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Original Article

Quality Control Assessment of Conventional Radiology Devices in Iran

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Abstract

Introduction
Quality control (QC) techniques are used in monitoring and maintenance of the components of an x-ray system. QC of radiology devices plays a significant role in reduction of medication dose and optimization of image quality. This study aimed to conduct QC tests on randomly selected radiology devices, installed in diagnostic imaging departments of Iran.
Materials and Methods
In total, quality control tests were conducted on 51 conventional radiology devices installed in 20 cities of Iran in order to assess the accuracy of peak kilovoltage (kVp), exposure time, exposure linearity and reciprocity, reproducibility of exposure and determination of half-value layer (HVL) using a calibrated Mult-O-Meter.
Results
In this study, 38.6% of devices had intolerable variance of kVp accuracy. The results of 34.5% of devices were out of the acceptable limits in exposure time accuracy test. In 46.7% and 53.1% of devices, variance was greater than the acceptable range for exposure linearity and exposure reciprocity, respectively. In terms of reproducibility of exposure test, the reproducibility variance and percentage of tube output variations in 19.4% of devices exceeded the limits. Moreover, the thickness of first HVL was lower than the acceptable limit in 14.7% of devices.
Conclusion
According to the results of this study, there were wide variations in QC test results, perhaps mainly due to the fact that it is not an obligation to implement QC programs in Iran. The most important problems were non-reciprocity of exposure, nonlinearity of exposure with milliampere-second (mAs), kVp and timer inaccuracy. Involvement of medical physicists, radiologists and radiographers in the implementation of QC programs at various stages of development, installation and use of equipment should enable the gradual improvement in equipment performance.

Keywords: Quality control, Diagnostic X-ray, Radiology

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1. Introduction

According to the classification published by the united nations scientific committee on the effects of atomic radiation (UNSCEAR) and data provided by the World Health Organization (WHO), Iran is a country of level two health-care [1, 2]. Annually, more than 20 million X-ray examinations are performed in radiology centers of Iran [3]. One of the fastest and easiest ways for a physician to view the internal organs and structures of the human body is X-ray imaging, which has no proper alternative. According to the safety protocol, it is recommended that the radiation exposure be maintained as low as reasonably achievable (ALARA) in order to keep exposures to ionizing radiation as far below the dose limits as practical, and at the same time, be able to provide valuable images of high usability [4]. In order to achieve this goal, quality assurance programs have been implemented in the diagnostic radiology and medical imaging departments [5, 6].

The purpose of quality control (QC) program is to ensure that there is optimal performance related to all imaging components [5]. The QC programs can give rise to the highest quality imagining with the lowest possible radiation dose to patients and to radiation workers through maintaining high diagnostic quality [5]. As stated by the American Association of Physicists in Medicine (AAPM), designing and supervising a quality assurance program is the primary responsibility of medical physicist [7]. In 1997, the European commission of protection against ionizing radiation published guidance for QC of diagnostic units [8]. The main components of QC programs have been described in a report by AAPM in 2002 [9]. A wide variety of studies have been implemented on QC of diagnostic radiographic units and some guidelines have been established for QC tests [10-18]. In a study by Ortiz et al. the results were indicative of minimized exposure dose to patients during radiological procedures through the evaluation and revision of the QC parameters [16]. In another study by Godechal et al. (1995), quality assurance program was used for X-ray devices to assess the efficiency of their specifications through a systematic measurement. According to their results, the main limitation for X-ray devices was inadequate filtration [11].

