

Quality assessment of conventional X-ray diagnostic equipment by measuring X-ray exposure and tube output parameters in Great Khorasan Province, Iran

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ABSTRACT

Introduction: Regular implementation of quality control (QC) program in diagnostic X-ray facilities may affect both image quality and patient radiation dose due to the changes in exposure parameters. Therefore, this study aimed to investigate the status of randomly selected conventional radiographic X-ray devices installed in radiology centers of Great Khorasan Province, Iran, to produce the data needed to formulate QC policies, which are essential to ensure the accuracy of the diagnosis while minimizing the radiation dose.

Material and Methods: This cross-sectional study was performed using a calibrated Piranha multi-purpose detector to measure QC parameters in order to unify X-ray imaging practices using international guidelines. The QC parameters included voltage accuracy, voltage reproducibility, exposure time accuracy, exposure time reproducibility, tube output linearity with time and milliamperere (mA), and tube output reproducibility. Data analysis procedures were performed based on the type of an X-ray generator, which has not been reported in previous studies.

Results: The results showed that the implementation of high-frequency X-ray generators were more advantageous compared to alternative current generators, due to their efficient, better accuracy, linearity, and reproducibility.

Conclusion: The survey revealed that the QC program was not conducted at regular intervals in some of the investigated radiology centers, mostly because of inadequate enforcement by national regulatory authorities for implementation of QC program.

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Introduction

The X-ray imaging techniques are one of the most common diagnostic methods with no proper alternative. According to radiation safety protocol, the ionizing radiation exposure should be as low as reasonably achievable to maintain exposures to ionizing radiation as far below the dose limit as possible, and provide good enough image quality at the same time [1]. To achieve this goal, regular implementation of quality control (QC) program in the diagnostic imaging department is of great importance. Effective QC programs enhance the chance to obtain high-quality images for medical diagnosis, minimize exposure dose to both the patient and radiation staff, and increase the long-life and efficiency of devices [2, 3].

Numerous studies have been performed on QC of diagnostic radiographic devices, and some international guidelines have been established in this field [2, 4-6]. A study conducted by Koir et al. revealed

that a quantitative QC assessment led to the image quality improvement by 13% and reduction in patient radiation dose within the range of 31%–77% [7]. Likewise, lack of comprehensive QC programs in Tanzania revealed higher exposure doses to the patient and poor image quality [8]. According to data published in the World Health Organization report, Iran is a country of level two healthcare, and more than 20 million diagnostic X-ray examinations are performed annually in Iran [9, 10].

In a study by Asadinezhad et al. on 51 conventional radiology devices installed in 20 cities of Iran, the results revealed that 38.6%, 46.7%, 34.5%, and 19.4% of units were not in the acceptable range in terms of Kilovoltage peak (kVp) accuracy, exposure linearity with mAs, exposure time accuracy, and reproducibility, respectively [11]. Moreover, a large number of QC programs for the diagnostic radiographic devices have been implemented in some

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cities of Iran, which makes it more important to unifying X-ray services nationally and internationally [2, 12, 13].

Therefore, this study aimed to investigate the status of randomly selected conventional radiographic X-ray devices installed in radiology centers of Great Khorasan Province, Iran, to formulate QC policies and strategies. The impetus for the present study originated from the concern that the recent dramatic increases in the numbers of radiographic X-ray devices in the largest province of Iran, Khorasan, with limited technical support to implement an appropriate regular QC program can increase radiation exposure to patients and reduce diagnostic accuracy through low-quality images. To the best of our knowledge, this study is the most comprehensive local QC program in terms of the number of investigated radiology devices that were conducted at the provincial level in Iran. Additionally, this study reported a comprehensive data analysis based on the X-ray generator type, which has not been reported in previous studies.

