Study the Quality Control for Three Diagnostic X – Ray Machines

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ABSTRACT _ It is crucial to study the diagnostic X – ray machines characteristics and factors that affecting the quality of beam and dose delivered to patients like reproducibility of tubes voltage ,dose output ,exposure time ,accuracy of KVp , exposure time (msec) ,mAs linearity ,x-ray tube efficiency and half value layer to reduce the dose delivered to patients . The values of these x – ray examinations are assessed and then matched to the international tolerance limit . The measurements were done via tests of quality control as acceptance procedures.The main aim of a radiology quality control (QC) program is to reduce the exposure dose for patient , increase the efficiency and the long – life of machines , and improve quality of image. The diagnostic X-rays effective energy is important for the quality assurance and the quality control purposes .All X – ray machines don't constantly produce similar x-rays quality for a specified voltage. Such thing might be because of non-correct calibrating, oldness of machines , wave form and different reasons . Diagnostic x –ray beam quality is often demonstrated by the KVp and the filtrating or , the 1/2 – value layer (HVL) in millimetres of aluminum . Three conventional x – ray machines (Philips , Toshiba , and Mobile) in radiation department at UROLOGY and NEPHROLOGY center in Mansoura were under investigation .

Key words : Quality Control , X-Ray , Half-Value Layer , Kilovoltage , Exposure time , Filtration.

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1 INTRODUCTION:

The aim of quality control programs of diagnostic x-ray machines is to reduce the exposure dose for patient , increase the efficiency and the machines long –life , and improve quality of image [1] . this can be assessed by testing the parameters of the x-ray machine like reproducibility of dose output ,tubes voltage , time , accuracy of KVp, time , mAs linearity, and HVL[2].

While taking radiographs, the tube current association , kilovoltage , exposure time, and the x-ray beam filtration are factors affecting the photons number and the spectrum of energy .

For the purposes of the exposure time test, determining the accuracy and the reproducibility of exposure time at fixed potential diagnostic x – ray machines. The accuracy of exposure time means that the agreement degree between the evaluated and selected time values. Reproducibility denotes that the agreement degree between many measuring of the exposure time values at similar selected time on the control panel of the x – ray. The reproducibility and the accuracy of the time on the equipment of the diagnosing x – ray are vital as they influence the mAs and the quantity of radiation produced. For the purposes of the Peak Tube Potential – KVp is to measure the peak electric potential through the X-ray tube whenever it's working. The KVp influences the intensity getting to the image receptor and the images contrasting. The assessed KVp must be in ±5 KVp of the set value between 65 and 95 KVp , for all mA stations that are applied [3] .

Milliampere-second (mAs) is the numerical product of the milliamperage and the time in (sec). With all the other factors held constant, the density of the film is related to mAs and will not change as the time and the mA are varied; as long as they are varied reciprocally and their product is unchanged [4].

The spectral distribution (curve A) is not preferred to diagnostic radiology for two reasons . Firstly, x – rays with low energy do not have enough energy to get via the case and don't give any diagnosing information on the film or image receptors , but skin is exposed to unnecessary exposure as the x-rays are sufficiently energetic to get through the skin . Secondly , the image contrast depends on the energy of the x-ray producing the image . Luckily, there is an easy technique to beat those problems, thru using filtrating .

