

Study the Quality Assurance of Conventional X-Ray Machine using Non-Invasive KV Meter

Taha.M.T^{1,2}

¹Atomic Energy Authority - Nuclear Research Center, Radiation Protection Department, Cairo, Egypt.

²Physics Department, Faculty of Applied Sciences, Umm AlQura University, Makkah, P.Box 715, Saudi Arabia

Abstract: This study was carried out to obtain optimum operation conditions for X-ray machines. We investigated some factors affecting on quality assurance of conventional Siemen X-ray machine, in one of Mansoura Hospitals such as reproducibility of dose output, time and applied high voltage, Kilo-voltage accuracy, mA accuracy, time accuracy, and linearity. We measured these factors using Non-Invasive kilo voltage meter, The NERO Max 8000 connected with suitable ionization chambers that located at 100 cm source to image detector. Reproducibility of dose output was ranged from 0.1 to 0.7 %, of time was ranged from 0.2 to 3.1 and of high voltage was ranged from 0.1% to 0.7% which is lower than the tolerance limit of the American Association of Physicist in Medicine reference values. Kilo-voltage accuracy percentage was ranged from 1.5 to 3.5 % and time accuracy percentage was ranged from 0.5 to 4.1 % respectively. This study concluded that as the kilo-voltage increases by one, the dose increases by 28%.

Keywords: Quality Assurance, Reproducibility, Diagnostic X-ray, NeroMax 8000

1. Introduction

The principle goal of quality assurance of X-ray machine is to obtain accurate, timely diagnosis (T.M. Taha, 2010, Ismail, 2015) and low dose to patients (Taha *et al.*, 2014). This can be assessed by performance of the X-ray machine by optimum operating parameters such as reproducibility of tube voltage, dose output, time, X-ray tube efficiency, Accuracy of KVp, mA, time, focal spot size and half value layer. Many authors published work concerning quality assurance of X-ray machine such as American Association of Physics in Medicine (AAPM, 1997) that issued quality assurance protocol for diagnostic X-ray equipment at the radiologic level. The quality of X-ray in terms of the half value layer considered as a part of quality assurance (Stephen *et al.*, 2001). The dose output reproducibility studied based on the procedures for measuring entrance skin exposure (ESE) that used in American Association of Physics in Medicine (AAPM, 1991). Some important parameters in diagnostic X-ray such as exposure time, mAs, peak tube potential, and X-ray output and beam quality were studied based on American Association of Physics in Medicine (AAPM, 1981 and Lipoti, 1997), and decreased entrance skin exposure by 34% for lumbar spine, 46% for chest, and 66% for foot X-ray procedures via improve the kVp and mAs, time accuracy control parameters that affecting on patient radiation exposure. (Timins *et al.*, 2007) mentioned that the mean entrance skin exposure (ESE) for post anterior chest X-rays had dropped by 39%, the ESE for anterior-posterior lumbar spine films had decreased by 18%, and the ESE for anterior-posterior foot x-rays had declined by 48% due to improve the quality control.

Our aim in this study was to investigate some factors affecting on quality assurance of conventional Siemen X-ray machine of Mansoura Hospitals. These factors include reproducibility of dose output, time and applied high voltage, Kilo-voltage accuracy, mA accuracy, time accuracy, and linearity to control the patient dose and ensure that the dose output does not exceed the reference values.

2. Material and Method

The NERO Max consists of the control console, detector cable, two filter cards, mA's leads, Excel Add-in, AC adapter, and HVL plates; the compact control console houses the rechargeable battery, supper bright easy to read backlit display, eight control buttons, and the sophisticated electronic necessary for accurate, reproducible measurements. Connectors or power input, RS-232, printer, scope output and the NERO max detector contains sensors for simultaneously measuring KV, exposure or rate and mAs. Solid state detectors are used to measure KV, an ion chamber, located in the top of the detector, is used for exposure rate measurements. The filter cards contain the various filters needed to accurately measure kilo voltage. Each filter card is coded so that the NERO Max "knows" which filter is in use and its position. Reproducibility of dose, time and high voltage parameters for Siemen X-ray machine of one of Mansoura Hospitals measured with the NERO Max that connected with detector that placed on the couch inside the selected field size and six exposures were made. The reproducibility P_z was calculated using the formula

$$P_z = \frac{SD}{Z_{av}} \times 100\%$$

Where : SD is the estimator of standard deviation of a series of measurements dose [mGy], time [ms] or voltage [KV], Z_{av} is the means value of the parameters measured [dose [mGy], time [ms] or voltage [KV].