Materials and Methods

According to our inventory, almost 35% of all installed units, which have been investigated in the present study, have alternative current (AC) generators. Moreover, nearly 65% of them are high frequency (HF) units that are the most common type of X-ray generators used today. The standard QC tests, including voltage accuracy, voltage reproducibility, exposure time accuracy, exposure time reproducibility, tube output linearity with time and milliamperage (mA), and tube output reproducibility were performed to assess the consistency of the optimal equipment performance. All measurements were performed using a calibrated X-ray Piranha Multi-purpose detector (MPD, M654, RTI Electronics, Sweden) which was placed on the radiographic tabletop along with the central axis of the X-ray beam at the focus-to-detector distance of 100 cm. In order to avoid possible scatter radiation to the dosimeter, the radiation field size was adjusted in a way to cover only the entire sensitive area of detector. All statistical analyses were performed using Microsoft Excel, 2016.

Voltage accuracy

The X-ray tube voltage is very effective on patient dose and image contrast [14]. Therefore, to make sure that an X-ray generator could provide the same voltage as regulated in control console, clinical tube voltages (45-90 kVp) were measured in tube currents ranged 50-320 mA. Then, the mean of three measurements for each voltage was used to measure voltage accuracy according to the Equation (1):

$$\text{Voltage accuracy} = \frac{\text{Average measured kVp} - \text{nominal kVp}}{\text{nominal kVp}} \times 100 \quad (1)$$

Variations between the nominal kVp and the measured kVp must be within $\pm 5\%$ [15, 16].

Voltage reproducibility

In order to determine the variation in average kVp over a number of exposures with the same generator setting, three exposures were performed at constant tube currents in various kVp settings (45-90 kVp). Afterward, standard deviation (SD) and coefficient of variation (CV) were calculated for the measured voltages. Reproducibility of the voltage should be within a coefficient of variation < 0.05 [15].

Exposure time accuracy

A wide range of exposure times (from less than 80 to more than 150 msec) were selected at a fixed tube voltage and current. The mean of three exposures for each specified time was compared to the selected values, like kV checking test methods to determine the differences. For exposure time greater than 10 msec, and less than 10 msec accuracy should be within $\pm 5\%$ and $\pm 10\%$, respectively [15].

Exposure time reproducibility

The variable of time was selected as a constant exposure setting. At least three exposures were recorded for each selected time, and then the SD and CV were calculated for the measured exposure times. The maximum variance in exposure time should be within $\pm 5\%$ ($CV \leq 0.05$) [15].

Tube output linearity with time

In order to evaluate the linearity of a radiation output as a function of exposure time at constant tube current and voltage, exposures were performed at different time. The linearity coefficient (L) was measured, using the following Equation:

$$\text{Linearity coefficient} = \frac{|Z_2 - Z_1|}{|Z_2 + Z_1|}$$

Where, Z_1 is Dose / mAs for the first selected time, and Z_2 is Dose / mAs for the second selected time [17]. This linearity coefficient should be < 0.1 (10%) [17, 18].

Tube output linearity with mA

The linearity of tube output with regard to tube current was investigated by recording the radiation output (using MPD in mGy) at fixed tube voltage and time for various tube currents. The radiation output linearity coefficient was also obtained using the Equation 2. Where, Z_1 is Dose / mAs for the first selected mA, and Z_2 is Dose / mAs for the second selected mA. The linearity coefficient should also be < 0.1 (or 10%) [17].

Tube output reproducibility

At constant tube voltages and currents, at least three exposures were recorded by detector and the means of exposure meter reading were used to determine tube output reproducibility. Measurements were repeated in

various combinations of exposure settings. Subsequently, SD and CV were calculated for the measured exposures. The maximum variance in tube output should be within 5% ($CV \leq 0.05$) [15, 16].

Results

Voltage accuracy

Figure 1 presents the results related to voltage accuracy. At 3 ranges of kVp setting, including 45-55, 55-70, and 70-90, almost 54.3%, 64.5%, and 70.3% of HF generator units, and 18.2%, 32.4%, and 70.3% of AC generator units had a minimum variation of <2% between the selected and the measured voltages, respectively. Furthermore, in the selected kVp ranged 45-90, only 6.1%, 2.1%, and 1.7% of AC generator units

had a maximum variation more than 10%, respectively, while the maximum variation for HF generator units was between 5% and 10%.

