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Original Article

Quality Control of Radiography Equipments in Golestan Province of IRAN

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Abstract

Introduction
The main goal of this study was to perform quality control test on all radiography units operating in Golestan province of IRAN.
Materials and Methods
Forty-four X-ray units were examined based on general accepted programs for quality control. Eight parameters including kVp accuracy, kVp reproducibility, mA-time reciprocity, exposure linearity, exposure reproducibility, timer accuracy, filtration, and beam alignment were measured and calculated. Measurements were carried out by a Baracuda X-ray beam analyzer.
Results
Variance of kVp reproducibility was acceptable in 100% of equipments. kVp accuracy was found to be unsatisfactory in 29.5% of equipments. Variance of mA-time reciprocity was measured to be within reliable limits. Thirty-nine percent of radiography equipments showed non-linear exposure attitude while 16.7 % of them exhibited unacceptable reproducibility of exposure. Moreover, beam misalignment was met in 29.5% of equipments. In 43.2% of radiography equipments, timer accuracy was out of permissible range.
Conclusion
Timer inaccuracy seems to be a common problem for X-ray units. Exposure non-linearity, mA-time non-reciprocity, kVp inaccuracy, beam misalignment, and finally non-reproducibility of exposure were found to have less importance.

Keywords: Golestan Province, Quality Control, Radiography Equipment

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1. Introduction

Diagnostic imaging is a multistage process, in which any fault can result in low quality images and the necessity to repeat the radiographs. The faults range from human errors, operational, and management, to instrumental problems. The main consequences would be an increase effective dose to population and excess of costs. In a radiology department, X-ray generator, image receptor; developing system, personnel qualification, and management are the main parameters determining the products. To examine and assess the function of an imaging system, three program namely quality assurance, acceptance test, and quality control with different objective and extent should be performed. The first one considers comprehensively all of above mentioned parameters. The second one is carried out at the time of introducing new coming equipments which is normally the responsibility of the seller company. Finally, the last only deals with the technical characteristics of equipments. Quality control depends on policy of department, local rules, and of course presence of necessary devices and may be performed quarterly, semi-annually, or annually. In IRAN, quality control tests are not mandatory yet and only some educational centers, in frame of a research program perform them. In the present work, only X-ray generator, which is the most important part of an imaging unit, has been considered. This work is the first one in our country which covers all working radiography equipments in a province. The first quality control test of diagnostic X-ray units in the world was carried out in England in 1966. American Association of Physicist in Medicine (AAPM) developed a comprehensive quality assurance program for diagnostic radiology units in 1977 [1]. World Health Organization (WHO), due to widespread use of radiology unit, published a guideline for quality control tests in 1982 [2]. Thereafter, a comprehensive quality assurance program was developed by National Council of Radiological Protection and Measurement (NCRP) in 1988 [3].

As stated in AAPM report of 1994, “Designing and supervising a quality assurance program is the prime responsibility of medical physicist“. [4]. Guidance for quality control of diagnostic units was published by European commission of protection against ionizing radiation in 1997 [5].

AAPM explained the main components of quality control program in its report named “Quality Control in Diagnostic Radiology” in 2002 [6]. Tamas Porubszky and his colleagues explained condition of quality control performing in Hungry on the First Central & Eastern European Workshop on Quality Control in 2007 [7]. They suggested using experience of other countries to run local quality control programs.

Zoeltief developed a quality control program for diagnostic radiology in the Netherlands in 1998 [8]. He and colleagues introduced a quality control program for digital and conventional radiology equipments, through which X-ray generator, laser printer, and image acquisition portion of the system were examined [9].

Van den berg et al. prepared a guideline for quality control of radiology units in the Netherlands, in which eleven parameters were recommended to be assessed [10].

Kharita and colleagues compared the results of quality control test at two periods before and after performing the national quality control program [11].

In different countries, depending on the sophistication of imaging systems and also presence of required devices, some parts of quality control tests have been accentuated [7-13].

In our country, no comprehensive national program for quality assurance has been developed yet. Saghatchi et al., performed quality control in five hospitals in Zanjan city [14]. Shahbazi et al., assessed seven equipments and measured and compared the entrance dose before and after quality control [15].