Accuracy of measurement is defined as the degree of closeness of measurements of a quantity to that quantity's actual (true) value. Accuracy of tube voltage and time setting was examined for each machine. Six exposures were recorded for tube voltage and time accuracy. The accuracy R_x was calculated using the formula

$$R_x = \left| \frac{X_m - X_n}{X_n} \right| . \%$$

Where: X_m is the measured value of time [ms] or voltage [KV], and X_n is the nominal value of time [ms] or voltage [KV]. Extensive measurements made to assess of changes in KV_p , mA, s and mAs on reproducibility and linearity of radiation output. It formed over a range of clinical settings. Calibrated ionization chamber used to measure output expressed as μGy per mAs, at a set distance, without backscatter. The linearity was checked using the formula (FDA,1999).

$$\frac{|X_1 - X_2|}{X_1 + X_2} < 0.1$$

Where X_1 and X_2 are two successive readings

Linearity between applied kilo-voltage and the dose output was studied for Siemen X-ray machine. The physical Siemen X-ray machine was adjusted at 10 mAs and 500 mSec. The source to image distance (SID) was adjusted at 100 cm where the ionization chamber of the NERO Maxlocated in center beam axis to avoid heel effect.kV, mA and time accuracy were performed by made the operating conditions constant and change these parameters over a range of clinical settings.

Beam Quality

Filtration of X-ray machine was measured at 70 kVp, 32 mAs, 200 Ma, 0.16 sec and source to detector distance 66 cm. The dose output was measured using Nero Max-8000. The dose output was measured with different thickness. The thickness which gave half of zero doses is considered as the half value thickness. It is the thickness of some standard material required to reduce the intensity of a beam to one half of its original value, (Cember and Johnson,2009).

Determination Focal spot size using STAR resolution pattern

Focal spot is defined as the area on the target of the X-ray tube which the electron stream strikes and from which x-rays are emitted. called also focus. The imaging diameter of star resolution pattern was measured via fixation the star resolution pattern in outrance of x-ray beam and record its image on the x-ray film. From the image the focal spot size for x-ray machine under study was calculated using the following equation.

$$f = \frac{\pi \theta D}{180} \text{ (M-1)}$$

M = Imaging diameter /Original diameter

D: the internal diameter between starting and ending the resolution

$$\theta = 2^\circ$$

F = focal spot size, mm

X-ray Beam Alignment

The X-ray beam alignment was checked using perpendicularity of reference axis with table/Bucky with field size of 20 x 20 cm, 5 mAs, 70 KVp and 100 cm source to detector distance. To ensure within acceptable limits that the x-ray field is of appropriate size and aligned with the image receptor. The X-ray beam alignment was carried out for six machines of the same type and manufacture in Al-Khair hospital, Mansora City, Egypt.

3. Results

3.1 Reproducibility

Reproducibility for applied kilo-voltage, time, dose output for six X-ray machines were carried out six times for each machine numbered from M1 to M2 and presented as shown in table (1).

Table 1 Reproducibility for applied kV, time and dose output (μGy) for six X-ray machines numbered from 1-6 were presented as shown in table (1).

Table 2: Reproducibility for applied kV, time and dose output (μGy).

Machine No.	FFD	Reproducibility (CV%)		
		KVp	Time	Dose output
M1	100 cm	0.70	0.20	0.1
M2	100 cm	5.6	3.10	0.2
M3	100 cm	0.10	0.15	0.4
M4	100 cm	0.60	0.16	0.1
M5	100 cm	0.56	0.30	0.1
M6	100 cm	0.15	0.20	0.7

Reproducibility of kilo voltage was ranged from 0.1% to 0.7% except machine no 2 which have 5.6 CV% which is higher than the tolerance (<5%), of time was ranged from 0.2% to 3% which is lower than the tolerance (<5%) and of dose output was ranged from 0.1 % to 0.7 % which is lower than the tolerance level (5%) (FDA,1999).

kV and Time accuracy

KVp Accuracy for different settings of six X-ray machines was examined by setting the source to detector distance at 66 cm of exposure, 12 mAs for different KV interval from 50-100 KV and average of KV accuracy (error accuracy) was presented as shown in table 2.In addition time accuracy for X-ray machines was checked by variation the time interval from 50-1000 second as shown in table (2).

