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Performance assessment of GE conventional X-ray System installed in Radiological Science Department of King Saud University

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ABSTRACT

As X-ray applications continue to evolve across medical disciplines, meticulous implementation of Quality Assurance (QA) protocols becomes paramount. It is the cornerstones in X-ray applications, ensuring accuracy, safety and effectiveness of diagnostic procedures. To get optimum use of medical equipment, specific performance tests must take place. The aim of this work is was to evaluate the performance of GE conventional X-ray System installed in 2007 at Radiological Science Department of King Saud University. Non-invasive auto meter used to evaluate the performance of such X-ray imaging system. The study investigates various Quality Control (QC) parameters, including milliampere-seconds (mAs) linearity, tube voltage accuracy, and exposure time reproducibility, to ensure compliance with established standards. All QC tests have done according to the intentional standard reports (AAPM No. 74) and National recommendations of King Abdullah City for Atomic & Renewable Energy. The obtained results indicate that the X-ray unit demonstrates acceptable mAs linearity, tube voltage accuracy, reproducibility and exposure time reproducibility tests and thus ensuring consistent X-ray output. All the obtained results meet the international standards. In general, the Department of Radiological Sciences adheres to strict quality control and quality assurance protocols for the department's equipment. To maintain consistency in radiation output, ensure user safety, and improve image quality in radiography. Through continuous monitoring and evaluation of equipment performance, while minimizing unnecessary radiation exposure to users.

Keywords: Diagnostic X-ray, Quality Control, X-Ray Machine, Quality Assurance, Equipment Assessment, Exposure Measurements

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INTRODUCTION

The Radiological Sciences program at King Saud University was launched in 1980 to meet the need in Kingdom of Saudi Arabia for skilled Radiologic Technologists. Since its establishment as the first BSc program of the field in the Kingdom, it has been playing a significant role in providing both the private and the public health sectors with highly competent professional graduates equipped with the knowledge and skills in the field of Diagnostic Radiologic Technology. The current program internationally accredited by the Accreditation Agency for Study Program in Health and Social Sciences (AHPGS). It divided into different units including Main X-Ray, Nuclear Medicine, Fluoroscopy, Computed Tomography Scan, Dental X-ray, Mammography, Ultrasound and the MRI units. All equipment used for practical, clinical and research activities for the Bachelor and Master students. All are located in the ground floor.

In conventional radiography, X-rays passed through the object causes attenuation of the incident beam. The uniform X-ray beam emitted from the source modulated as it passes through the human body and these changes recorded on the film. Quality Control (QC) and Quality Assurance (QA) in the realm of X-ray technology stand as cornerstones in ensuring the precision, safety, and efficacy of diagnostic and therapeutic procedures. As X-ray applications continue to evolve and expand across various medical disciplines, the meticulous implementation of QC and QA protocols becomes paramount. QC in X-ray involves a set of systematic tests and procedures meticulously designed to validate the mechanical stability of X-ray equipment and ascertain the completeness of safety mechanisms [1-3]. These tests, integrated into a broader QA framework, play a pivotal role in maintaining the technical integrity of X-ray systems. A program of QC specifically engineered to guarantee optimal equipment performance, resulting in the production of high-quality images with minimal patient radiation exposure.

QC involves systematic tests and procedures designed to validate the mechanical stability of X-ray equipment and ensure the completeness of safety mechanisms, all within a broader QA framework. These measures are crucial for maintaining optimal equipment performance, resulting in high-quality images with minimal patient radiation exposure [4]. Table 1 demonstrate the QC tests carried out on the conventional X-ray imaging system.

Table 1: List of QC tests for fixed X-ray machine. All these tests conducted in this study

Tests	Limits
1 Kilovoltage Accuracy	Max. Inaccuracy $\leq \pm 5\%$
2 Kilovoltage Reproducibility	Should be $\leq \pm 5\%$
3 mAs Linearity	mGy/mAs should be $\leq \pm 10\%$
4 Beam Quality HVL	Within the limits
5 Light Field/X-ray Field Alignment (Congruence)	Within $\pm 2\%$ of the SID

MATERIALS AND METHOD

Table 1 lists all the measurements carried out on the GE conventional X-ray shown in Fig. 1 and its model information listed in table 2. High voltage generator to accelerate electrons from cathode to anode, focal spot size and collimation used to define size and shape of X-ray beam are most important parameters for image quality. To determine the quality control tests for tube voltage reproducibility, tube voltage accuracy, mAs linearity and half value layer specialized tools were needed to obtain measurements [5, 6]. All the measurements carried out using the X-ray QA meter shown in Fig. 2. It is a black piranha system used for quality control X-ray equipment. It can measure mammography, fluoroscopy, computed tomography, and dental X-ray. It is multi-functional QA meter used for most of X-ray QC measurements. The black Piranha is solid-state detector and has several properties to measure kV, mAs, calculate and detect wide range of total filtration directly from one exposure. All tests of machine performed by using black Piranha with distance 100 cm source detector distance.