Voltage reproducibility

Figure 2 illustrates the results related to voltage reproducibility. At 3 ranges of kVp, including 45-55, 55-70, and 70-90, more than 90% of HF generator units and 60% of AC generator units had a minimum coefficient of variation less than 0.01, respectively. Furthermore, 2.8% of AC and 1.6% of HF generator units at the kVp range of 55-70, and only 1.7% of AC generator units at the kVp range of 70-90, had a maximum coefficient of variation more than 0.05.

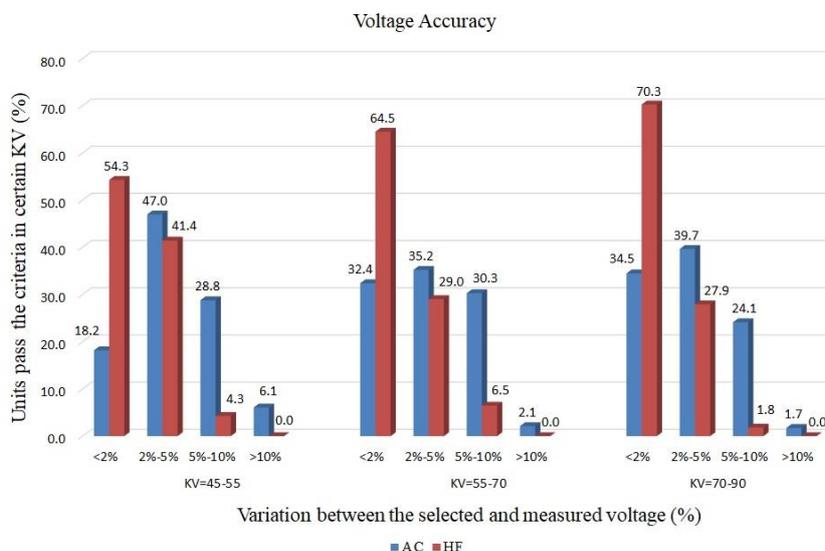


Figure 1. Accuracy of tube voltage in high frequency (HF) and alternating current (AC) generators

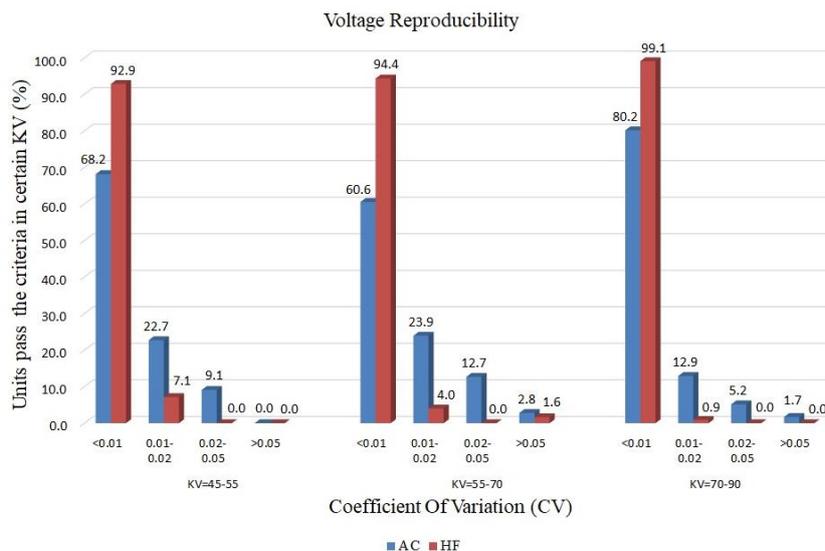


Figure 2. Reproducibility of tube voltage in both high frequency and alternating current generator units