Table 2: kVp Accuracy at source to image detector 100 cm and 12mAs

Machine No.	Mean KVp % Error	Mean time % Error
M1	1.50	3.00
M2	20.00	4.21
M3	5.00	4.20
M4	1.74	3.70
M5	4.00	4.10
M6	1.30	3.80

P/F: pass/fail

Kilo-voltage Accuracy is good for all the machines except one machine which gave accuracy 20% which is higher than the tolerance limit ($\pm 5\%$). That means this machine needs calibration. Time accuracy is good at all-time settings setting stations for all examined machine which is lower than the tolerance limit ($\pm 10\%$). (Lipoti, 1995).

3.2 mAs Linearity

Linearity of X-ray machine in Abu Alkhair hospital of Al-Mansoura hospital 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 shown in table 3.

Table 3: Linearity for SiemenX-ray machine in AbuAlkmaar hospital of Al-Mansoura hospital at kV=81, SID=100, time=500

Machine No.	Linearity Coefficient
M1	0.10
M2	0.20
M3	0.09
M4	0.08
M5	0.07
M6	0.08

The mAs linearity in this study for six X-Ray units is vary from 0.07 to 0.09 which was in the tolerance limit (<0.1) except two machines linearity is out the limit 0.1 and 0.2 which indicate that this two X-ray unit need urgent calibration.(FDA,1999).

3.3 Linearity of Tube Kilo-Voltage

Applied tube voltage is directly proportional with output dose. As the kilo-voltage increases by one the dose increases by 28% of a dose as presented in figure (1).

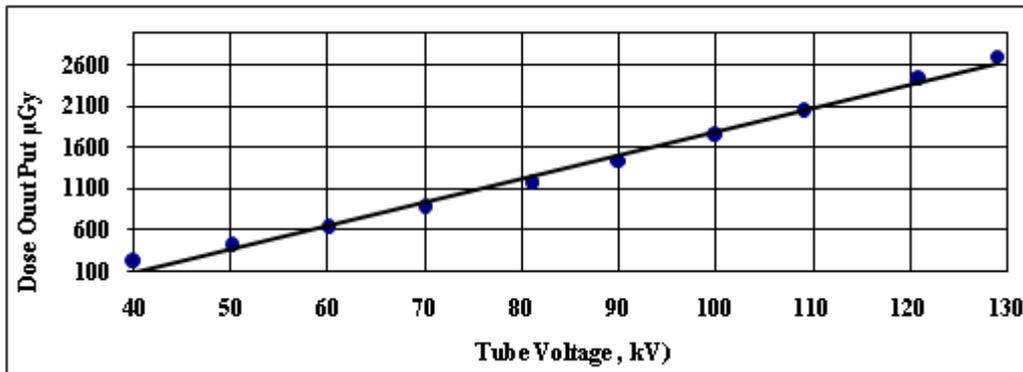


Figure 1: Relationship between tube voltage kV and Dose output, mGy

From figure (1) a tube voltage (kV) can convert into air absorbed dose by equation (1)

$$y = 28.22x - 1028 \quad (1)$$

Dose in $\mu\text{Gy}/\text{kV} = 28.22$, so $1 \mu\text{Gy} = \text{kV} \times 28.22$

Beam Quality

Half value layers were calculated as shown table 4. that thickness has an ability to prevent the hazard of soft X-ray, by reducing the surface doses during X-ray imaging.

Table 4: Measurement of the Half value thickness

Machine No.	Half Value Layer, mm
M1	2.31
M2	2.40
M3	2.70
M4	2.32
M5	2.60
M6	2.40

Half value layer, is exceeding the minimum value, passed above 2.3 mm Al at 70 KeV. This is within the accepted value of FDA (FDA,1999).