Figure: 1 the GE conventional X-ray System

Table 2: A list of the X-ray machine information at King Saud University.

Department / Room	Radiological Sciences Dept. X-Ray Room	Model No.	46-155400G46
Manufacture	GE	Serial No.	54342BC1



Figure 2: A photo of the Black Piranha X-ray QA meter. A self-contained, multifunctional meter for all X-ray based QA applications, providing easy and fast X-ray quality control tests.

RESULTS AND DISCUSSION:

QA for X-ray machines must be conducted during acceptance testing post-installation, ensuring conformity with specified operating licenses [5]. The primary goal of QA for X-ray machines is to ensure minimal radiation exposure to patients while achieving optimal image quality in radiological procedures. This involves systematic actions to instill confidence that medical diagnostic X-ray equipment complies with safety standards set by the Saudi Authority. Under the Nuclear and Radiological Regulatory Authority (NRRA) program, User responsibility includes subsequent regular interval tests (typically annually), and tests after repairs or suspected malfunctions, ensuring ongoing adherence to prescribed standards. Various tests are integral to QA, including those assessing the kVp meter and exposure timer. The kVp meter measures peak x-ray accelerating voltage, crucial for controlling the quality of the X-ray beam. This parameter influences the contrast or gray scale in X-ray films or detectors, with higher kVp leading to lower contrast. Regular QA tests guarantee continued equipment functionality within specified standards.

Table 3: The mAs linearity test that performed 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.

Thus, the kV were set to 80 kV and four exposure where made as shown below.

#	Set mAs (mAs)	Focal spot	Exposure (mGy)	Exposure /mAs (mGy/mAs)
1	10.00	Large	0.3929	0.03929
2	20.00	Large	0.8006	0.04003
3	40.00	Large	1.604	0.04011
4	80.00	Large	3.214	0.04017

mAs linearity

Linearity means that sequential increases in milli ampere-seconds should produce the same sequential increase in the exposure measured. Linearity is a crucial aspect of radiography, ensuring

consistent radiation output across various combinations of Milliampere (mA) and exposure time. In clinical practice, it is imperative that all general X-ray units exhibit a proportional change in exposure as mA settings vary. The expectation is that increasing the mAs should result in a proportional increase in radiation exposure. If an X-ray unit demonstrates deviation from this expected linearity, it must be promptly serviced and retested before used for diagnostic procedures. Linearity tests conducted to monitor both patient dose and image quality, as inconsistencies in output intensity during diagnostic exposures can lead to unnecessary dose to the patient due to image retakes prompted by poor-quality images. Milliampere is the measure of electrical current flowing through circuit. Milliampere directly controls the beam intensity and the Intensity of beam means quantity. It is the product ma and exposure time in second and the mA and time are inversely proportional. Table 3 and table 4 outlined the mAs linearity tests for large and small focal spot respectively. Measurements should not exceed 0.1. The Coefficient of linearity determined by:

$$\text{Coefficient of linearity} = (\times_{\max} - \times_{\min} / \times_{\max} + \times_{\min}) \quad \text{Eq. 1}$$

Table 4: The mAs linearity test that performed 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. Thus, the kV were set to 80 kV and four exposure were made as shown below.

