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Original Article

Quality Control of Conventional Radiology Devices in Selected Hospitals of Khuzestan Province, Iran

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Abstract

Introduction
Quality control techniques used to test the components of the radiological system and verify that the equipment is operating satisfactorily. In this study, quality control (QC) assessment of conventional radiology devices was performed in frequently visited radiology centers of Khuzestan province, Iran.
Materials and Methods
Fifteen conventional radiology devices were examined, based on the protocol proposed in Report No. 77 by the Institute of Physics and Engineering in Medicine (IPEM). Ten standard QC tests, including voltage accuracy and reproducibility, exposure time accuracy and reproducibility, tube output linearity (time and milliampere), filtration (half-value layer), tube output (70 kV at FSD =100 cm), tube output reproducibility and beam alignment were performed and assessed. All measurements were performed, using Barracuda multi-purpose detector.
Results
The reproducibility of voltage, exposure time and dose output, as well as output linearity, met the standard criteria in all devices. However, in 60% of the units, the results of the beam alignment test were poor. We also found that 66.7% of the studied units offer services to more than 18,000 patients annually or 50 patients per day.
Conclusion
Despite the fact that radiological devices in Khuzestan province are relatively old with high workload, the obtained results showed that these devices met the standard criteria. This may be mainly related to proper after-sale services, provided by the companies. Although these services may be expensive for radiology centers, the costs may be significantly reduced if QC is defined as a routine procedure performed by qualified medical physicists or radiation safety officers.

Keywords: Radiation Protection, Quality Control, Diagnostic X-Ray, Radiography, Radiology Device

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1. Introduction

X-ray is the most frequently used tool in the diagnosis of diseases and constitutes a major part of man's exposure to artificial resources [1]. X-ray imaging is an efficient diagnostic method in medicine with no suitable alternative. Based on the principle of "as low as reasonably achievable" (ALARA), x-ray examinations should provide images containing valuable diagnostic information with the lowest achievable radiation dose [2]. To achieve this goal, some legislative institutions have implemented quality assurance programs in medical imaging departments of hospitals [3-5].

In Iran, quality control (QC) programs of medical imaging devices are mainly implemented by authorized companies, which are supervised by the National Radiation Protection Department (NRPD). Also, QC tests on conventional radiology devices are performed biennially [6]. Based on the official statistics of the Atomic Energy Organization of Iran (AEOI), 18,867,000 x-ray examinations were carried out on 12,963,000 patients in 2003 [7].

The rapidly-growing demand for x-ray application by medical practitioners has led to unnecessary patient exposure. Routine QC tests (daily, weekly and monthly) are not performed regularly at any radiology departments. This is partly due to the absence of trained personnel and mainly the weakness of rules and lack of appropriate equipment for QC tests. Furthermore, QC tests are limited to biennial examinations.

Considering the importance of QC tests in patients' radiation exposure, several studies have been performed in some provinces of Iran. Shahbazi et al. assessed seven radiology devices in Chahar Mahal Bakhtiari province and evaluated QC effect on patient dose. They revealed that QC can reduce patient dose by at least 30%. [8]

Moreover, Khoshnazar et al. studied 44 devices in Golestan province, Iran and found that in 43.2% of radiology equipment, exposure time accuracy was out of the standard range [9]. Additionally, Aghahadadi et al. evaluated the effect of QC on ten radiology devices in Tehran province and showed that patient dose decreased in 65% of cases as a result of performing QC tests on these devices [10].

Since no study has been conducted in Khuzestan province to assess the performance of QC programs on radiographic devices, the main purpose of this study was to perform QC assessment of conventional radiology devices in frequently-visited radiology centers of Khuzestan province as an undeveloped region in Iran.

2. Materials and Methods

Fifteen conventional radiology devices in seven major cities of Khuzestan province (Ahvaz, Dezful, Behbahan, Mahshahr, Khoramshahr, Ramhormoz and Masjed Soleyman) were selected and studied from October to December 2013. High-load radiology centers with homogeneous geographic distribution in Khuzestan province were included in this study.

Ten standard QC tests, including voltage accuracy and reproducibility, exposure time accuracy and reproducibility, tube output linearity (time and milliampere), filtration (half-value layer or HVL), tube output (70 kV at FSD=100 cm), tube output reproducibility and beam alignment were performed to assess the devices. QC tests were performed, based on the protocol proposed in Report No. 77 by the Institute of Physics and Engineering in Medicine (IPEM) [5], as shown in table 1. These parameters were chosen as valuable tests for evaluating the devices.

