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Performance Assessment of a Digital X-ray Unit in a Private Medical Complex in Riyadh.

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ABSTRACT

Digital radiography allows the user to replace film-screen systems without the need to replace other parts of the X-ray system. The aim of this work is to ensure that radiology facility produces consistently high-quality images with minimum radiation doses to the patients and workers. This is achieved by planning a systematic Quality Assurance (QA) program. A number of Quality Control (QC) tests were performed consisting of a series of standardized procedures developed to detect changes in X-ray equipment's functions from its original level of performance. Four QC tests were acquired and analyzed. The first one is tube voltage, exposure, exposure time reproducibility tests. The main objective of this multi test is to investigate the ability of radiographic unit to produce the same exposure even though in short intervals. Secondly, tube voltage accuracy and kVp accuracy is maintained to ensure that the desired technique is coming out of the tube. After that mAs linearity which is the ability of radiographic unit to produce a constant radiation output for various combinations of mA and exposure time. The forth test is Half Value Layer (HVL) which is the amount of absorbing material that will reduce the intensity of the primary beam to one-half its original value. Finally the image the image quality is also assessed. The digital X-ray machine namely (Siemens 4803404X1953) successfully pass all the QC tests. In other word the calibration establishment accuracy confirm that, the X-Ray machine result is pass. This comply with the Saudi Food and Drug Authority (KSA-SFDA) that covered all medical regulatory aspects of ionizing radiation of diagnostic X-ray facilities for all practices requirements. The obtained results were performed according to the results and recommendations of the AAPM and ICRP103.

Keywords: QA, QC, X-ray, Equipment Assessment, Exposure Measurements.

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INTRODUCTION

Medical practices and hospitals found themselves faced with a new challenge: The rise of digitalization meant that vast amounts of digital image data were being generated on a daily basis. The last few years, medical imaging technology has evolved exponentially, shifting steadily from analogue to digital radiology. A quality assurance (QA) program is basically an organized effort by a facility to ensure that their product is of consistently high quality. X rays are widely used in medicine to provide diagnosis and treatment for patients. On the 9th of February 2022, the authors visited the X-ray room in in Olaya Medical Complex and performed the QC tests focusing on accuracy calibration and the maintenance establishment. The reported QC tests have done according to the intentional standard reports (AAPM No. 74) [1] and National recommendations of King Abdullah City for Atomic & Renewable Energy and Saudi FDA [2, 3]. To calibrate all the exposure parameters and to check functional performance of the X-ray equipment and radiation safety around the X-ray installation. QA checks are necessary for every diagnostic X-ray equipment. The routine QC tests are necessary to ensure that the functional performance of the equipment is similar to its baseline values and within the tolerance values as specified by regulatory body [4]. These tests should be performed at regular intervals (annually) and immediately after repair or part replacement of X-ray equipment [3, 4].

MATERIALS AND METHOD

Digital radiography systems used in this study is from Siemens (see Fig. 1), cover virtually all clinical applications, and offer workflow optimization, imaging excellence. At Olaya medical complex in Riyadh, the quality tests wear performed on digital X-ray machine. The X-ray unit consists of tube type Opti 150-30-50 HC. The RTI Piranha MULTI X-ray meter (see Fig. 2), of (Ocean Next™ software) standard for complies with relevant parts of the standards IEC 61674 and IEC 61676 for Dosimetry instruments [5]. The Electromagnetic Compatibility (EMC) is the term used to describe how well a device or system is able to function in an electromagnetic environment without introducing electromagnetic disturbances that interfere with the operation of other electrical products in the environment. EMC is tested according to the International Electrotechnical Commission (IEC) 61326-1:2012. Thus, it provides quick and repeatable QA work of X-ray parameters. The meter is attached to a laptop that provides both an interactive display during the measurements as well as work as a powerful analysis tool. The equipment used in this work is to measure the QC of the X-Ray unit. At the beginning, according to type and number radiographs, kV, mA, and exposure times, which are mostly used, have been identified and the measurements were carried out within recommended range [6-11].