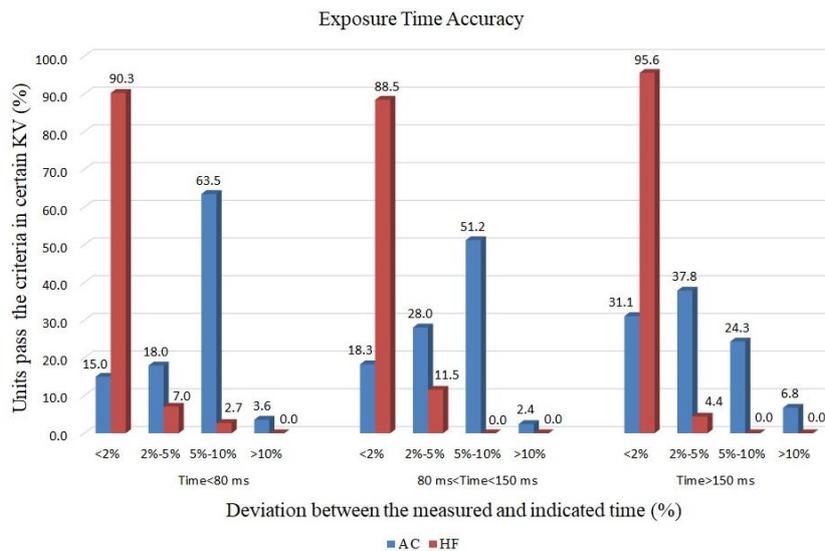


Figure 3. Accuracy of exposure time in high frequency and alternating current X-ray generators