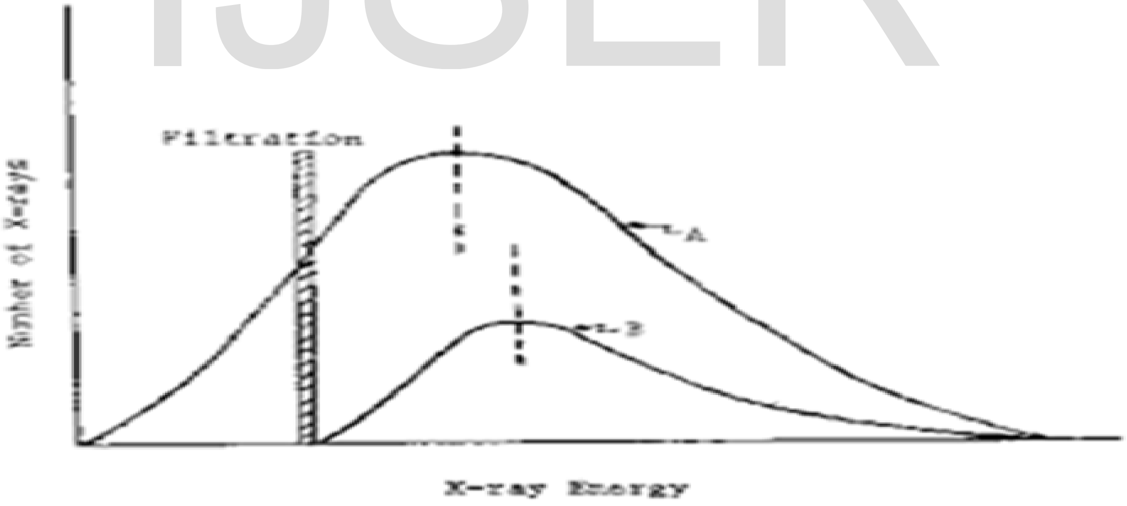

Figure (1): An x-ray spectrum ; curve (A) an x-ray spectrum devoid of any filtrating, and curve(B) is similar spectrum with the beam filtered.

Like demonstrated in the previous figure, curve A is an X-ray spectrum with no filtrating, and curve B has similar sprectrum with filtration of the beam. The filtrating eliminates photons which have lower energy and the effective energy turns out to be higher than before. By adding more filtrating , the effective energy increases , produces a useful image , and the penetrability (quality) is also increased . In radiology, the x –

rays quality is distinguished numerically thru half – value layer. Though any material might be utilized for filtrating, aluminum is the foremost frequent substance as it's non-expensive, simple to use, light weighted, and has necessary absorption characters for energies of diagnosing x – ray . The HVL need is stated in terms of mms of aluminum equivalence [5] . The HVL of a beam of x – ray is the thickness of the absorbing substance which must be put in the beam to decline the transfer of the beam thru one half [6] .

Studies were done by Hollins , Jankwoski et al . proved that carrying out the quality controlling regimens on radiological x – ray machines reduces the dose absorbed by patients by 30 – 50 % [7][8] .

In a previous research , the Quality Assurance of traditional X – ray devices utilizing non-invasive KV meter has been assessed. Study few elements influencing the quality assurance of diagnosing X-ray like reproducibility of KVp , time , dosage , x – ray tube efficiency , Accuracy of KVp , mA , time , focal spot size , and the HVL .The exams of the quality assurance of X-ray devices under research attained precise and timely diagnoses. The assessed dosages output have been within the international reference dosages [9].

In another study by Oluwafisoye et al., studied tests of the quality control of 5 X – ray devices undertaken with aim of security and dosage optimizing in the centers of the X – rays . The oldness of 3 out of 5 devices are well through 10 years . additionally, the assessed KVp deviation from set value upon the control panel differed amongst facilities. 2 out of 5 devices conformed with the needed standard of application , whilst 3 devices surpassed the need. The exam of the quality control done on KVp accuracy and consistency demonstrate non-compliance in 2 facilities [10] .

Al-kinani et al., Studied the quality assurance of 6 traditional x – ray devices in medicinal city at Baghdad of various sources and various manufacturing times [11] .

Ismail et al., Evaluate quality control (QC) of X – Ray Units at Khartoum State facilities . Evaluates some of x – ray machine distributed at Khartoum state hospitals in terms of quality control and few elements influencing on image quality and patient dose of diagnostic x – ray like reproducibility of dose output , tubes voltage , time , Accuracy of KVp , time , and check the Coincidence of light field with radiation field and check the fog level in darkroom [12] .