#	Set mAs (mAs)	Focal spot	Exposure (mGy)	Exposure /mAs (mGy/mAs)
1	2.50	Small	0.09900	0.03960
2	5.00	Small	0.1985	0.03988
3	10.00	Small	0.3985	0.03985
4	20.00	Small	0.7968	0.03984

By adhering to rigorous testing protocols and promptly addressing any deviations, healthcare providers can uphold high standards of care in radiography while minimizing unnecessary radiation exposure to patients. In this study, the measurements taken while keeping the kilo voltage (kV) and exposure time constant and varying the mA settings (see table 3 and table 4). The set kV maintained at 80 kV. The relationship between mA and exposure graphically represented for large and small focal spots as demonstrated in Figure 3 and Figure 4 respectively. The Coefficient of Linearity was calculated. For small focus and large focus configurations, the coefficients of linearity found to be 0.03929 and 0.04003, respectively, and 0.04011 and 0.04017, respectively. The variation between the set mAs and the measured values fell within acceptable limits of $\pm 10\%$. Ensuring mAs linearity is critical for maintaining consistency in radiation output, which directly impacts both patient safety and the quality of diagnostic images.

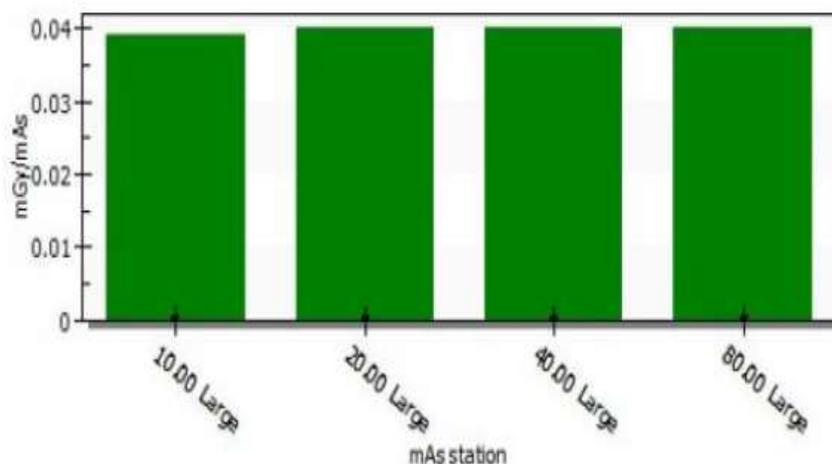


Figure 3: The mAs linearity analysis for large focal spot passed the test as the maximum differences in mGy/mAs between adjacent stations is 0.9% and the limit is 10%.

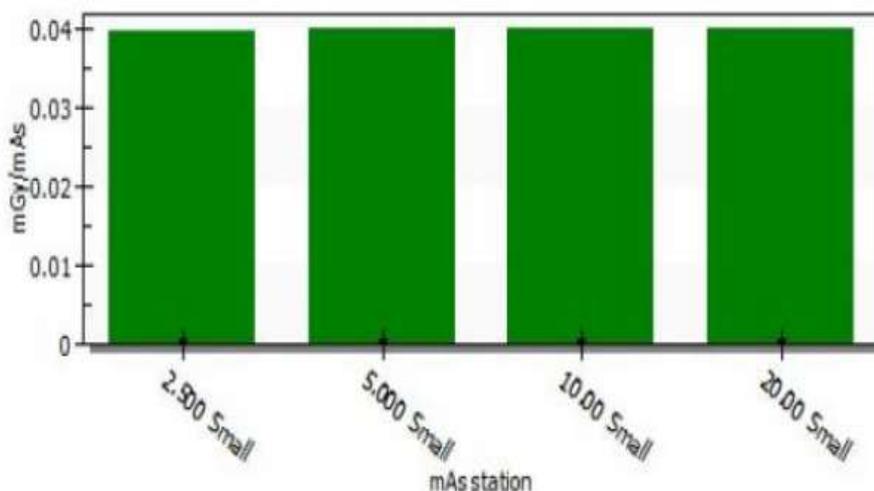


Figure 4: The mAs linearity analysis for small focal spot passed the test as the maximum differences in mGy/mAs between adjacent stations is 0.4% and the limit is 10%.

Tube voltage accuracy:

Kilovolt peak (kVp) is a technical factor set by the technologist when performing X-rays. Its purpose 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. The most direct way of measuring kVp is by using a high voltage divider. This invasive test device connected between the generator and the X-ray tube and provides isolated low level analog voltage signals proportional to the kilovoltage applied across the tube. Such invasive test is not very common. On the other hand, electronic, non-invasive kVp devices provide a measurement based on the change in X-ray transmission through varying thicknesses of filtration. These devices are accurate (if properly used) and widely employed for routine quality control due to their ease of use. Accurately

calibrated and consistent kVp are important in diagnostic imaging to control both optical density and contrast of the X-ray image as well as radiation dose to the patient. Poor kV calibration can increase dose if kV is too low and can cause poor mA linearity, leading to possible repeats.