Figure 1: A photo of the X-ray unit model (Siemens 4803404X1953) manufactured in March 2002 and installed in July 2012.

Figure 2: Show the recommended equipment for performing accuracy of reproducibility of exposure time and other tests: Piranha dosimetry MULTI X-ray meter of (Ocean Next™ software) Standard for Complies with relevant parts of the standards IEC 61674 and IEC 61676 for Dosimetry instruments. Such meter was used for the QC measurements

RESULTS AND DISCUSSION:

The quality control programs for radiography units are essential procedures to produce the desirable image quality, reduce patient dose, as well as reduce the number of repeated radiographic examinations. Parameters affecting image quality have been checked that include operating potential, operating current, Exposure Time, Total Filtration and Leakage from tube housing. In HVL test, the purpose is to measure the quality of the X-ray beam. It is essential to continually assess the diagnostic X-ray machines characteristics and parameters that affect the quality of beam and dose delivered to patients. These include reproducibility of tubes voltage, dose output, exposure time, accuracy of KVp, exposure time (mSec), linearity in (mAs), X-ray tube efficiency and half value layer to reduce the dose delivered to patients. The main purpose of tube voltage, exposure and exposure time reproducibility tests is to ensure continuing production of diagnostic images with optimum quality, using minimum necessary dose to the patient. QC should include checks and test measurements on all parts of the imaging system at intervals not exceeding one year. The Saudi practice for most common digital equipment that the radiographic (X-ray tubes) performed once per year [3, 6]. At first the X-ray field was collimated to the smallest reasonable size. All measurements performed at the middle of the X-ray field. Peak kilovoltages of the beam (kVp) is the first to investigate as this parameter is directly responsible for the maximum energy of the photon beam produced from the tube.

Tube Voltage, Exposure and Exposure Time Reproducibility

The Arrangement of the filament, the focusing cup, the anode surface and the tube voltage generates an electric field accelerating the electrons towards the focal spot at the anode. The machine mAs was set up to 10.0 and the kV was set to 81 and noted down the readings of kV. The same procedure was repeated three times for the voltage of 81 to find the reproducibility of kV, exposure, exposure time reproducibility by using digital kV meter/multifunction meter (See Fig. 2). This is very important in order to determine the variation in average kVp over several exposures at the same generator setting. This is essential as the peak potential of the X-ray generator affects quality of the X-ray beam and exposure to the patient. On the other hand if the exposure time of the X-ray unit is not in order, the radiograph can be under exposed or overexposed. For this, absolute timer method is adopted by measuring set and measured time with digital timers. Fig. 3 show the tube voltage reproducibility teat. The result of accuracy of kVp and time, linearity of exposure with mAs, and reproducibility of exposure are shown in Figures 4-7. Note that the exposure time is measured in impulses because x-rays are produced in bursts rather than in a continuous stream. One impulse occurs every 1/60 of a second. Therefore, 60 impulses occur in one second. Table 1 shows the results of reproducibility of tube voltage (KV), exposure in milligray (mGy) and exposure time. Figure 4 indicates the reproducibility of tube output for X-ray machines in 3 separate ranges of exposure reading.