Akpochafor et al., assess the accuracy of the peak kilovoltage in ten X – ray centers in South – Western Nigeria . Carried out the quality control test to determine the energy output accuracy of the X – ray generator . 1/4 of the absolute accuracy of KVp outcomes have been over ±5% tolerance limits. Old device had greater opportunities of failed accuracy of KVp . Hints of failed exam have been noted in devices lower than five years [13] .

The goal of such study is to assess some factors influencing quality control of 3 diagnostic x – ray devices like reproducibility of time , dosage output , tubes voltage , accuracy of KVp , exposure time , mAs linearity , and half – value layer . Using SpekCalc program for determining the HVL and effective energy values at 80 KVp .The HVL and effective energy were determined experimentally by Toshiba machine and theoretically using SpekCalc program at 80 KVp.

2 MATERIAL AND METHOD:

This study was conducted with three conventional X – ray machines (Philips,Toshiba,Mobile machine) in radiation department at UROLOGY and NEPHROLOGY center in Mansoura . Quality control tests [Accuracy of time and KVp , reproducibility of time , KVp , and dose , mAs linearity , HVL] were carried out .

2.1 Philips X-ray machine

Philips (M1) Model OMNI DIAGNOST ,Biomed Number 02/dia/xry/02 ,Location is in Radiology Department (Main hospital) , Tube S/N , and Housing Insert 4154910/000356 .

2.2 Toshiba X-ray machine

Equipment is an X – RAY machine is manufactured by TOSHIBA (M2) , input 12V/100V ~ 50/60 Hz , Max. Input power 100VA , 10.5W ,Max. tube voltage 150KV , and the Min. filtrating in the collimator is 1.2 mm Al correspondent (at75 KV , first half value layer : 2.7mm Al). Model BLF – 15B, Serial Number J4D1646599 , the Constant filtrating in the tube of the X – ray is 1.0 Al/75, Tube type G – 1598TRI , and Located in Radiology Department (Main hospital). Cathode material is tungsten and anode (target) material is also tungsten . The Toshiba machine has an anode angle of 12° . Nominal focus of 1.0 .

2.3 Philips X-ray machine

Philips (M3) Model PRACTIX 400 ,Location is in Radiology Department (Main hospital)(IC). Manufactured date is October 2001 ,Tube S/N , Housing insert 44114 – 1V , and Filtration 0.6 Al .

2.4 X2 unfors Raysafe sensor

X – ray dosimeter and electrometer calibrated for x – ray beam quality. X – ray solid state dosimeter (ray safe X2) Model R/F sensor , Serial number 208556 and designed by unfors Raysafe made in Sweden .

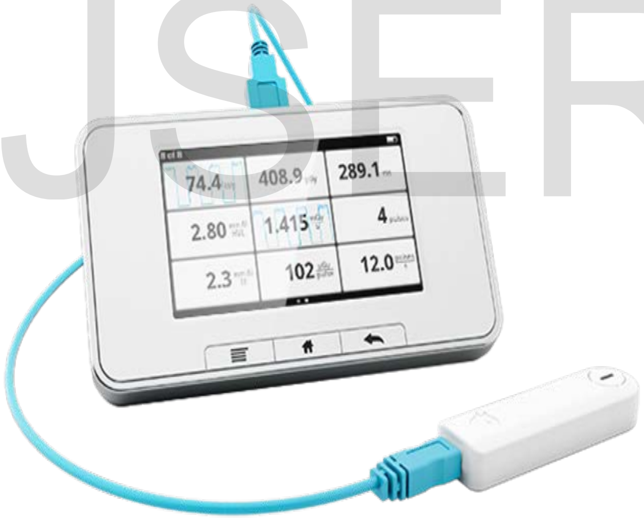

Figure (2) : X2 unfors Raysafe sensor

2.5 Aluminium filters

Aluminium sheets (attenuators) are used in Half – Value Layer test of 7 cm x 7 cm with different thicknesses of (0.1 , 0.5 , 1 , 2 ,….,5) mm have been utilized in such research . The aluminium attenuators density is 2.699 g/cm3 . Nominal composition : 99.5% minimum Aluminium , Si < 2500 ppm , Fe <4000 ppm , Cu <500 ppm , Mn < 500 ppm , Zn < 700 ppm , Ti < 500 ppm , Other each < 300 ppm . Using Al filters as additional filtration .