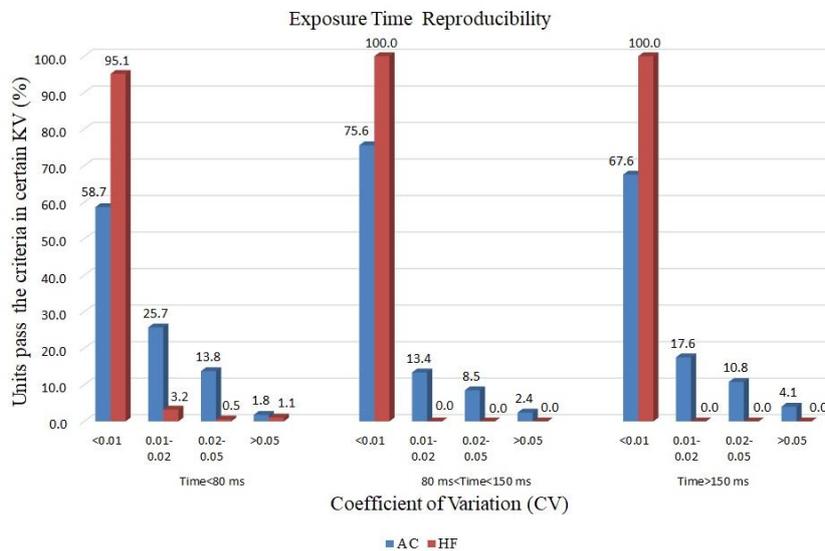


Figure 4. Exposure time reproducibility at three separate ranges of time setting

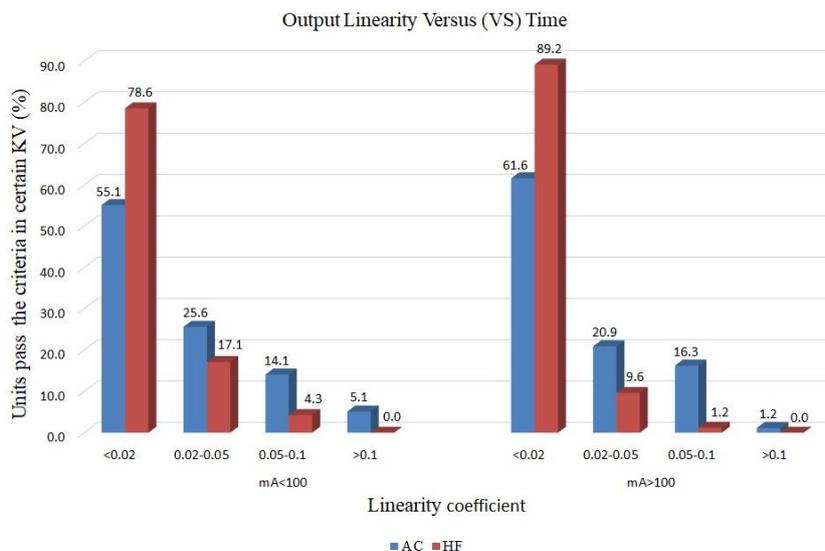


Figure 5. Linearity coefficient of tube output as a function of time in the investigated high frequency and alternating current X-ray generator units

Exposure time accuracy

Figure 3 demonstrates the accuracy level of exposure time in 3 separate ranges of time setting in the deviation ranged from less than 2% to more than 10%. With regard to 3 groups of the exposure time, including less than 80 msec, between 80 and 150 msec, and more than 150 msec, 97.3%, 100%, and 100% of HF generator units, and 43.1%, 46.3%, and 68.9% of AC generator units had a time variation within 5% between the measured and indicated time, respectively. At 3 exposure time settings ranged from less than 80 msec to more than 150 msec, 3.6%, 2.4%, and 6.8% of only AC generator units had a maximum time variation more than 10%, respectively.

Exposure time reproducibility

Figure 4 shows the results of time reproducibility. At the exposure time less than 80 msec, time reproducibility was less than 0.01 for 95.1% and 58.7% of HF and AC generator units, and was more than 5% only for 1.8% and 1.1% of AC and HF generator units, respectively. At the exposure time between 80 msec to 150 msec, and more than 150 msec, time reproducibility was less than 0.01 for 100% of HF generator units, as well as 75.6% and 67.6% of AC generator units, respectively. Furthermore, time reproducibility was more than 5% for 2.4% and 4.1% of only AC units, respectively.

Tube output linearity versus time

Figure 5 is a presentation of the results related to tube output linearity with time in the investigated X-ray units. At mA stations less than 100 msec, 78.6% of HF, and 55.1% of AC generator units had a minimum

linearity coefficient of less than 0.02 (<0.02), while only 5.1% of AC generator units had a maximum variation of >0.1 (>10%). Additionally, at mA stations more than 100 msec, the minimum variation in linearity belonged to the 89.2% of HF and 61.6% of AC generator units, whereas, only 1.2% of AC generator units had a variation more than 0.1.

Tube output linearity versus mA

Figure 6 depicts the results related to tube output linearity with mA. At time stations less than 100 msec, 76.2% of HF, and 32.8% of AC generator units had a minimum linearity coefficient of less than 0.02 (<0.02), while 1.6% of HF and 3.3% of AC generator units had a maximum variation of >0.1 (>10%). Moreover, at time stations more than 100 msec, the minimum variation in linearity belonged to the 100% of HF and 31.8% of AC generator units, whereas, only 6.8% of AC generator units had a variation more than 0.1.

Tube output reproducibility

Figure 7 indicates the reproducibility of tube output for X-ray machines in 3 separate ranges of exposure reading. At 3 ranges of exposure reading from <150 mGy, between 150mGy to 500 mGy, to >500 mGy, 79.3%, 96.3%, and 94.8% of HF generator units, and 44.5%, 71.2%, and 65% of AC generator units had the minimum coefficient variation of less than 0.01, respectively. Furthermore, at all recorded exposures ranged from <150 mGy to > 500 mGy, 1.4% of AC and HF, 0.9%, and also 1.7% of only HF generator units had CV more than 0.05, respectively, that was higher than the tolerance (<0.05) [15, 16].