Table 1. The definition and grading of the most important parameters for QC evaluation of conventional radiology units

Parameters	Definition	Good	Normal	Poor
Voltage accuracy	$\frac{kV\ (\text{measured}) - kV\ (\text{nominal})}{kV\ (\text{nominal})}$	±5%	±10%	> ±10%
Voltage reproducibility	$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$ $CV = \frac{SD}{\bar{X}}$	±5%	±10%	> ±10%
Exposure time accuracy	$\frac{time\ (\text{measured}) - time\ (\text{nominal})}{\text{time(nominal)}}$	±5%	±10%	> ±10%
Exposure time reproducibility	$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$ $X = \frac{Dose}{mAs}$	±5%	±10%	> ±10%
Tube output linearity (D=f(s))	$L = \frac{X_1 - X_2}{X_1 + X_2}$ $X = \frac{Dose}{mAs}$	±5%	±10%	> ±10%
Tube output linearity (D=f(mA))	$L = \frac{X_1 - X_2}{X_1 + X_2}$ $X = \frac{Dose}{mAs}$	±5%	±10%	> ±10%
Filtration (HVL)	Thickness of aluminum filter reducing x-ray intensity to half	$> 2.5mmAl$	-	$< 2.5mmAl$
Tube output (70 kV at FSD=100 cm)	$X = \frac{Dose}{mAs}$	43-52 µGy/mAs	26-43 , 52-69 Gy/mAs	< 26 µGy/mAs > 69 µGy/mAs
Tube output reproducibility	$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$, $CV = \frac{SD}{\bar{X}}$	±5%	±10%	> ±10%
Beam alignment	The distance between light and x-ray field	< 1%	≤ 2%	> 2%

This study was performed, using a calibrated Barracuda x-ray multi-purpose detector (MPD) (RTI electronics, Sweden) for dosimetric tests, alpha test phantom (Pehamed, Germany) for beam alignment evaluation and pure aluminum HVL filter (RTI electronics, Sweden). All tests were performed by the first author who is qualified to run QC tests on diagnostic medical imaging devices. MPD was positioned on the table at beam center at 100 cm FSD. In order to avoid backscatter radiation, MPD was placed on a lead apron.

Voltage accuracy: At constant tube currents, clinical tube voltages (60-110 kVp) were tested (5 kVp steps). Then, the measurements were compared with the specified values to determine the differences.

Voltage reproducibility: Exposure was performed at constant tube voltages and clinical tube loadings. The experiments at this step were repeated at least three times to

enable statistical analysis on the obtained data. Afterwards, standard deviation (SD) and coefficient of variation (CV) were calculated for the measured voltages.

Exposure time accuracy: At a constant tube voltage (usually 70 kVp) and adjustable tube current, exposure times were tested (0.1-0.5, 0.1 s steps) at 0.1s intervals from 0.1s to 0.5s. Then, the measurements were compared with the specified values to evaluate the differences.

Exposure time reproducibility: At the constant exposure time and clinical tube loadings, at least three exposures were performed. Then, SD and CV were calculated for the measured exposure time.

The linearity of tube output (D=f(s)): At constant tube voltage and current, two exposures were performed at different time intervals (e.g., 0.1 and 0.2). Dose-to-mA ratio(x) The X parameter was defined as "Dose to mA ratio" and was calculated for both exposure times. Afterwards, linearity coefficient (L) was calculated, using the formula presented in table 3.

***The linearity of tube output (D=f (mA))*:** At a constant tube voltage and time, two exposures were performed with different tube currents (e.g., 100 and 200). Dose-to-mA ratio(x) The X parameter was calculated for both tube currents, and L value was determined.

Filtration (HVL): At clinical tube voltages, an aluminum attenuator was used to reduce the intensity to half of its initial value. Afterwards, the attenuation curve was plotted and HVL value was extracted.

Tube output (70 kV at FSD=100 cm): At 70 kVp and typical mAs, the tube output was measured by placing MPD at 100-cm FSD. This parameter can be used for evaluating patient's skin dose.

Reproducibility of the tube output: At constant tube voltages and clinical tube loadings, at least three exposures were performed. Then, SD and CV were calculated for the measured dose.

Beam alignment: In order to have a more congruent form of light and x-ray beam, the collimator pattern was applied.

Based on IPEM Report No.77, the devices were categorized into three groups: "good", "normal" and "poor" (< 5%, 5-10% and > 10% of error and CV, respectively).

3. Result

The technical characteristics of devices are shown in table 2. Among the studied devices, seven devices were made by Varian (USA), five by Shimadzu (Japan), two by Toshiba (Japan) and one by Villa Medical System (Italy). We noted that 66.7% of the units had been used for over ten years. Also, 73.3% of the devices had three-phase 12-pulse generators. Only in Behbahan (A), automatic exposure control had been applied by radiation technologists to set exposure conditions. In other words, although 90% of departments were employed with automatic exposure control (AEC) systems, these systems could not be used for determining the exposure conditions.