2.6 The SpekCalc program

A program is utilized to measure X – ray photons spectrum from anode of tungsten at X – ray tubes. SpekCalc has been created by REAL basal and editions executable are obtainable for mutually Mac O/S and Windows. In screenshots of the Graphical User Interfaces (GUI) ; the user selects the electron energy in KeV, the anode angle (θ) and the amount of filtration (Total filtration) (mm) . Then , clicking the < Calculate > key, a spectrum is shown in few secs. The potentials ranging which may be used is broad (40 – 300 KV) making the utility useful to both the superficial/orthovoltage radiotherapy fields and the diagnostic imaging ; anode angles with a maximal of 90^o in regard to the axis of beam. And the bremsstrahlung and characteristic tube output (μGy/ mAs @ 1m) are shown.

2.7 Quality Control tests

2.7.1 The reproducibility measurement

Put the x – ray dosimeter at the focus of the beam axis of the x – ray table at a Source-to-Image Distance of hundred cm (SID) where SID is the difference from the target (anode) of the X-ray tube to the X-ray film or other image receptor [4] , 80 KVp ,and 20 mAs was set on the machine control panel .The x – ray dosimeter is placed about 30 cm above the x – ray table to minimize the scattering influence which tends to increase the HVL value,so the source to dosimeter distance (SDD) 70 cm.

Use large focal spot , where focal spot is the area of anode where beam of x-ray is produced [4] , and determine the x – ray field which is minimum field to cover the x – ray dosimeter at the table i.e. X – ray dosimeter is completely contained in the X – ray field of 10 x 10 cm as shown in figure (3). Take five exposures and record the output (dose) , KVp , and time for each exposure . Then, we can know if there is a reproducibility problem or not , then calculate the coefficient of variation (CV%).Reproducibility of tube voltage , exposure time , and dose were measured . The Coefficient of Variance has been measured by the formula (1) :

$$CV = SD/Z_{av} . 100\% \quad (1)$$

Whereas : SD the standard deviation detector of a sequence of measuring dosage [mGy], voltages [KV] or times [ms] , Zav the mean value of the parameters assessed dosage [mGy], voltages[KV] or times[ms] [9][12].

The reproducibility (repeatability) of time in a fixed exposure time set on every radiology X-ray device, the exposure time measured is equal to the value set on the radiology x – ray machine (fixed exposure time). The reproducibility (repeatability) of the output of x – ray tubes means that giving the same values of radiations in a radiology x – ray machine in a stable radiation conditions which are 80 KVp ,fixed time,20 mAs and 100 cm SID . The reproducibility (repeatability) of voltage in a stable peak of 80 KV set on the radiology x – ray machine , the value of the evaluated voltage is equivalent to the voltage value modified on the x-ray device (stable peak of KV) [14] .

2.7.2 The kilovoltage (KVp) and exposure time accuracy test

The peak kilovoltage (KVp) is recognized as the maximal value of voltages at any time through the exposure and is a vital parameter of an X-ray device [13]. KVp accuracy for various settings of 3 x-ray devices where voltage has been assessed by setting the x – ray dosimeter at the focus of the beam axis of the x – ray table at the source to dosimeter distance (SDD) 70 cm of exposure for different KVp intervals from 50-120 KVp and 20 mAs was set on the machine control panel .The x – ray dosimeter is placed about 30 cm above the x – ray table to minimize the scattering influence which tends to increase the value of HVL . Use large focal spot , and determine the x – ray field which is minimum field to cover the x – ray dosimeter at the table i.e. X – ray dosimeter is completely contained in the X – ray field of 10 x 10 cm . At each set KVp on the controlling panel , the evaluated KVp has been recorded , then accuracy of the tube voltage[%error] was calculated using the equation (2) :

$$\%\mathrm{Error} = |\mathrm{Xm} - \mathrm{Xn} / \mathrm{Xn}| . 100\% \qquad (2)$$

Where : Xm the assessed value of voltage [KV] or time [ms] from the non-invasive meter ,and Xn the nominal value of voltage [KV] or time [ms][12][9] from the controlling panel of the x – ray device. The mean of KVp accuracy has been presented like demonstrated in table (2) for three x - ray machines .