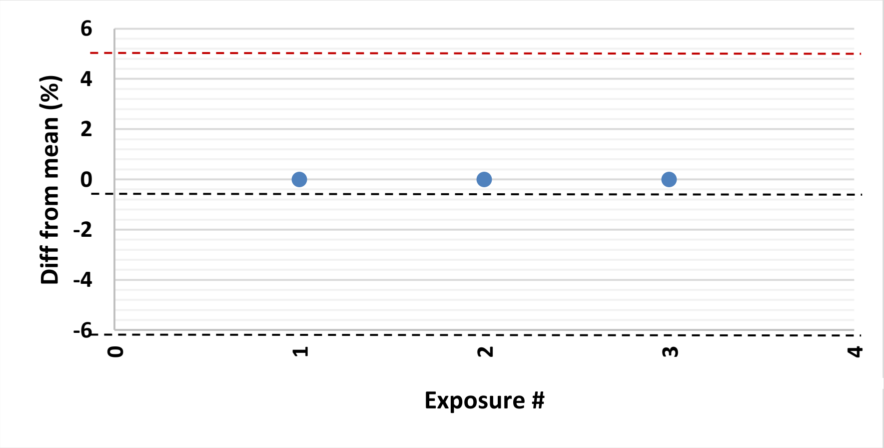

Figure 3: Shows the tube voltage reproducibility teat. The analysis result of Tube Voltage reproducibility is pass as the Coefficient of variation is nearly 0.0% (Limit: 10.0). The mean

value is 80.58 (standard deviation: 0.02 kV). The maximum deviation from the mean value is 0.0 % (Limit 5.0%).

Table1 1: Outlined the measurements obtained by setting the mAs to 10.0 and the KV to 81. The listed results of tube voltage, exposure and exposure time (60 impulses occur in one second) reproducibility indicates a pass

#	Tube Voltage(KV)	Exposure (mGy)	Exposure time in impulses
1	80.60	1.014	42.17
2	80.58	1.015	42.15
3	80.57	1.014	41.67

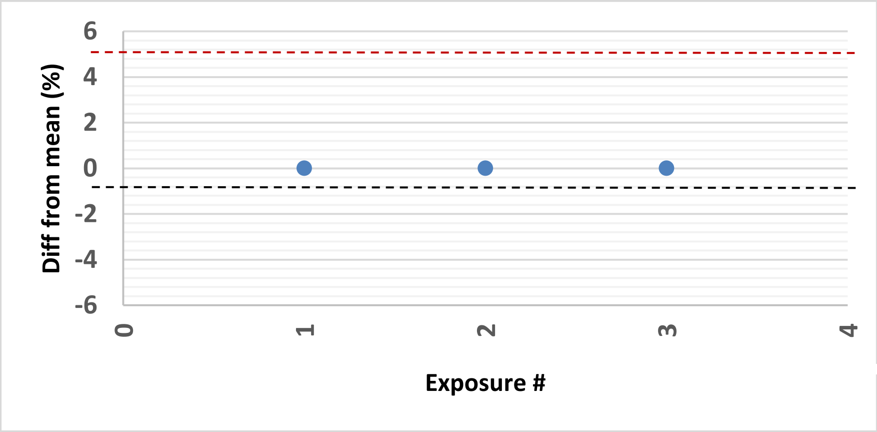

Figure 4: shows the exposure reproducibility test. The Result was passed as the Coefficient of variation is 0.0% (Limit: 10.0). The mean value is 1.015 (standard deviation: 0.0002627 mGy). The Maximum deviation from the mean value was found almost 0.0% and the accepted limit is 5.0%.

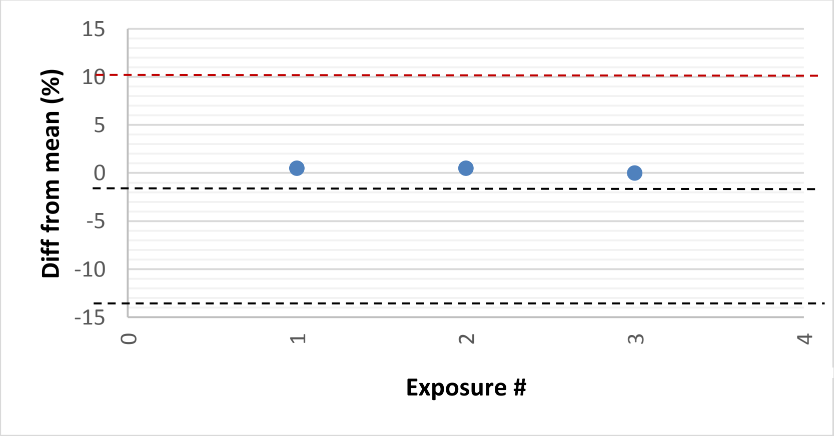

Figure 5: The Exposure time reproducibility test and its result is pass as the Coefficient of variation is 0.7% (Limit: 10.0) and the mean value is 42.00 (standard deviation: 0.2820 mS). The maximum deviation from the mean value was 0.8 % whereas the limit is 10.0%.