Focal spot size using STAR resolution pattern.

The results of focal spot size estimation are presented as shown in table 5. The estimated focal spot size was compared with assigned value stated by the manufacture and was within the tolerance level ± 0.3 nominal focal spot. The size of the radiation source has considerable impact upon the resolution in the image. The result of focal spot size was in range from 0.87 to 1.52 mm and was within the range

published by (AAPM, 1981, FDA,1999and Plotti,1995) respectively.

Table 5: Focal spot sizes for some conventional X-ray machines

Code	"Nominal size" mm	Acceptable size, mm	Estimated size, mm
M1	1.3	1.6	1.52
M2	1.0	1.3	1.008
M3	0.9	1.2	0.870
M4	1.0	1.3	1.07
M5	1.0		1.12
M6	1.2	1.5	0.87

X-ray Beam Alignment

The beam alignment was calculated as shown in table 6.The measured X-ray beam alignment provided to align the center of the X-ray field with respect to the center of the image receptor lower than 2 percent of the source-image receptor distance(SID) as mentioned in (FDA,1999).

Table 6: X-ray Beam Alignment %.

Machine No.	Perpendicularity, cm
M1	0.7
M2	0.4
M3	0.6
M4	0.3
M5	0.5
M6	0.6

4. Discussion

The output of the system was evaluated using a fixed and reproducible geometry (AAPM-1991).Coefficient of variation for dose output was 0.003. All the calculated dose

coefficients were lower than the tolerance levels of AAPM, (AAPM, 1990, 1981). Time Reproducibility will mean the degree of agreement between several measurements of the exposure time at the same indicated time on the X-ray control panel. The accuracy and reproducibility of the timer stations on diagnostic X-ray equipment are important because they directly timer reproducibility affect the mAs and hence the amount of radiation emitted (AAPM-1991). The coefficient of variation of time reproducibility was 0.001. timer reproducibility was good and resulted normal reference radiation dose. Peak tube potential –kVp provides a measurement of the peak electrical potential across the X-ray tube when it is operating. The X-ray tube kVp is most critical. A small error of this variable will have a greater effect on the final radiographic image than will an equivalent variation in any of the other parameters such as tube current (mA), exposure time, target film distance. The X-ray intensity reaching the image receptor after the beam (AAPM-1991). Peak tube potential –kVp was 0.01 and within kV accuracy as mentioned in American Association of Physics where the measured kVp within ± 5 kVp of the set value between 65 and 95 kVp, which are used in (AAPM-1991) and close to values published by (Ismail, 2015). Kilo-voltage Accuracy was studied for Siemen X-ray machine in AbuoAlkhair hospital of Al mansoura hospital and was ranged from 1.5 to 3.5 % and was within kV accuracy as mentioned in American Association of Physics in Medicine. KV accuracy was good at all kVp stations. Time Accuracy was studied for Siemen X-ray machine in AbuoAlkhair hospital of Al-Mansoura hospital and it was ranged from 0.5 to 4.1 % and was within the time reproducibility as mentioned by (AAPM.1991)., Time accuracy was good at all time station. Linearity of X-ray machine was studied and coefficient of linearity was lower than 0.1. Half Value Layer, HVL for Siemen X-ray machine at AbuoAlkhair hospital of Al-Mansoura hospital was studied at 70 kVp, and at 20 mAs, 100cm source to image distance. 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.

5. Conclusion

Reproducibility of dose output was ranged from 0.1 to 0.7 %, of time was ranged from 0.2 to 3.1 and of high voltage was ranged from 0.1% to 0.7% which is lower than the tolerance limit. Kilo-voltage and time Accuracy were within the tolerance levels. The quality assurance tests of X-ray machines under study obtained accurate and timely diagnosis. As the kilo-voltage increases by one the dose increases by 28% of a dose. The measured HVL thickness has an ability to prevent the hazard of soft X-ray by reducing the surface doses during X-ray imaging. The obtained focal spot size was small leads to obtain at a good image quality.

The findings support of the importance of the on-going quality assurance program to ensure the stability of parameters that affecting on patient doses. The quality assurance program should generalize for all hospitals to ensure the quality of the X-ray machines under services.

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