For accuracy of exposure time for the diagnostic x-ray devices has been checked by variation the time interval from 500-2000 millisecond (msec) and at 80 KVp , 20 mAs and SID = 100 cm and the mean of time accuracy shown in table (2) for the three machines . Time accuracy test is not carried out for Toshiba , and Mobile machines because these machines have automatic system and cannot change the time , where the x – ray machines are equipped with an automatic exposure control device . So that this test is cancelled for these machines .

2.7.3 Milliampere-second (mAs) linearity

Put the X – ray dosimeter as mentioned in the other tests . Select 80 KVp and select the lowest mAs station within the normal range of use (5 to 80 mAs) . Take an exposure and record the output (micrograys). Select the next higher mAs station adjacent to the first mAs station . Ensure that the kilovoltage is maintained at 80 KVp throughout the test. Take an exposure and record the output (micrograys) . Repeat steps until all adjacent mAs stations in the normal range of use have been checked , which starting at the lowest mAs setting used , then double each subsequent setting up to the maximum mAs used . Calculate the μGy/mAs for each station checked . Then calculate the coefficient of linearity (CL) for each machine using the equation (3) . The average of linearity coefficient is calculated (CL) for each machine as shown in table (3).

$$\text{Coefficient of linearity (CL)} = \frac{(\frac{D}{X})_{\max} - (\frac{D}{X})_{\min}}{(\frac{D}{X})_{\max} + (\frac{D}{X})_{\min}} < 0.1 \qquad (3)$$

Where : D is the Entrance Surface Air Kerma (ESD) values founded upon ten exposures at every 2 successive x-ray tube current sets, and X is the exposure (mAs)[11].

2.7.4 Half – value layer measurement

HVL is an essential test of quality control as it is used to measure if or not there is sufficient filtration in the beam of x-ray to remove photons with low energy, which can be damaging. The 1/2 – value layer assessed the quality of the X – ray beam . The X – ray dosimeter was used to measure the output of X – ray machine and put it at 30 cm above the X – ray table to minimize the scattering influence which tends to increase the HVL value . The X – ray dosimeter has been placed seventy cm perpendicular to the x-ray tubes. The X-ray dosimeter has been totally collimated in the fields of X-ray and has been placed in the centre of the ten xten cm field .HVL measurements should always be made under narrow-beam geometry conditions to ensure that only primary (unattenuated) photons reach the detector as shown in figure (3).The KVp was set at 80 , mAs at 20 ,and source to image distance 100 cm [SID].

Figure (3) : the x – ray dosimeter at the focus of beam axis of the x – ray table at a focus to image distance of hundred cm , and use minimum field to cover the x – ray dosimeter at the table in radiation department in UROLOGY and NEPHROLOGY center in Mansoura (illustrates the experimental set-up and the instruments used).

The 1st measuring has been performed with no usage of the aluminum attenuator. Then, the measuring has been done once more whilst incrementing the thickness of aluminum between the X-ray tube and exposure meter. The exposure of aluminum by half mm every time till the exposure dropped to less than fifty percent of the original non-attenuated value. A graph of the dosage versus the thickness of aluminum has been ploted. From graph , the aluminium thickness needed to decline the non-attenuated dosage by fifty percent is the radiation beam HVL. The dosage output has been calculated by unfors Raysafe sensor (x-ray dosimeter).

HVL is the thickness of few standard substance (e.g. aluminum) needed to decrease the beam intensity to 1/2 its initial value[9][15][11]. This thickness has an ability to prevent the soft x-ray hazard , by decreasing the surface dosages through imaging of x-ray [9].