Tube Voltage Accuracy:

The main purpose of this test is to set the penetrating power of the X-rays or the quality of the beam. The number set is the highest amount of energy that an x-ray photon could have leaving the tube. It is important that the kVp setting reflects what is actually coming out of the tube to ensure reproducibility. Thus, this test was performed at lowest tube voltage, 50 kV up to 109 kV tube voltage. The highest available tube current (200 mA) and an exposure time of 0.1s were sated. The voltage, time and the output were noted down to find the accuracy of tube output time and kV. The Exposure in (mGy) along with the Exposure time in (mS) were obtained and outlined in table 2.

Table 2: The tube voltage measurements. All the obtained readings indicate that the Tube Voltage Accuracy pass all the tests. Note that the peak potential of the X-ray generator affects quality of the X-ray beam and exposure to the patient.

#	Set kV(kV)	Tube voltage(KV)	kVp diff%	Exposure (mGy)	Exposure time (mS)
1	50	50.66	1.3	0.1851	16.05
2	60	59.95	-0.1	0.2794	15.55
3	70	69.76	-0.3	0.3839	18.09
4	81	80.36	-0.8	0.5098	21.07
5	90	89.71	-0.3	0.6231	23.60
6	100	98.97	-1.0	0.7515	26.11
7	109	108.03	-0.9	0.8818	28.60

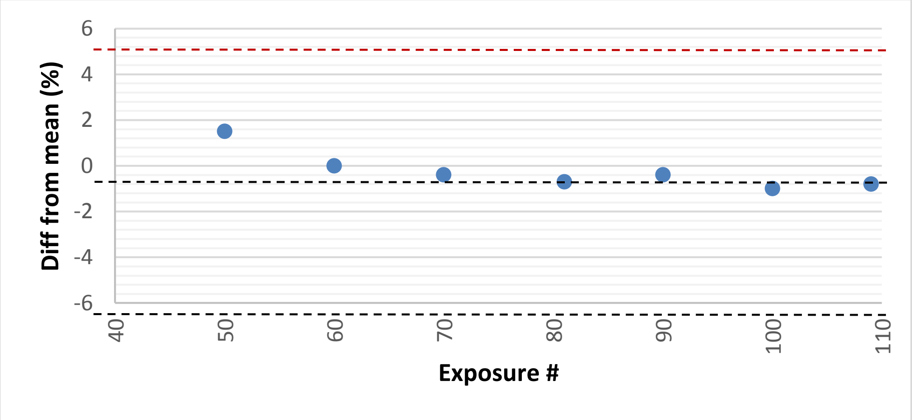

Figure 6: An analysis of the tube voltage accuracy and its result is pass as the maximum inaccuracy is 1.3% at 50.0 kV and the accepted limit is between -5.0% to 5.0%.mAs

Linearity:

In the clinical setting, it is extremely important that all general X-ray units produce a proportional change in exposure as milliamperage (mA) varies. The assumption is that an increase in mAs, should produce proportional increases in radiation exposure. If the X-ray unit is not properly functioning, the unit must be serviced as retested before used again for diagnostic procedures. The main objective of this test is to determine if the X-ray unit produces the same radiation output linearity for the same kVp and mAs regardless of the mA station used. Linearity tests are performed to monitor patient dose and image quality by placing the dosimeter on the table on a sheet of lead rubber to absorb back-scatter. To do this we need to ensure that the SID is 100cm to the top of the dosimeter. Four exposures using 80 kV and 20 mAs were then taken. Each exposure should have a different mA and time combination to equal 20mAs. As illustrated in Fig. 7. Variation in output intensity during diagnostic exposures can result in unnecessary dose to the patient due to repeats from poor quality images. While performing this test, the assumption is that every other factor, such as kVp and the timer, are working accurately. For assessing the linearity of mA loading stations the tube current (mA) is equal to the number of electrons flowing from the cathode to the anode per unit time. This test attempts to establish if the same film density is achieved using the same kVp (81) but different mAs and different focal spot according to mAs, to evaluate the linearity of a generator for commonly used exposure settings.