Table 5: Non-Invasive kVp Measurements. It is important to note that in most instruments used for these tests, the measured value does not directly correspond to the true peak voltage. Rather, it is a calculated value obtained through integration over exposure time and signal ratios. This derived value is known as effective kV (kV_{eff}), which typically registers lower than the actual kVp.

#	Set kV (kVp)	Tube voltage (kVp)	kVp diff%	Exposure (mGu)	Exposure time (ms)	HVL (mmAl)
1	50	49.10	-1.8	0.1221	49.69	2.50
2	60	59.74	-0.4	0.2009	49.69	2.87
3	70	69.71	-0.4	0.2882	49.68	3.38
4	80	79.88	-0.1	0.3896	49.68	3.88
5	90	90.78	0.9	0.5057	50.18	4.46
6	100	100.03	0.0	0.6326	50.20	5.03
7	110	110.35	0.3	0.7677	49.69	5.56

Test was performed 50 kV up to 110 kV tube voltage, at the highest available tube current 20mAs. The voltage, time and the output noted down to find the accuracy of tube output time and kV. From the values shown in table 5 represent, maximum tube voltage inaccuracy is approximately -1.8% at 50 kV. Recommended Variation between set kVp and the measured should be with in $\pm 5\%$. The analyses of the values from the differences shown in Figure 3.

$$\text{Percentage KVp error \%} = (V_0 - V_s) / V_s \times 100 \quad \text{Eq. 2}$$

The reproducibility of kVp output of an X-Ray machine at a given setting should be reproducible when all the other parameters are fixed. Measurements of tube voltage accuracy and reproducibility should be between $\pm 5\%$ kVp.

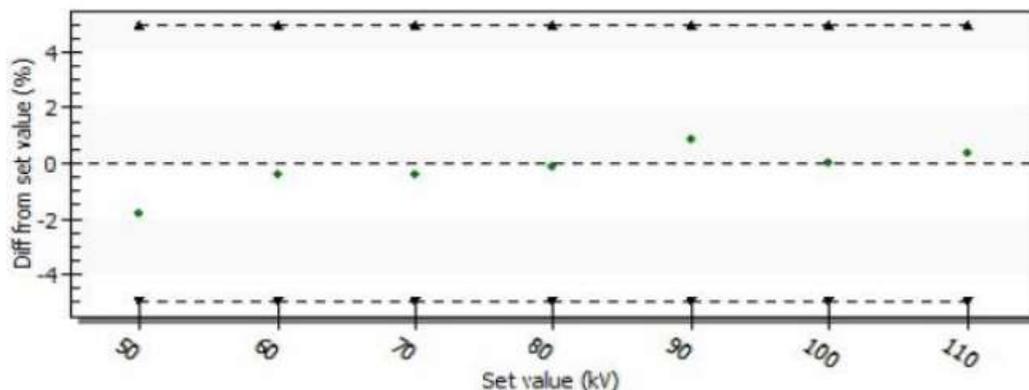


Figure 5: The analysis of tube voltage accuracy. Demonstrating pass the test as the maximum inaccuracy is -1.8% at 50 kV and the limit: -5% to 5%.

Tube Voltage Reproducibility:

A high voltage power source, for example 40 to 130 kilovolts (kV), called the tube voltage, is connected across cathode and anode to accelerate the electrons. The X-ray spectrum depends on the anode material and the accelerating voltage. Kilo voltage peak (kVp) is the peak potential applied to the x-ray tube, which accelerates electrons from the cathode to the anode in radiography or computed tomography. Tube voltage, in turn, determines the quantity and quality of the photons generated. Peak kilo voltage (kVp) refers to the maximum high voltage applied across an X-ray tube to produce the X-rays. During X-ray generation, surface electrons released from a heated cathode by thermionic emission. The increase in x-ray tube voltage increases the amount of radiation coming out of the x-ray tube, as well as the average photon energy (i.e., increased penetration). Accordingly, the tube current exposure time product value (mAs) reduced to 36 mAs; whereas at 60 kV, the value was much higher (141 mAs). Kilo voltage peak or peak kilo voltage (kVp) is the maximum voltage across the X-ray tube. Because voltage across the tube is not constant, kVp is higher than mean kV. Exposures made at the same kVp and mA stations of the same phantom thickness should produce the same optical density on the resulting image. This referred to as reproducibility.