2. Materials and Methods

A Baracuda X-ray analyzer made by RTI Electronics of Austria with the MPD Multi-Purpose Detector was used to measure and calculate eight parameters including: kVp accuracy, kVp reproducibility, mA-time reciprocity, exposure linearity, exposure reproducibility, timer accuracy, filtration, and beam alignment.

Inaccuracy of measurement of kVp is ±1.5%, while for time it is ±1% or ±0.5 sec. For dose, dose rate, HVL, and total filtration inaccuracy of measurement, they are ±5%, ±5%, ±10%, and ±10%, respectively as described in specification of the device.

Methods of measurement were based on specifications mentioned by manufacturer's instruction.Table 1 shows the equations used for calculation of each parameter and their acceptable range.

Forty-four radiography equipments, working in 16 private and 23 governmental imaging centers, were assessed. Statistical analyses were performed using SPSS software. To compare averages among three age groups of radiology units, independent sample t-test was performed at significant level of $p \leq 0.05$.

2.1. Condition of measurement for each parameters

kVp accuracy: At a fixed mAs, six kVp stations (50, 70, 80, 90, 100, and 110) were selected and exposures were done. SSD was set at 100 cm. Baracuda detector was placed on the tabletop at selected SSD on a lead apron to minimize scattered radiation and then the measurements were fulfilled.

Table 1. Parameters which were measured for quality control test and their definition and acceptable ranges.

Parameter	Definition	Acceptable range
kVp accuracy	$\frac{measured kVp - input kVp}{input kVp}$	±5%
Variance of kVp reproducibility	$\frac{kVp \max - kVp \min}{kVp \max + kVp \min}$	±5%
Variance of mA-time reciprocity	$(\frac{\frac{mGy}{mAs}\max - \frac{mGy}{mAs}\min}{\frac{mGy}{mAs} avg}) \div 2$	±10%
Variance of exposure linearity	$(\frac{\frac{mGy}{mAs}\max - \frac{mGy}{mAs}\min}{\frac{mGy}{mAs} avg}) \div 2$	±10%
Beam alignment	The distance of light and x-ray field	2% of focal film distance=2 cm
Timer accuracy	$\frac{measured time - input time}{input time}$	t≤10 msec : ±20% t≥10 msec : ±5%
Filtration (HVL)	Thickness of aluminum reducing x-ray intensity to half	Depends to kVp: refer to the text
Variance of exposure reproducibility	$(\frac{mGy \max - mGy \min}{mGy \max + mGy \min}) \div 2$	±5%

kVp reproducibility: Baracuda detector was placed at 100 cm SSD on a lead apron. Exposure factors were 400 mA, and 200 ms while kVp station was kept at 70. Five exposures were done and kVps were measured by detector.

mA-time reciprocity: Baracuda detector was placed (lead apron) at 100 cm SSD. Five exposures were made at 80 kVp and 20 mAs condition through various combination of mA and time (fixed mAs). Exposures were measured by detector and then divided to fixed selected mAs.

Exposure linearity: Baracuda detector was placed (lead apron) at 100 cm SSD. Five exposures were made at fixed time of 0.1 sec (100 ms), 70 kVp, and various mAs including 50, 100, 200, and 400. mAs were selected so that each mAs was twice as the preceding one. Exposures were measured and divided to mAs in each step.

Exposure reproducibility: Baracuda detector was placed (over the lead apron) at 100 cm SSD. Five exposures were repeated with similar condition of 80 KVp, 100 mA, and 100 ms and exposures were measured at each condition.

Beam alignment: Eight markers with known dimensions were put at corners and lateral borders of light field and then exposure was made. Coincidence of light and X-ray fields was measured with precise micrometer.

Timer accuracy: Multimeter was placed (over the lead apron) at 100 cm SSD.

Three exposures with times less than 10 ms and three exposures with times more than 10 ms were made.

Filtration: Baracuda detector was placed (over the lead apron) at 100 cm SSD.

HVL values were measured at five kVps (50, 70, 80, 90, and 100).

To correlate age of equipments with calculated parameters, bivariate correlation test (Pearson) at significant level of $p \leq 0.05$ was implemented.