Table 2. Technical characteristics of the devices

Radiology Department	Manufacturer	Year of installation	kVp_{max}	AEC	Generator type	Total filtration (mm Al)
Ahvaz A	Shimadzu	Unknown	150	No	1-phase	1mm inh at 70
Ahvaz B	Varian	1997	150	No	HF	2.7
Ahvaz C	Shimadzu	Unknown	150	No	3ph-12pu	1mm inh at 70
Behbahan A	Toshiba	1999	150	Yes	1-phase	0.7mm inh at 75
Behbahan B	Varian	1999	150	Not used	3ph-12pu	2.7
Dezful A	Varian	2011	150	Not used	3ph-12pu	2.7
Dezful B	Varian	2011	150	Not used	3ph-12pu	2.7
Khoramshahr A	Toshiba	2006	125	Not used	3ph-12pu	2.1
Khoramshahr B	Varian	2000	150	Not used	3ph-12pu	2.7
Mahshahr A	Shimadzu	1999	150	Not used	3ph-12pu	2.5
Mahshahr B	Shimadzu	2011	150	Not used	3ph-12pu	2.5
Masjed Soleyman	Villa Medical Systems	< 1990	150	No	1-phase	Unknown
Ramhormoz A	Varian	2003	150	Not used	3ph-12pu	2.7
Ramhormoz B	Varian	2003	150	Not used	3ph-12pu	2.7
Ramhormoz C	Shimadzu	2007	150	Not used	3ph-12pu	2.5

The results of the tests and the used criteria, are presented in table 3. The reproducibility of voltage, exposure time and dose output, as well as output linearity, met the standard criteria in all cases. However, in 60% of the units, beam alignment test results were poor, and the collimator needed to be corrected collimator should be considered to repair.

Table 3. Test results and the corresponding criteria

	Criteria		
Tests	Good	Normal	Poor
Voltage accuracy	86.6 %	6.7 %	6.7 %
Voltage reproducibility	100 %	0 %	0 %
Exposure time accuracy	93.3 %	6.7 %	0 %
Exposure time reproducibility	100 %	0 %	0 %
Tube output linearity (s)	100 %	0 %	0 %
Tube output linearity (mA)	80 %	6.7 %	13.3 %
Filtration (HVL)	73.3 %	-	26.7 %
Tube output (70 kV at FSD=100 cm)	53.3 %	33.3 %	13.4 %
Reproducibility of the tube output	100 %	0 %	0 %
Beam alignment	40 %	53.3 %	6.7 %

Table 4. The load of devices (patient/year)

Load per year	≤ 9000	9000-18000	18000-36000	≥ 36000
Percentage of devices	20 %	13.3 %	6.7 %	60 %

4. Discussion

The main purpose of this study was to perform QC assessment of conventional radiology devices in frequently-visited radiology centers of Khuzestan province, as an undeveloped region in Iran. In Iran, QC programs of medical imaging devices are generally implemented by authorized companies, which are supervised by NRPD. Also, QC tests of conventional radiology devices are performed biennially [6], which may lead to some problems regarding the appropriate function of the devices.

As presented in table 4, 46.7% of the devices did not show proper tube output, which is mainly due to the inadequacy of added filters to the collimators. At least 9 units (60%) did not show a good performance in the beam alignment test, which is related to the high workload. Collimator field size should be adjusted for any patient, since in some cases, patients accidentally collide with the collimator while sitting on the table.

Most devices with single-phase generators (two-thirds of devices) did not have a good presentation in voltage accuracy test, which can be due to high ripple voltage. None of single-phase generators met linearity (mA) criteria and two-thirds of the devices showed poor performance, which was due to the high performance of filament in radiology tubes and the imbalance between the generated heat and outgoing electrons.

Devices, used more than ten years, had some problems with HVL test, which may be due to frequent repairs and displacement of filters. All devices with a patient load of more than 36,000 per year did not perform well at least in

two tests. In other words, QC programs should be implemented more orderly for high-load devices and old units.

QC test of radiology devices depends on parameters such as the QC examiner, age of the device, working load, QC dosimeters and the technologist's working procedures. Accordingly, we believe that the results of the QC assessment in different periods and countries cannot be very reliable. In 2013, Khoshnazar et al. assessed 44 radiology units in Golestan province, Iran [9]. The results related to voltage and output reproducibility were in accordance with our study. However, in the present study, voltage accuracy, beam alignment and exposure time accuracy test results (86%, 93.3% and 6.7%, respectively) were better than the mentioned study (29.5%, 63% and 29%, respectively).

Shahbazi et al. assessed seven radiology units in Chahar Mahal Bakhtiari province, Iran [8]. The results of the exposure time reproducibility test were in accordance with the present study, although voltage accuracy test results were better in our study (93.3% vs. 43%). This is mainly due to the fact that the QC program was implemented in 2007 in Iran, while the study by Shahbazi et al. was performed before 2007.

The main limitation of our study was the small sample size due to financial constraints. In order to perform a comprehensive study on this subject, we recommend that future studies evaluate a larger number of devices, including digital units, CT scans and dynamic imaging modalities such as angiography.

5. Conclusion

Despite the fact that radiological devices in Khuzestan province are relatively old with high workload, the test results were mainly satisfactory. This may be due to the proper after-sale services, provided by the companies. Although these services are expensive, the costs may be significantly reduced if QC is defined as a routine procedure performed by qualified medical physicists or radiation safety officers.

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