Many studies have been performed on the QC of diagnostic radiographic equipment in Chaharmahal and Bakhtiari, Zanjan, Khorasan, Lorestan, Golestan, Khuzestan, Hormozgan and Kerman provinces of Iran [19-27]. Saghatchi (1999) performed QC assessment of radiographic equipment in Zanjan province and marked that the status of 57%, 42%, 14%, and 7% of the units was not acceptable in terms of kVp accuracy, exposure linearity, timer accuracy, and timer reproducibility, respectively [20]. In 2004, Shahbazi conducted an assessment on medical equipment in order to measure the entrance dose and compare the results before and after the QC [19]. The results demonstrated that QC conduction led to 40% decrease in the mean dose required for chest examination. Results obtained by Khoshbin Khoshnazar et al. (2013) indicated that timer accuracy was a common problem of X-ray units in Golestan province [23]. In another study, Gholamhosseinian-Najjar et al. (2014) observed that the status of 27% and 45% of apparatuses in Khorasan province were unacceptable regarding kVp accuracy and timer accuracy, respectively [21]. Moreover, Rasuli et al. (2014) and Gholami et al. (2015) evaluated the performance of radiographic X-ray equipment in Khuzestan and Lorestan provinces, respectively [22, 24]. Jomehzadeh et al. (2016) conducted a study in Kerman province and affirmed that kVp accuracy, kVp reproducibility, timer accuracy, timer reproducibility, exposure reproducibility, mA/timer linearity and half-value layer (HVL) were not within the acceptable limits in 25%, 4%, 29%, 18%, 11%, 12%, and 7% of the evaluated units, respectively [26]. Before this study, no comprehensive national program for quality assurance of radiology devices has been developed in Iran. To the best of our knowledge, no comprehensive national QC program has been developed yet in Iran. With this background in mind, this study was conducted to perform QC tests on randomly selected radiology devices installed in diagnostic imaging departments of Iran.

2. Materials and Methods

In total, 51 conventional radiology devices from 31 radiology centers in 20 cities of Iran (Arak, Isfahan, Ahvaz, Amol, Mahshahr, Bushehr, Tabriz, Tehran, Rasht, Zahedan, Sanandaj, Shahriar, Shiraz, Qazvin, Karaj, Lahijan, Mashhad, Mamasani, Hashtrood and Hashtgerd) were selected using systematic random sampling. kVp accuracy, exposure time accuracy, exposure linearity, exposure reciprocity, reproducibility of exposure and determination of HVL were the evaluated QC tests, performed to assess the devices. To evaluate these tests, a calibrated Mult-O-Meter Model 303 (Unfors, Sweden) was placed on the radiographic tabletop on top of a lead apron, 100 cm from the focal spot and in the center of the field. The lead apron can absorb backscatter from the table top material; therefore, it can prevent the reduction of any readings inaccuracy. Inaccuracy of kVp and exposure rate measurements was 2%, whereas it was 0.5% for time measurements. All QC tests were performed according to standards set forth in the "quality management in the imaging science" [28].

Data are presented as mean±standard deviation (SD). Data analysis was performed in SPSS version 17.

2.1. kVP Accuracy

At SSD=100 cm, we measured kVp from 50-100 (50, 60, 70, 80, 90 and 100) in two mA (100, 300 or 320) and identified the difference between the selected and measured values. This difference should be within ±5% [28].

2.2. Exposure Time Accuracy

Variable times of (>10, =20,80,100 and 200 mSec) were selected at a fixed condition (kVp=60, mA=100). The average of three exposes were used in order to measure exposure time. Exposure time accuracy was determined using the equation 1. In this test, ±5% variation was acceptable for exposure times >10 mSec and ±20% for exposure time <10 mSec [28].

$$\frac{measured\ time - nominal\ time}{nominal\ time} \times 100 \qquad (1)$$

2.3. Exposure Linearity

This test was performed in stationary conditions (kVp=70, exposure time=100 mSec) and various mA, including 50, 100, 200 and 400. Using the equation (2), exposure linearity variance was obtained:

$$\text{Linearity variance}=\frac{\left(\frac{mR}{mAs_{max}}-\frac{mR}{mAs_{min}}\right)}{2*\frac{mR}{mAs_{average}}} \qquad (2)$$

This variance should be <0.1 (or 10%) [28].