3. Results

Among 44 assessed equipments, 15 were Shimadzu, 13 Varian, 4 General Electric, 3 Siemens, 3 Pars pad, and the rest were of other brands. kVp_{max} was 150 in 61.3% of equipments, 125 in 20% of them and other values in the remainder of equipments. mA was 500 in 45% of equipments, 600 in 25%, and higher values were noticed in the remainder of equipments. Table 2 shows mean±SD of all examined parameters.

Table 2. Mean±SD of main parameters measured in the study. Values for filtration and alignment are written in the text

Parameter	Mean±SD
Age of equipment	15.78±12.83
KVp accuracy	5.084±5.64
Variance of KVp reproducibilty	0.55±0.81
Variance of mA-time reciprocity	14.02±21.96
Variance of exposure linearity	17.69±21.367
Variance of exposure reproducibility	3.312±9.06
Timer accuracy (time≤10msec)	17.863±24.71
Timer accuracy (time≥10msec)	17.53±25.42
Filtration	Refer to text
Beam alignment	Refer to text

KVp Accuracy

Measured kVp must be within 5% of set kVp. kVp accuracy was in tolerable range in 29.5% of examined equipments. Average kVp accuracy was 5.084±5.04.

KVp reproducibility

Variance of kVp reproducibility was within acceptable range in all of the equipments. Average value was equal to 0.55±0.81.

mA-time reciprocity

Reciprocity means stability of unit output with constant mAs and various combinations of mA and time. Variance of mA-time reciprocity within ±10% is considered tolerable. We found that 30% of equipments had reciprocity out of range. Because of technical limits, it was impossible to measure the parameter in eighth equipments. Average value for mA-time reciprocity was 14.02±21.96.

Exposure linearity

The parameter showed increasing linearity of output as mA increased (at fixed kVp and time). Variance of exposure linearity must be within ±10%. It was shown that 39% of equipments had intolerable variance of linearity. Measurement was impossible in three equipments due to technical limits. Average of variance was 17.69±1.37.

Exposure reproducibility

The parameter showed stability of unit output during the fixed exposure technique. Acceptable variance of exposure reproducibility is ±5%. We found 16.7% of equipments having variance greater than 5%. Average variance was 3.31±9.06.

Beam alignment

It delineates how much light and X-ray fields are superimposed. The tolerable range was taken as 2% of focal film distance (normally 100 cm). Our measurements showed that 29% of equipments at least in one direction, parallel or perpendicular to table axis, had misalignment.

Filtration

Adequate filtration can remove low energy photons which if present increase patient dose. HVL values were measured at different kVps (50, 70, 80, 90, and 100). Measured values were more than the minimum recommended HVL in each kVp for all of the units. Table 3 shows the measured and acceptable HVLs.

Table 3. Measured and acceptable HVLs for different KVp

kVp	Minimum acceptable HVL (mm Al)	Measured HVL(mm Al)
60	1.3	2.12±0.47
70	1.5	2.44±0.39
80	2.3	2.63±0.44
90	2.5	2.82±0.55
100	2.7	3.009±0.64

Timer accuracy

For times less than 10 ms, acceptable accuracy is ±20% and for times more than 10 ms, it is normally ±5%. For 37% of radiography equipments, timer accuracy was not acceptable, while for times less than 10 ms, it was the case for 26% of equipments.

Effect of equipment age on some parameters

Radiography equipments were categorized in to three groups in terms of age: less than 10, between 10 and 20, and more than 20 years of service. Numbers of equipments in three age groups were 10, 15, and 19, respectively.

Accuracy and reproducibility of KVp

Considering kVp accuracy, there was no significant difference (p≥0.05), when values were compared by means of independent t-test. Table 4 shows the results in three age groups. By implementing Pearson's correlation test between kVp reproducibility and age, we found a correlation coefficient at level of α=0.01.

Table 4. KVp accuracy and reproducibility in three age groups of ≤10, 10-11, and ≥20 years.

