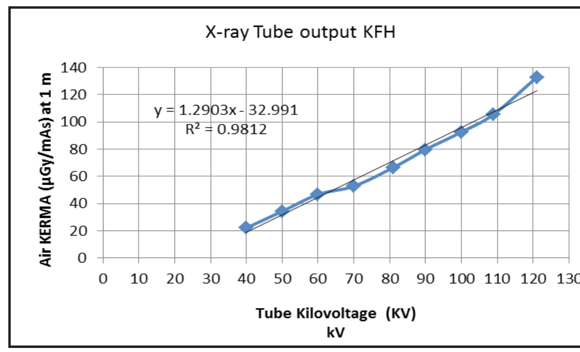

Fig. (3): Tube Voltage (kV) against Air KERMA in the MCH.

The fitted equation for the relationship between tube voltage (kV) against air kerma in the KAMC, the KAMC, HGH, MCH, and KFH was presented in equations (1-4) respectively.so one body can estimate the dose out, µGy/mAs for each tube voltage for x-ray tubes in the four radiology departments in the interested hospital as presented in the empirical equations (4-7).

$$Y = 2.8211\, X - 102.79 \qquad (4)$$

$$Y = 1.245X - 46.727 \qquad (5)$$

$$Y = 1.5487X - 55.727 \qquad (6)$$

$$Y = 1.2903X - 32.991 \qquad (7)$$

Where :

Y : *is the air kerma (µGy/mAs) at one meter*

X : *Tube voltage in kV*

DISCUSSION

Reproducibility for kilovoltage for X-ray machines was varied from 0.07% to 0.14%, of time was varied from 0.05% to 0.07 % and dose output was varied from 0.14 % to 1.29 % that is lower than the tolerance level (5%) **(FDA, 1999),** American Association of Physics in Medicine **(AAPM, 1981 and Plotti,1995).**

Kilo-voltage accuracy and time accuracy for King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) were within the kilovoltage and time accuracy of 5% that issued by **(Plotti,1995)**. The obtained results were close to the data set published by **(Taha, 2015** and **Ismail, 2015)** and was lower than tolerance (±10%) **(Plotti, 1995).**

Coefficient of linearity of X-ray machine in King Abdullah Medical City Hospital (KAMCH), Hera General Hospital (HGH), King Faisal Hospital (KFH), Maternity & Children Hospital (MCH) was 0.020, 0.004, 0.020 and 0.024 which lower than 0.1

that reported by **(Plotti, 1995)**. It means that the mAs was directly proportional with the dose output at any setting points. All half value layers are exceeding the minimum value, 2.3 mm Al at 70 kV as an accepted value of FDA, **(FDA, 1999).** Half value layers were constant at energies close to that value given by **FDA (1999).** So HVL has an ability to prevent the hazard of soft X-ray by reducing the entrance skin doses during X-ray imaging. HVL is expected of X-ray tube (age), voltage waveform **(Begum *et al*., 2011)**. The dose out, µGy/mAs for each tube voltage for X-ray tubes in the four radiology departments in the interested hospital can be calculated via the empirical equations and used in dose assessment.

CONCLUSION

The quality assurance for radiographic X-ray plays an important role in obtain accurate and timely diagnosis. As the kilo-voltage increases by one the air kerma output increases by 2.83, 1.245, 1.548 and 1.290 at KAMC, HGH, MCH and KFH respectively as presented in figures (1-4). The dose output for each x-ray tube is used as input factor in mathematical patient dose calculation.

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