2.4. Exposure Reciprocity

This test was performed in kVp=80 using five different combinations of mA and time, in all of which mAs was equal to 20 (mAs=20). The amount of reciprocity variance obtained from equation (3) should be <0.1 (or 10%) [28].

$$\text{Reciprocity variance}=\frac{\left(\frac{mR}{mAs_{max}}-\frac{mR}{mAs_{min}}\right)}{2*\frac{mR}{mAs_{average}}} \qquad (3)$$

2.5. Reproducibility of Exposure

Five exposures were measured at 80 kVp, 100 mA and 100 mSec. Reproducibility variance was obtained from the equation (4):

$$\text{Reproducibility variance}=\frac{mR_{max}-mR_{min}}{mR_{max}+mR_{min}} \qquad (4)$$

This variance should be <0.05 [28].

The variation in tube output can be obtained from equation (5):

$$\text{Output variation}=\frac{\left(\frac{mR}{mAs_{max}}-\frac{mR}{mAs_{min}}\right)}{\frac{mR}{mAs_{max}}} \qquad (5)$$

The maximum allowable current quantity is 10% [28].

2.6. Determination of HVL

The aluminum HVL attenuator set was used to determine the HVL of X-ray beams. The first HVL for three phase devices at kVp=80 and mAs=50 must be at least equal to 2.3 mm of aluminum [28]. All of the devices in our research included three phases of radiation, and the HVL was determined in kVp=80.

3. Results

Among 51 devices, 19 were Shimadzu, 10 Siemens, five Varian, five General Electric, three Parspad and the rest were manufactured by other companies. Mean age of the equipment was 11.90±9.79 years. The maximum rates of kVp and mA were 165 and 1000, respectively.

Table 1. Kilovolt peak accuracy test results

mA	Kilovolt peak Set	Measured kilovolt peak (±SD)	Failure (%)
100	50	57.08 (8.00)	50.0
	60	60.59 (5.04)	35.7
	70	68.45 (5.24)	29.0
	80	78.33 (5.98)	25.8
	90	87.88 (6.82)	36.7
	100	96.97 (6.56)	31.0
300 or 320	50	56.39 (5.55)	62.5
	60	59.91 (4.64)	33.3
	70	68.69 (5.25)	44.8
	80	77.80 (5.67)	45.5
	90	87.29 (6.12)	35.5
	100	97.04 (7.23)	33.3

Table 2. Exposure time accuracy test results

Exposure time set (mSec)	Measured exposure time (±SD) (mSec)	Failure (%)
6 to 10 (mean=7.75)	8.68 (2.39)	37.5%
20	21.00 (6.73)	64.5%
80	80.24 (14.04)	35.5%
100	105.77 (23.26)	20.0%
200	205.07 (29.39)	14.8%

3.1. kVP Accuracy

Results related to kVp accuracy are presented in Table 1. According to this table, 38.6% of devices had intolerable variance of kVp accuracy. Mean kVp accuracy was 6.10±4.47.

3.2. Exposure Time Accuracy

According to the results, 34.5% of the devices were out of the acceptable limits, as provided in Table 2. In addition, Figure 1 illustrated the relationship between exposure time accuracy and age of equipment. Results of Pearson's correlation test revealed a correlation coefficient at level of α=0.01between exposure time accuracy and age of equipment.

3.3. Exposure Linearity

In 46.7% of the devices, variance was greater than the acceptable range. Moreover, mean variance was 14.84±12.04.

3.4. Exposure Reciprocity

The results demonstrated that variance was out of range in 53.1% of equipment. Mean value for exposure reciprocity was 15.06±20.22.

3.5. Reproducibility of Exposure

Our findings indicated that 19.4% of devices failed to achieve acceptable results. Mean variance was 1.98±3.01.

3.6. Determination of HVL

In 14.7% of the devices, thickness of the first HVL was lower than the limited range. Mean value of HVL was 3.02±0.58 mm Al.

4. Discussion

The results related to all of QC tests on the 51 radiology devices are presented in Figure 2. It is evident that a relatively high percentage of devices failed to successfully pass the tests. In this regard, the most common problems were reciprocity of exposure, linearity of exposure with mAs, kVp and timer accuracy. In Table 3, the QC test results of the present study were compared with some other Iranian studies.