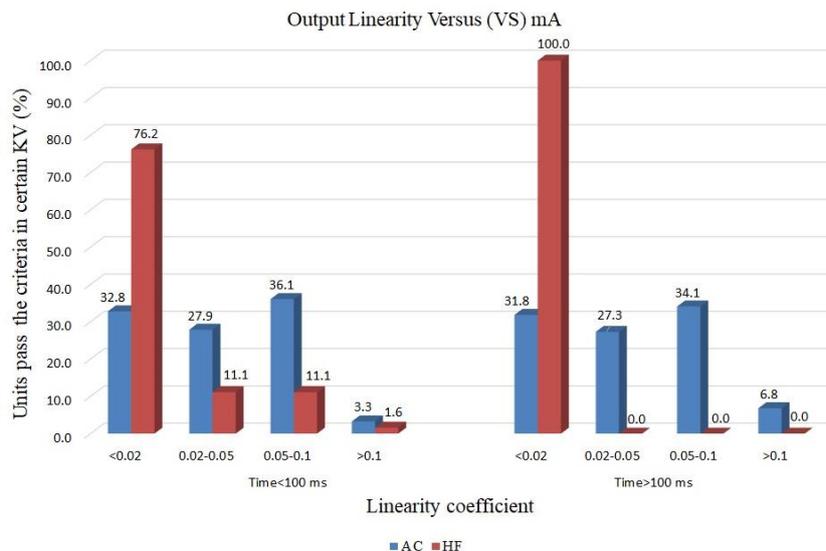


Figure 6. Linearity coefficient of tube output as a function of mA in the investigated high frequency and alternating current X-ray generator units

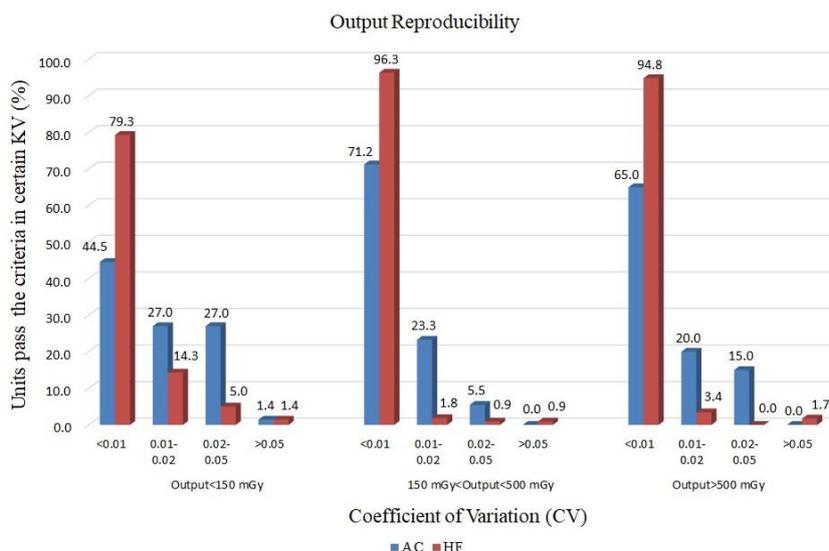


Figure 7. Tube output reproducibility in both high frequency and alternating current X-ray generator units

Discussion

Implementation of QC program on a regular basis in medical diagnostic radiology is essential to reduce X-ray system malfunctioning, and generate high-quality diagnostic images with the lowest radiation exposure to the patient. Generally, the result of this survey has revealed that a regular QC program for radiographic X-ray device is not systematically implemented in some of the medical institutions of Great Khorasan province of Iran. This is mainly because there is lack of well-trained staff, radiation safety officers, or quality assurance program officer, who are able to implement such a complex process. Moreover, inadequate binding regulations, lack of cooperation between imaging staff of a radiology department and qualified medical physicist or service engineers in performing ongoing QC programs, and limitations in medical institutions budget are some other factors, which lead to the insufficient implementation of QC programs.