2.8 Determination of half-value layer and effective energy using SpekCalc program

By using SpekCalc program , through GUI ; select peak energy at 80 KVp, X – ray anode angle (θ) = 12° , the amount of filtration (Al thickness) equals (total filtration 6 mm) and air thickness equals 700 mm. Then click < Calculate >and record the value of HVL and the effective energy at 80 KVp . Then the SpekCalc HVL and the Eeff were compared with the Toshiba x-ray machine HVL and the Eeff at the same KVp. The quality of beam depends on the filtration , tube voltage , and anode angle ; so SpekCalc was used to mimic spectra with similar parameters like the device utilized in direct measuring. The quality of beam detected through direct measuring has been considered to be the standard.

3 RESULTS AND DISCUSSION:

3.1. Reproducibility Measurement:

Machine No.	Reproducibility (CV%)		
	dose	KVp	time
Philips (M1)	0.914%	0.0902%	0.082%

TOSHIBA (M2)	1.052%	0.0886%	0%
Philips (M3)	0.05678%	0.055362%	0%

Table(1) : Reproducibility for the three machines

As demonstrated in table (1), reproducibility of dosage output has varied from (CV%) 0.914 percent to 0.05678 percent that is lesser than the tolerance value (<5%) [4].Reproducibility of time has varied from 0.082 percent to 0 percent that is lesser than the tolerance (<5%), and of high voltage has varied from(CV%) 0.0902 percent to 0.055362 percent that is lesser than the tolerance value (<5%) [12][16].

3.2 Accuracy of tube voltage and exposure time:

Device No.	Mean KVp accurateness (%error)	Mean time accurateness (%error)
Philips (M1)	1.545%	0.71%
TOSHIBA (M2)	0.374%	_
Philips (M3)	1.453%	_

Table (2) : KVp and Time accuracy for three x – ray machines

KVp accuracy is good at every KVp positions for all the machines that gave %error (accuracy%) equals to 1.545%, 0.374%,and 1.453% which is lower than the tolerance limit (±5%)[9][12][13][14].Time accuracy is good at all time sets stations for the assessed device [Philips] and the mean time accuracy for this machine equals 0.71% which is lower than the tolerance limit (±5%)[4][17].