Age of equipment(year)	≤10	10-20	≥20
kVp accuracy	3.3±5.22	3.86±4.87	10.87±5.56
kVp reproducibility	0.1±0.16	0.2±0.26	1.08±0.83

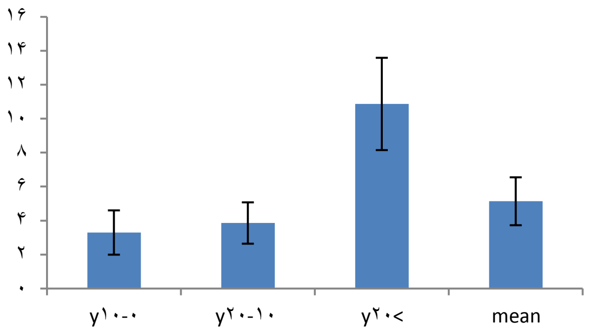

Figure 1. KVp accuracy in three age groups of equipments (error bars are depicted as one fourth of the real values)

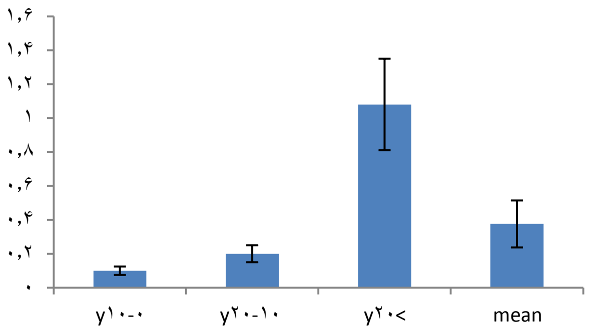

Figure 2. KVp reproducibility in three age groups (error bars are depicted as one fourth of the real values)

Exposure reproducibility

Regarding exposure reproducibility, independent t-test showed no significant difference between three age groups ($p \geq 0.05$). Pearson's correlation test showed no significant correlation between exposure reproducibility and age of equipments.

kVp accuracy and reproducibility

Independent t-test shows no significant difference between kVp accuracy of three age groups. Moreover, Pearson's correlation test showed a correlation between kVp reproducibility and age of equipments at level of $\alpha=0.01$.

Table 5 shows values of exposure reproducibility, exposure linearity, and mA-time reciprocity in three age groups.

Table 5. Exposure reproducibility, linearity, and mA-time reciprocity in three age groups.

Age of equipment	≤10	10-20	≥20
Exposure reproducibility	11.7±19.72	8.79±19.94	21.48±17.15
Exposure linearity	19.95±24.1	10.30±17.39	31.82±10.60
mA-time reciprocity	1.22±1.22	1.07±1.82	12.22±19.34

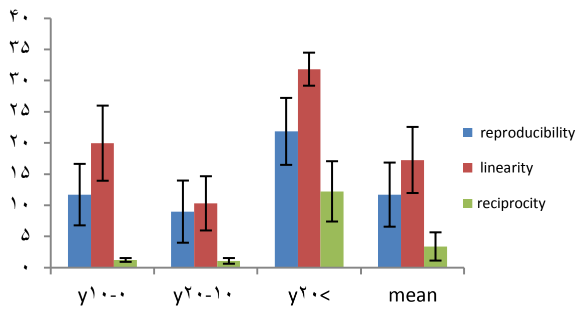

Figure 3. Exposure reproducibility, linearity, and mA-time reciprocity in three age groups (error bars are depicted as one fourth of real).

Timer accuracy

Independent t-test showed a significant difference between the three age groups ($p \leq 0.05$) and based on the results, for the set time more than 10 ms, only equipments aging over 20 years showed significant difference. Table 6 shows timer accuracy for set times more and less than 10 ms.

Table 6. Timer accuracy for set times in three age groups of equipments

Age \ Set time	<10ms	>10ms
≤10	11.78±18.36	6.1±9.98
10-20	6.87±5.08	6.84±15.18
≥20	64.66±20.97	57.21±28.67
mean±SD	18.87±25.12	16.78±25.03

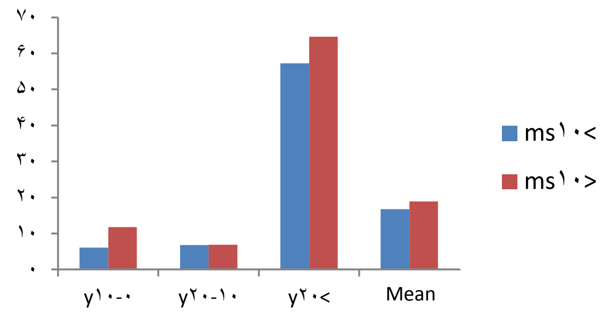

Figure 4. Timer accuracy for set times in three age groups of equipments (error bars are depicted as one fourth of real).