Table 6: Measurements of kVp reproducibility. In this QC test we use a kV of 80 and mAs of 10, and we perform the test three times and in each time we registered the reading of tube voltage, Exposure and the exposure time

#	Tube voltage (kVp)	Exposure (mGy)	Exposure time (ms)
1	79.87	0.3924	50.18
2	80.02	0.3930	49.69
3	80.03	0.3923	50.20

The machine was set up to 10 mAs, the X-ray meter at distance 100cm from source and the kV was set to 80. The same procedures repeated for the voltage of 80 to find the reproducibility of kV. The coefficient of variation calculated and found to be 0.1%. The mean value of is 79.98 and standard deviation approximately 0.09 kV the maximum deviation from mean value is 0.1%. Consequently, the reproducibility on the kVp of the machine was 0.1% much less than the limit, which is $\pm 5\%$.

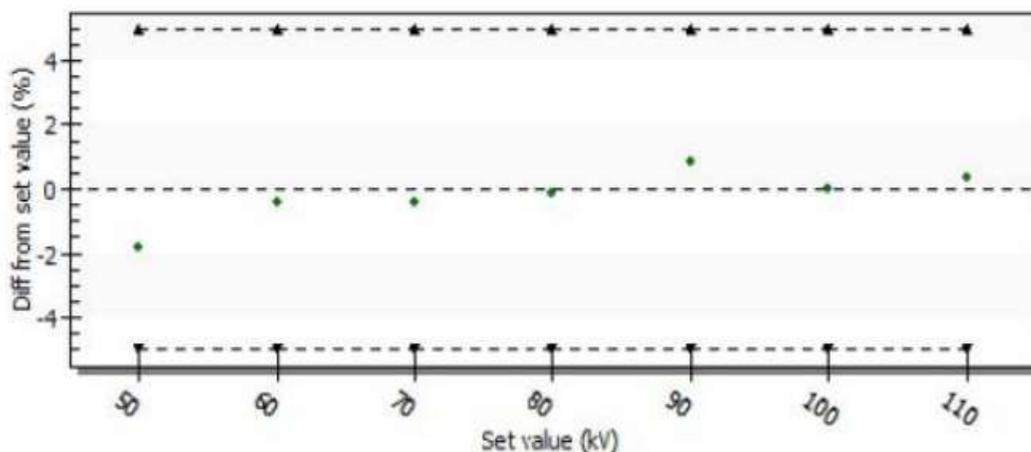


Figure 6: The analysis of tube voltage accuracy and result is pass as the maximum inaccuracy is 1.8% at 50 kV and the limit: -5% to 5%.

Exposure time reproducibility:

Reproducibility refers to features that remain the same when extracted using different equipment, different software, different image acquisition settings, or different operators (e.g. other clinics), be that in the same subject or in different subjects. The ability of an exposure system to duplicate an exposure, time after time. It expressed as a log exposure or as a percent exposure change. The smaller the change, the more reproducible the system. If the consecutive exposures are not reproducible, films of varying density will be produced, leading to an increase in the rate of repeated examinations.

The machine was set up to 10 mAs, the kV was set to 80 and noted down the readings of kV. The machine was set the time 50 mS three times and noted down the results. Coefficient of variation is 0.6%. The mean value of is 50.03 and standard deviation approximately 0.2873 ms the maximum deviation from mean value is 0.7%. Exposure time reproducibility: The exposure timer ensures that the X-ray machine produces radiation for the correct duration, which directly influences image quality and patient safety, Reproducibility refers to the ability of the exposure timer to consistently produce the same exposure time under similar conditions.

Table 7: Mechanical Checkup of the GE Conventional X-ray

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



Figure 7: The result of exposure time reproducibility test is pass as the coefficient of variation is 0.6% the limit is 10%. The mean value is 50.03 with standard deviation 0.2873 mS. The maximum deviation from the mean value is 0.7% and the limit is 10%

Image Quality Test:

There are certain qualities of an image that affect each other and determine the quality of the displayed image; contrast, resolution and noise, as well as un-sharpness, magnification, distortion and artifacts. The important components of the radiographic image quality include contrast, dynamic range, spatial resolution, noise, and artifacts [7]. Contrast is the difference in the displayed or image signal intensity between two areas of interest e.g. a lesion and background tissue. A high contrast image has a greater difference between the grey shades displayed but a smaller range of greys. A low contrast image has a smaller difference (i.e. it is more difficult to make out different areas) but a larger range of greys. The obtained result of image quality outlined in table 8.