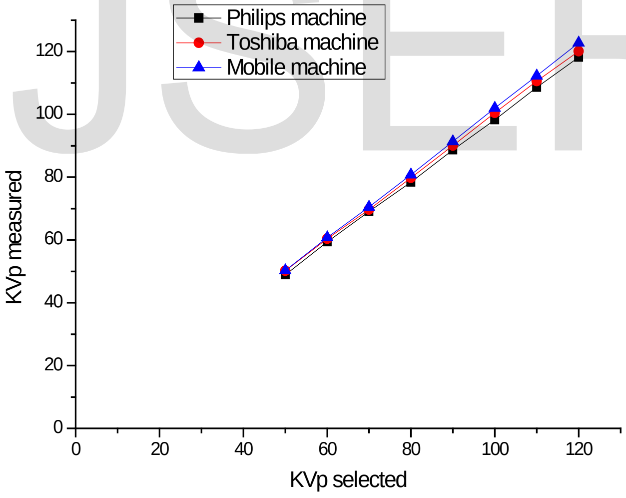

Figure (4) : KVp measured against KVp selected for three x – ray machines

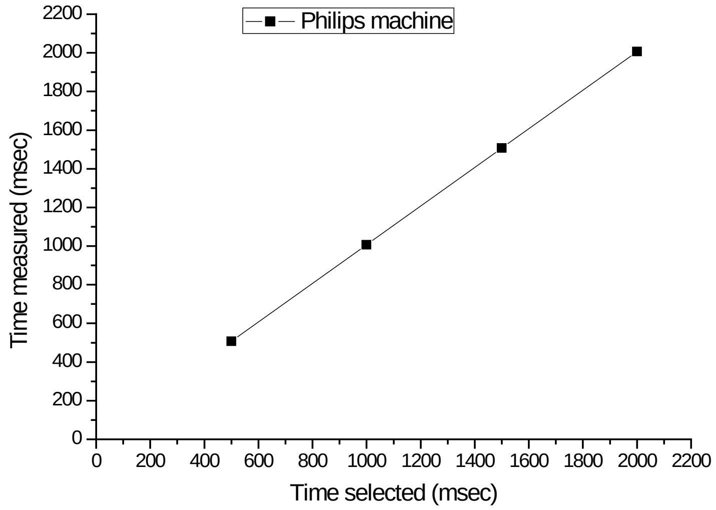

Figure (5) : Exposure time accuracy for machine (Philips) M1

3.3 Tube current exposure – time product (mAs) linearity

Machine No.	CL
Philips (M1)	0.0191
TOSHIBA (M2)	0.0217
Philips (M3)	2.6765x10-3

Table (3) : Coefficient linearity for three x – ray machines

The median of coefficient of linearity (CL) for mAs for the machines M1,M2 and M3 were 0.0191, 0.0217, and 2.6765x10-3 respectively which is not exceed the tolerance limit (0.1). Another method to evaluate the linearity of mAs is to plot mAs on x – axis as functions of dosage (µGy) on y – axis to have visual assessment of the linearity[11]. The plot of tube current exposure-time product as functions of dosage (µGy) was linear as shown in figure (5).

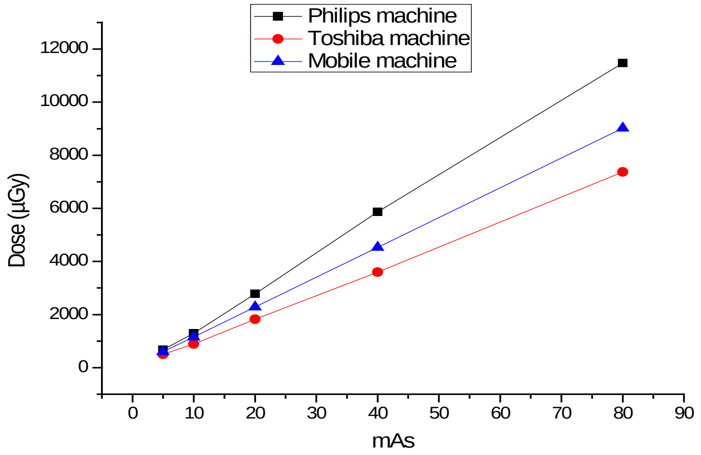

Figure (6) : X – ray tube output (µGy) at 80 KVp as a function of mAs for three x – ray machines; Philips, Toshiba ,and Mobile X-ray machines

3.4 Half-Value Layer (HVL) measurements:

Machine	HVL (mm)	μm (cm²/g)	Effective energy (KeV)
Philips	3.7 mm	0.69 cm²/g	37.5 KeV
Toshiba	3.62 mm	0.71 cm²/g	37.3 KeV
Philips (portable or mobile machine)	3.6 mm	0.72 cm²/g	37 KeV

Table (4) : HVL and Eeff for three x – ray machines

The thick of aluminum needed to decrease the beam intensity to one 1/2 of its original value , HVLs were 3.7 mm , 3.62 mm, and 3.6 mm for machines Philips, Toshiba, and Mobile correspondingly. HVL is surpassing the minimal value ,crossed over 2.3mm Al at 80 KVp . This is within the accepted value of IAEA [4]. The HVLs determined from the direct measurements for the three machines have been utilized to detect the effective energies.

The effective energy of the Philips X-ray device was higher than the Toshiba and Mobile X-ray device due to the thicker filtrating in the aluminum equivalent inside X-ray tubes of Philips [18] .

Determine the attenuation coefficient (μ) by using the determined HVL using equation 4 :

$$\mu = \frac{\ln 2}{\text{HVL}} \qquad (4)$$

Then , obtain mass attenuation coefficient (μm); μ/ρ in which ρ is the material specific mass . It can be found in some books or specifies tables [19] .At National Institute of Standards and Technology (NIST) .The X – ray device effective energy has detected from the mass attenuating coefficient of the aluminum attenuator for 80 voltage utilizing information from the National Institution of Standards and Technology (NIST) [20] .