Table 3. Comparison of the quality control test results of the present study with other Iranian studies

QC test	Failure (%)						
	Present study	Esmaeilli [25]	Gholam hosseinian [21]	Jomeh zadeh [26]	Khoshbin [23]	Rasuli [24]	Saghatchi [20]
Kilovolt peak accuracy	38.6	55	27	25	29.5	6.7	57
Exposure time accuracy	34.5	30	45	29	37	0	14
Exposure linearity	46.7	50	54	11	39	0	42
Reciprocity of exposure	53.7	---	---	---	30	---	---
Reproducibility of exposure	19.4	30	30	39	0	0	7
Determination of half value layer	14.7	---	---	13	0	26.7	---

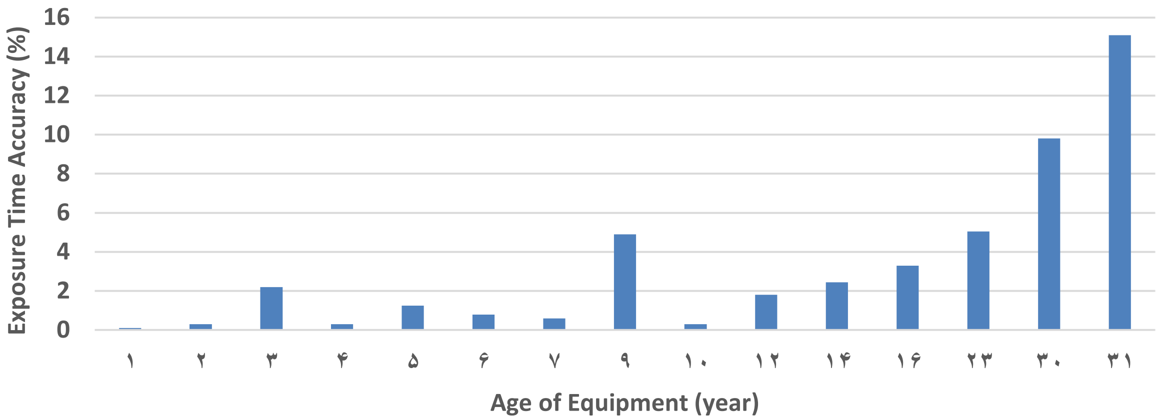

Figure 1. Relationship between exposure time accuracy and age of equipment

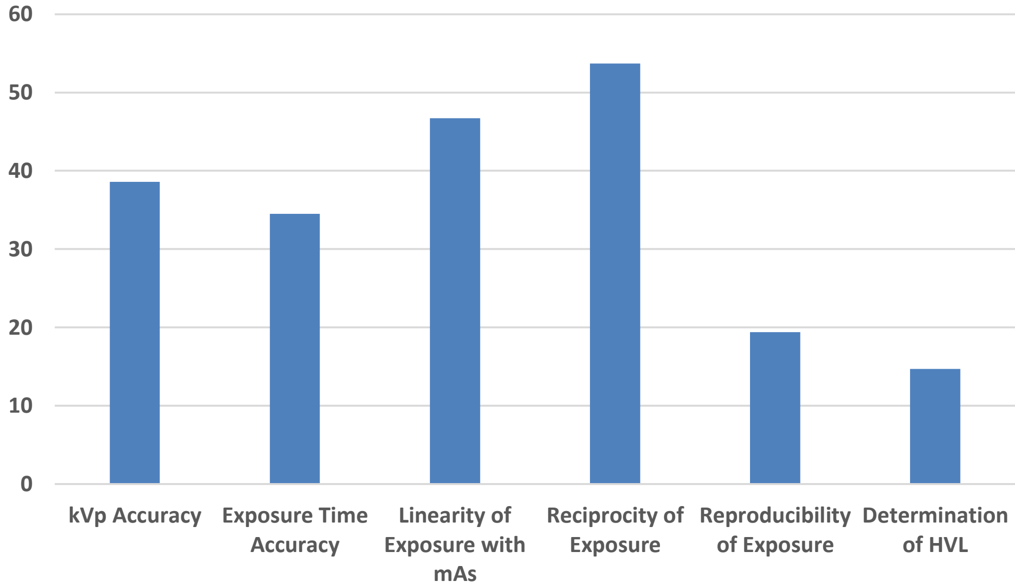

Figure 2. Failure percentage in all QC test results

In kVp accuracy test, 38.6% of devices failed to pass the test. In previous studies in Iran, 6.7-57% of devices failed this test [20, 21, 23, 25, 26]. Variations in kVp may be caused by variations in the line voltage supplying the x-ray generator by faulty high voltage cables or problems with the autotransformer/kVp selection circuitry. Given the significant similarity between our findings and previous studies in this regard, it is important to evaluate and correct any defects in these devices.

Differences between measured kVp and nominal kVp at different mA stations may be more important than across-the-board errors. Unfortunately, there is no similar Iranian study to compare the results. Kilovoltage settings tend to drift over time, primarily as a result of tubing aging. Results of the t-test were indicative of statistically significant differences between measured kVp and nominal kVp at different mA settings (P=0.15).

Furthermore, in the exposure time accuracy test, 34.5% of devices did not meet the standards. This amount was 14-45% in other Iranian studies [20, 21, 23, 25, 26]. However, Rasuli et al. affirmed that the results met the standard criteria in all devices [24]. Age of equipment is an effective factor for timer circuit function. As a result, correction of this variable is vital in order to have an appropriate radiograph and avoid repeating the radiograph and increasing patient exposure.

Exposure linearity test demonstrated that 46.7% of devices were out of the standard range. This amount was 11-54% in some of the previously conducted studies in Iran [20, 21, 23, 25, 26]. In a study by Rasuli et al. [24], the results were in line with the defined standards. Given the use of mAs selector for setting the cathode filament temperature in X-ray generator in order to determine the quantity of X-ray tube output along with exposure time, the selected mA as the accuracy of exposure time is important. As a result, it is necessary to amend this rate of failure.