Radiographic linearity is the production of a constant amount of radiation for different combinations of milliamperage and exposure time. It is important to perform QC tests on the kVp as well as the timer before completing the linearity test as if there are variations in linearity, mAs may not be the culprit - inaccurate performance from the kVp meter and the X-ray timer can also produce the same results. For the first component of the QC, the linearity for mAs change was tested. Exposure output (in microroentgens) was recorded using the dosimeter and was later converted to milliroentgen to calculate mR/mAs.

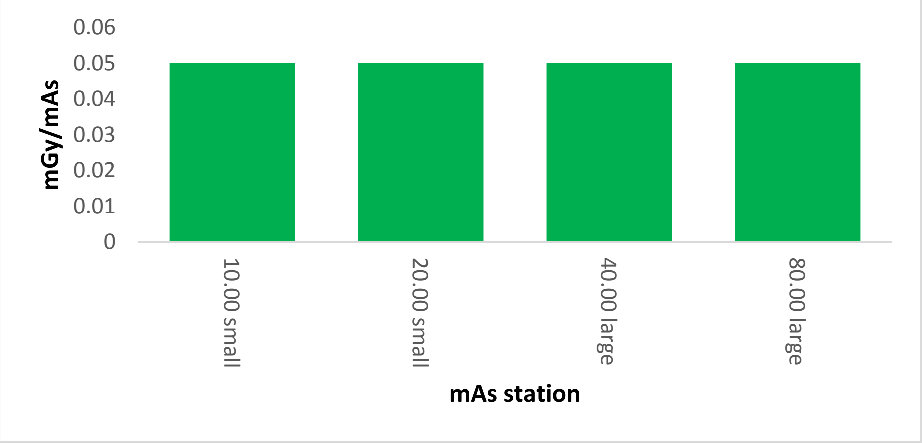

Figure 7: Shows the graph of the mAs linearity analysis. Lockley the X-ray machined pass the mAs linearity test as the Maximum difference in mGy /mAs between adjacent stations was 0.3% and the acceptable limit is 10.0%.

Using a fixed kV (81 kV) and starting at 10 mAs, two exposures were taken after approximately doubling the selected mAs until 80 mAs was reached. Exposures were taken at 81 mA on a small focal spot setting and at a large focal spot setting i.e. two exposures at each focal spot sizes. A 75cm SID was used in order to reduce anode-heel effect. When we chose to double the mAs, holding other factors constant, we should obtain (approximately) double the exposure, which explains why the ratio of mR/mAs should remain constant at a set kVp. The obtained results were outlined in table 3.

Table 3: The measurements of set kV at 81 mA.

#	Set mAs (mAs)	Focal Spot	Exposure (mGy)	Exposure mAs (mGy / mAs)
1	10.00	Small	0.5091	0.05091
2	20.00	Small	1.012	0.5061
3	40.00	Large	2.020	0.05049
4	80.00	Large	4.034	0.05043

Half Value Layer (HVL):

The HVL of an X-ray beam is defined as the amount of absorbing material that is needed to reduce the beam to half of its original potential. HVL is an indirect measure of photon energy or beam hardness. The intensity of an X-ray beam is an important property in radiography and can be reduced as it penetrates an object by absorption or scattering. Reduction in the intensity of the beam can be affected by the atomic number of the absorbing material or beam energy. In radiography, technologists uses the HVL to measure the quality or intensity of the beam. HVL is an important quality control test as it is used to measure whether or not there is sufficient filtration in the X-ray beam to remove low energy radiation, which can be damaging. It also helps to determine the type and thickness of shielding required in the facility. Total X-ray filtration (incl. housing & LBD) is assessed by HVL measurement (Alum.) at known kV (80kVp). The dosimeter which is rad check that being used in this work is to measure the HVL by detecting the quality of aluminium filtration that will reduce the beam intensity to the half the original value.