As presented in Figure 1, at 3 kVp ranges of 45-55, 55-70, and 70-90, almost 95.7%, 93.5%, and 98.2% of HF and also 65.2%, 67.6%, and 74.2% of AC X-ray generator units had voltage accuracy within the acceptable limit (5%), respectively [15]. The kVp reproducibility was outside the acceptable limit in 2.8% of AC and 1.6% of HF generator units, and only 1.7% of AC generator units at the selected tube potential of 55-70, and 70-90, respectively. Problems with the autotransformer circuitry or faulty high voltage cables could result in great variations in the incoming line voltage supplying the generator.

A high-frequency generator waveform has ripple less than 2%, so voltage is highly consistent with little variation in kV ripple [19]. Furthermore, the presences of control circuits in the HF X-ray generator allowed the constant adjustment of the potential difference during the exposure. This better reproducibility with the same settings will reduce the number of repeated radiographs, which lead to reduction of unnecessary radiation to

personnel and patients and cost of radiographic examinations [20]. Additionally, exposure time accuracy and reproducibility directly affected the mAs and the total quantity of radiation emitted from the X-ray tubes [21]. Therefore, an accurate exposure time is critical for proper radiographic exposure and reasonable patient radiation exposure.

In 3 separate ranges of time setting, including less than 80 msec, between 80 to 150 msec to more than 150 msec, 3.6%, 2.4% and 6.8% of only AC generator units in terms of time accuracy, and 1.8% of AC and 1.1% HF, 2.4% and 4.1% of only HF generator units, did not comply with the requirements, respectively. Radiation output linearity with mA has an important effect on producing good quality radiographs consistently [17]. Based on output linearity with mA tests, at time stations less than 100 msec, the performance of 96.7% of AC, and 98.4% of HF X-ray units were within the acceptable limits. However, at time stations more than 100 msec, 100% of HF and 93.2% of AC X-ray generator units had a linearity coefficient within the acceptable limits (<0.1).

According to the presented data for output linearity with time, the linearity only in 5.1% of the AC units at mA station less than 100 msec, and also in 1.2% of AC units at mA station more than 100 msec was out of the acceptable limit. It was concluded that the HF X-ray generator had a better capability to produce constant radiation output at various conditions of mA and exposure time and produced higher quality images with greater contrast, compared to any radiographs produced by the AC X-ray generator units. In terms of tube output reproducibility, the percentage of defective equipment that exceeded range 3 ranges of exposure reading from <150 mGy, between 150mGy to 500 mGy, to more than 500 mGy, were 1.4% of AC and HF, 0.9%, and 1.7% of HF X-ray units, respectively. At some X-ray building, the equipment was not immediately installed after delivery, and because of inadequate

record keeping, the age of the devices was not considered in this study. It was noticeable a considerable reduction in variations from the normal performance was noted in some radiology departments, where one of the well-trained technicians was responsible for routine checks of equipment and identifying potential problems. As a result of this study, a report was sent to the government legal authorities, who decided to have stricter monitoring on the QC inspection visits to the X-ray imaging center.

Conclusion

Nowadays, 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 survey revealed that QC program is not conducted at regular intervals in some of the investigated radiology centers, mostly because of inadequate enforcement by national regulatory authorities, and lack of good cooperation between imaging personnel and qualified staff who are responsible for implementation of QC program. Finally, all the imaging centers equipped with HF X-ray generators were approximately more efficient in producing high-quality images with the least possible exposure to the patient.