4. Discussion

The main objective of this quality control study was to monitor the changes in the performance of units which may result in significant loss of image quality or increase of patient's dose by repeated radiographs [1].

Quality control test may be performed at different intervals. As the equipments get older, necessity for doing these tests will be greater. Since average age of equipments working in our province is 15.78±12.83 years, it demands more frequent quality control tests with shorter intervals.

Regular quality control tests with 6 to 12 months interval can result in a more reliable and updated knowledge of medical physicist of the condition of equipments. This leads to high quality images, less repeated radiographs, and more importantly reduced patient dose [1, 4, and 6].

In the present work, variance of KVp accuracy was found to be out of acceptable range in 29.5 % of equipments. kVp determines quality of X-ray beam and hence image contrast and patient dose. kVp recalibration assures kVp accuracy.

Neofotistou and colleagues performed quality control tests on 400 X-ray generators in Greece [12]. kVp accuracy was satisfactory in 65% of equipments. Seventy percent of them showed good filtration and beam alignment was found to be acceptable in 75% of equipments. The results enforced the need to perform the tests regularly.

Our results state that except for timer accuracy, exposure linearity is in the worst condition. At a fixed kVp and time, by increasing mA, linear increase of exposure was examined. Variance of mA-time reciprocity was shown to be satisfied in 30% of the equipments. Radiographers must be assured of a constant exposure with constant mAs while selecting various combinations of mA and time. Without this capability it would be hard for radiographers to predict quality of the images. Our result is comparable with kharita et al. report whose reciprocity was claimed to be unacceptable in 34% of equipments [11].

Regarding exposure reproducibility, percentage of faulty equipments in our study was 16.7% where in Neofotistou's study it was 5% [12] which shows a worse condition in our experiment. Exposure linearity in our study was found to be unsatisfactory in 39% of equipments, where Neofotistou's result was 55% which shows a better condition in our case.

Moreover, 37% of equipments showed bad timer accuracy for set times more than 10 ms. Therefore, bad condition of reciprocity may be related to bad condition of timer function. The results showed that timer accuracy is the most important problem seen, which should be seriously considered and fixed. For the set time less than 10 ms, age of equipment was a contributing factor, the fact that necessitates quality control programs for old equipments.

Kharita et al, compared quality control test results in two periods before and after mandatory national quality control program in Syria [11]. They found a significant improvement in all parameters after quality control program. Percentages of equipments with faulty kVp accuracy before and after program were 20.8% and 12.6%, respectively. Regarding kVp accuracy, our results is something between Neofotistou's and Kharita's results before national quality control program.

Kharita showed beam alignment getting better after the period, so that the percentage of faulty equipments changed from 10.8% to 5.4%. In the present work, we found that 29.5% of equipments had beam misalignment more than 2 cm in at least one direction. In the study by Kharita et al., 10.8 % of equipments showed bad condition of alignment before national quality control program. Neofotistou showed that 75% of equipments had proper beam alignment which is near to our results.

Minimum filtration was met in all kVps. Of course, excess filtration can reduce intensity of radiation which in turn imposes more loads on equipments via selecting higher mAs and kVp than normal condition.

In 2008, Bosnjac et al. compared quality control test results acquired in 2002 and 2005, before and after national quality assurance program [13]. Ninety-two X-ray units were examined in this study. Twenty-nine percent of equipments were found to have acceptable kVp accuracy, before program, which changed to 11% after it. Regarding timer accuracy, percentage of equipments in poor condition before and after program was 17 and 12%, respectively which is better than our result.

Kharita et al., showed better result for timer accuracy in Syria than ours, so that percentages of faulty X-ray units before and after national quality assurance program were 15 and 7%, respectively which is again better than ours.

An interesting finding is that nearly 30% of equipments had poor functions which is nearly similar to results from other groups [11,12,13]. Shahbazi et al. showed that in hospitals of Chaharmal bakhtiari province, there was 40% improvement in patient dose after chest radiography because of implementing quality control test [15].

5. Conclusion

It seems timer accuracy was the most important problem of our radiography equipments. Next important parameters with less importance than timer accuracy were exposure linearity, mA-time reciprocity, kVp accuracy, beam alignment, and finally exposure reproducibility.

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