In this work, 1 mm thick aluminium sheets were used as attenuating material. The beam energy was tested at 70 kVp, 80 kVp and 90 kVp with a range from 0-7mm of aluminium thickness. First, the exposure was measured at 70 kVp with 0mm of added filtration and with each subsequent exposure, 1mm of aluminium was added until an exposure with 5 mm was achieved. This was repeated at 80 kVp and 90 kVp. The exposure was measured using the Piranha Smart X-ray Meter in milligray and microgray and the results for the 80 kVp are included in table 4.

Table 4: HVL measurements used to assess the X-ray beam quality and determine the adequacy of filtration

Tube voltage (KV)	Exposure time (mS)	Exposure (mGy)	Exposure rate (mGy/s)	HVL (mm A1)	Total filter (mm A1)
80.34	42.09	0.5093	24.14	3.27	3.4

Table 5: Outlined the Image Quality Tests

Test	Test Results	Pass/ Fail
Spatial Resolution	1.6 1p / mm	Pass
Contrast Resolution	0.8%	Pass

Table 6: Demonstrate the mechanical Check-up

Test	Pass /Fail
Movement of tube	Pass
Movement of table	Pass
Movement of tube aligned with Table	Pass
Movement of tube aligned with wall Bucky	Pass

Table 7: Summarized the Quality Control Tests

Test	Limits	Pass/ Fail
Kilovoltages Accuracy	Max. Inaccuracy ≤ ± 5%	Pass
Kilovoltages Reproducibility	Should be ≤ ± 5%	Pass
mAs Linearity	mGy / mAs should be ≤ ± 10%	Pass
Beam Quality HVL	Within the limits	Pass
Light Field X-ray Field Alignment (congruence)	Within ± 2% of the SID	Pass

Optimization of patient dose and image quality is of primary concern in the field of diagnostic imaging. It is recognized that comprehensive quality assurance programmes are a vital component of the optimization process. Due to the importance of quality control in diagnostic imaging, it is recommended that the appropriate facility personnel review the control tests, data and images periodically (e.g. quarterly reviews). QC tests were performed to evaluate the performance of the equipment. kV accuracy test, kV reproducibility, time accuracy, X-Ray beam collimation, HVL/Filtration, and Leakage Radiation all these tests were done and complied with the requirements of the standards and manufacture's specifications. QA of medical diagnostic x-ray equipment means systematic actions necessary to provide adequate confidence to the end-user(s) that a medical diagnostic x-ray equipment will perform satisfactory in compliance with safety standards specified by the Competent Authority [4, 8].

CONCLUSION

The widespread clinical use of X-ray imaging in diagnosing various diseases has led to the increased radiation exposure to patients and staff. Generally, the implementation of QC tests based on a periodic program will result in minimizing the frequency of examination tests and radiation dose to the staff and patients, increasing the lifetime of the tube, as well as producing high-quality images. The obtained tests revealed that QC program is conducted at regular intervals mostly because of enforcement by national regulatory authorities, and good cooperation between imaging personnel and qualified staff who are responsible for implementation of QC program. Finally, the imaging department equipped with X-ray is efficient in producing high-quality images with the least possible exposure to the patient. kV accuracy test, kV Reproducibility, time accuracy, X-ray beam collimation, HVL/Filtration, and Leakage Radiation all these tests were done and complied with the requirements of the standards and manufacture's specifications. The QC tests for X-ray machine were good and were within the tolerance limit. 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. Therefore must spread quality control program in all hospitals in Saudi to ensure the quality of the X-ray machines.

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