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References

1. Pernicka F, McLean ID. Dosimetry in diagnostic radiology: an international code of practice. International Atomic Energy Agency. 2007.
2. Sungita YY, Mdoe SS, Msaki P. Diagnostic X-ray facilities as per quality control performances in Tanzania. *Journal of Applied Clinical Medical Physics*. 2006 Sep 1;7(4):66-73.
3. World Health Organisation. Global Initiative on Radiation Safety Health Care Settings. Technical Meeting Report. Geneva. 2008;21-6.
4. Bosnjak J, Ciraj-Bjelac O, Strbac B. Implementation of quality assurance in diagnostic radiology in Bosnia and Herzegovina (Republic of Srpska). *Radiation protection dosimetry*. 2008 Feb 18; 129(1-3):249-52.
5. Gray L, Dowling A, Gallagher A, Gorman D, O'Connor U, Devine M, et al. Acceptance testing and routine quality control in general radiography: mobile units and film/screen fixed systems. *Radiation protection dosimetry*. 2008 Mar 1; 129(1-3):276-8.
6. Van den Berg L, Aarts JC, Beentjes LB, Van Dalen A, Elsackers P, Julius HW, et al. Guidelines for quality control of equipment used in diagnostic radiology in the Netherlands. *Radiation protection dosimetry*. 1998 Nov 1; 80(1-3):95-7.
7. Korir GK, Wambani JS, Ochieng BO. Optimisation of patient protection and image quality in diagnostic radiology. *East African medical journal*. 2010; 87(3):127-33.
8. Ngoye WM, Motto JA, Muhogora WE. Quality Control Measures in Tanzania: Is it Done? *Journal of Medical Imaging and Radiation Sciences*. 2015 Sep 1; 46(3): S23-30.
9. World Health Organization. *World Health Statistics*. Switzerland. 2006.
10. Asadinezhad M, Toossi MT. Doses to patients in some routine diagnostic X-ray examinations in Iran: proposed the first Iranian diagnostic reference levels. *Radiation protection dosimetry*. 2008 Dec 1;132(4):409-14. DOI: 10.1093/rpd/ncn308.
11. Asadinezhad M, Bahreini Toossi MT, Ebrahiminia A, Giahi M. Quality Control Assessment of Conventional Radiology Devices in Iran. *Iranian Journal of Medical Physics*. 2017 Mar 1;14(1):1-7.
12. Jomehzadeh Z, Jomehzadeh A, Tavakoli MB. Quality Control Assessment of Radiology Devices in Kerman Province, Iran. *Iranian Journal of Medical Physics*. 2016 Mar 1;13(1):25-35.
13. Khoshbin Khoshnazar A, Hejazi P, Mokhtarian M, Nooshi S. Quality control of radiography equipments in Golestan Province of Iran. *Iranian Journal of Medical Physics*. 2013; 10(1):37-44.
14. Brindhaban A, Al Khalifah K, Al Wathiqi G, Al Ostath H. Effect of x-ray tube potential on image quality and patient dose for lumbar spine computed radiography examinations. *Australasian Physics & Engineering Sciences in Medicine*. 2005 Dec 1; 28(4):216.
15. The American Association of Physicists in Medicine (AAPM). *Quality Control in Diagnostic Radiology*. Report No.74. 2002.
16. International Commission on Radiological Protection. ICRP 103. *The 2007 Recommendations of the International Commission on Radiological Protection*. Ann. ICRP. 2007; 37(2-4)
17. Wagner LK, Fontenla DP, Kimme-Smith C, Rothenberg LN, Shepard J, Boone JM. Recommendations on performance characteristics of diagnostic exposure meters: Report of AAPM Diagnostic X-Ray Imaging Task Group No. 6. *Medical physics*. 1992 Jan 1; 19(1):231-41.
18. Papp J. *Quality Management in the Imaging Sciences-E-Book*. Elsevier Health Sciences; 2014 Sep 30.
19. McClelland IR. X-ray equipment maintenance and repairs workbook for radiographers and radiological technologists. World Health Organization. 2004; 215.
20. Barthez PY, Manwaring N, Mitelmann PM, Benoit E. Comparison of single-phase and high-frequency generators for x-ray units. *Veterinary Radiology & Ultrasound*. 2002 Mar 1; 43(2):118-22.
21. Brahme A. *Comprehensive biomedical physics*. Sweden: Newnes. 2014 Jul 25; 170-1.