Table 8: Image Quality Test

Test	Test results	Pass/Fail
Spatial Resolution	1.6 lp/mm	Pass
Contrast Resolution	0.8%	Pass

Table 9: Summary of Quality Control Tests

Test	Limits	Pass/Fail
Kilovoltage Accuracy	Max. Inaccuracy $\leq \pm 5\%$	Pass
Kilovoltage Reproducibility	Should be $\leq \pm 5\%$	Pass
mAs Linearity	mGy/mAs should be $\leq \pm 10\%$	Pass
Beam Quality HVL	Within the limits	Pass
Light Field/X-ray Field Alignment (Congruence)	Within $\pm 2\%$ of the SID	Pass

CONCLUSION:

In conclusion, QA and QC practices are indispensable for ensuring the accuracy, safety, and

effectiveness of X-ray technology in diagnostic and therapeutic applications. QC procedures in X-ray encompass a systematic series of tests and measures designed to validate the mechanical stability of X-ray equipment and ensure the integrity of safety mechanisms. These tests, integrated into a comprehensive QA framework, are crucial for maintaining optimal equipment performance and generating high-quality images while minimizing radiation exposure. This study focused on several key aspects of QC in X-ray technology; including mAs linearity, tube voltage accuracy and reproducibility, and exposure time reproducibility. These parameters are fundamental for assessing the consistency and reliability of X-ray equipment performance. For mAs linearity, our findings demonstrated that the X-ray unit exhibited consistent radiation output across various combinations of Milliamperage and exposure time, as evidenced by the calculated coefficients of linearity falling within acceptable limits. The same goes with tube voltage accuracy and reproducibility all output were within the prescribed tolerance levels, ensuring consistent image quality and patient safety. A summary of QC tests shown in Fig.9 Overall results indicated that the machine exhibited satisfactory reproducibility, with minimal deviation from the mean value maintaining the reliability and effectiveness of X-ray technology.

REFERENCE

1. AL-Jasim, A. K., Hulugalle, S. N. C. W. M. P. S. K., & Al-Hamadani, H. K. (2017). A quality control test for general X-ray machine. *World Scientific News*, 90, 11-30.0.-98b
2. Rasuli, B., Pashazadeh, A. M., Tahmasebi Birgani, M. J., Ghorbani, M., Naserpour, M., & Fatahi-Asl, J. (2015). Quality control of conventional radiology devices in selected hospitals of Khuzestan province, Iran. *Iranian journal of medical physics*, 12(2), 101-108.
3. Sonawane, A. U., Singh, M., Kumar, J. S., Kulkarni, A., Shirva, V. K., & Pradhan, A. S. (2010). Radiological safety status and quality assurance audit of medical X-ray diagnostic installations in India. *Journal of Medical Physics/Association of Medical Physicists of India*, 35(4), 229.
4. Williams MB, Krupinski EA, Strauss KJ, Breeden WK, Rzeszotarski MS, Applegate K, Wyatt M, Bjork S, Seibert JA. Digital radiography image quality: image acquisition. *J Am Coll Radiol*. 2007 Jun;4(6):371-88.
5. Saudi Food and Drug Authority (SFDA). Requirements on Radiation Protection and Safety for Healthcare Providers; Version Number: 2.0 Version Date: 23/12/2019; Saudi food and drug authority, 2019; pp. 1–14. Available online: <https://beta.sfda.gov.sa/sites/default/files/2021-03/>(accessed on 29 October 2022).

6. Wilbroad E. Muhogora, Nada A. Ahmed, Aziz Almosabihi, Jamila S. Alsuwaidi, Adnan Beganovic, Ciraj-Bjelac Olivera, et al. Patient doses in radiographic examinations in 12 countries in Asia, Africa, and Eastern Europe: initial results from IAEA projects. *AJR American Journal of Roentgenology*, 190 (6) (2008), pp. 1453-1461.
7. Mohammed A. Alnafea and Jawhara A. Annab, "Implementation of Quality Control Tests for two Digital X-Ray Equipment in Riyadh", *Br. J. Med. Health Res.* July 2023; 10 (07).

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