Parameter	Mean	SD
HVL (mm)	3.64	0.04
Effective energy (KeV)	37.27	0.21

Table (5) : Mean and the standard deviation of half-value layer and effective energy for the three X-ray machines

The mean of the HVLs for the three machines is 3.64 and the mean of the effective energy is 37.27 , while the standard deviation of HVL is 0.04 and for effective energy is 0.21 .

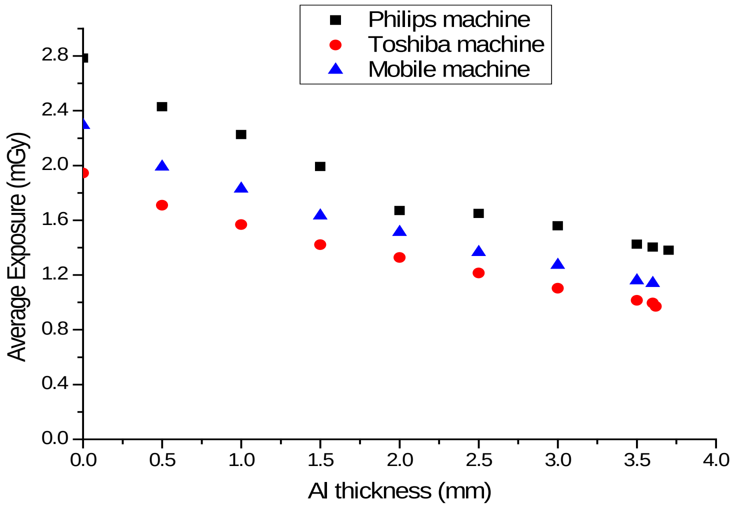

Figure (7) : HVL for three x – ray machines(shows the attenuation curve for Philips ,Toshiba , and Mobile machines at 80 KVp and 20 mAs).

The plot of the dose in a polychromatic beam as a function of the thickness of aluminum will not be a straight line but will be a curve as shown in figure (6) . The initial slope of the curve declines because the photons with low energy are attenuated .

3.5 Comparison between Toshiba x-ray machine and SpekCalc program at 80 KVp and 20 mAs:

Parameter	Toshiba (Experimental results)	SpekCalc program (Theoretical results)
HVL (mm)	3.62 mm	4.36
Eeff (KeV)	37.3	39.4

Table (6) : Comparison of the HVL and Eeff estimations from Toshiba X-ray machine and SpekCalc program at 80 tube voltage

The SpekCalc program was run to mimic spectra with similar parameters like the Toshiba device utilized in the direct measuring .

The total filtrating of the Toshiba X-ray device should be recognized as it's needed like an input parameter for the SpekCalc program . The total filtrating value will affect the theoretical outcomes. The total filtrating of the Toshiba X-ray device has been attained from the label in the X-ray tubes. The filtrating wasn't the real thickness and substance of the filter in the tube yet the thickness in aluminum equivalents.

Without recognizing the real filtrating in the tube of x-ray, the thickness of the inherent filtrating in aluminum equivalents has been utilized like the input parameter in the SpekCalc program. The usage of those filtrations can influence the detection of the beam quality whenever utilizing the SpekCalc program. The beam quality detection with the SpekCalc program shall be affected once the actual filtrationg inside the tube of X-ray isn't identified [18].

The SpekCalc program is utilized to measure X – ray photon spectra from anode of tungsten at X – ray tubes[21] , so Toshiba machine is used because of anode (target) material at its X-ray tube is tungsten.

SpekCalc program is used to calculate HVLs ,using the Physical Reference Data of NIST [22][23] for Al and Cu materials.

4 CONCLUSION

The quality control tests for X – ray machines were good for all machines and were within the tolerance limit . And thus ensure the reduction of the dose , keep the patient from exposure to doses of excessive radiation , maintain the quality of the image , not to repeat the process once again , maintain the age of machines and quality . And therefore must spread quality control program in all hospitals in Egypt to ensure the quality of the x-ray machines .

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