In the exposure reciprocity test, 53.7% of the devices failed to pass the test. The result of this test is in congruence with the results obtained by Khoshbin khoshnazar et al. (=30%) [23]. In these studies, the maximum failure was observed in QC test, which consisted more than half of the devices. Given the lack of research in this area, it is suggested that more studies be conducted in the future in order to reach more accurate results. The percentage of failure in the reproducibility of exposure in observed devices was 19.4%, which was 7-39% in the other Iranian studies. Meanwhile, the results by khoshbin khoshnazar et al. and Rasuli et al. were in the allowed range and had pass the defined limits [20, 21, 23-26]. In this test, no difference was observed between the results of observation, which is needed to correct the devices for the purpose of ALARA goals.

In 14.7% of the evaluated devices, the tube output beam had HVL less than the allowed limit. In a study by Jomeh zadeh et al., the results indicated that HVL was in an acceptable level, with the exception of two devices (13% less than the limit) [26]. Results obtained by Khoshbin khoshnazar et al. demonstrated that the measured amount of HVL was more than the acceptable limit [23]. The minimum filtration is needed to omit the low energy beam but the extra filtration causes the elimination of suitable beams. As a result, more exposure is needed to reach the desirable dose, which leads to consequent increase of patient dose.

In the united states of America and European countries, QC has been an important issue for a long time. In many developed countries, QC is an obligatory activity. In Iran, many people have emphasized the importance of this issue; nevertheless, it seems that this subject has not come to practice yet.

5. Conclusion

According to the results of this study, wide variations in QA test results might be due to the fact that it is not mandatory to implement QA programs in Iran. Non-reciprocity of exposure, nonlinearity of exposure with mAs, kVp and timer inaccuracy were reported to be the most important problems. Involvement of medical physicists, radiologists and radiographers in the implementation of QA programs at various stages of development, installation and use of equipment should enable the gradual improvement in equipment performance.

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