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ORIGINAL ARTICLE

Evaluation of Conventional Radiographic Systems in Shahid Sadoughi University of Medical Sciences: A Multi-Centric Quality Control Study

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Abstract

Introduction: Generally, the benefits of radiological examinations performed on individuals far outweigh their risks; however, this is not true when the radiographic system fails to work properly. Therefore, to avoid such errors, it is crucial to frequently perform Quality Control (QC) checks in an imaging facility.

Material and Methods: A total of 11 highly-referred centers out of 62 radiology rooms located in Yazd province were included in this investigation, and QC tests comprising light/radiation field alignment, the accuracy of kilovoltage and exposure time, reproducibility of kilovoltage, exposure time, and output, and linearity of output against exposure time and milliamperage were performed for each equipment. The light and radiation field alignment test were carried out by a quantitative assessment of digital images of a collimator template (PTW-Freiburg, Germany). The measurements were made by a Barracuda package and a Multi-Purpose Detector (MPD).

Results: In terms of the light/radiation field alignment check, unit A failed to satisfy the national regulations. Concerning the timer reproducibility, 64% of the units failed to meet the criteria. All of the devices passed the rest of the checks satisfactorily.

Conclusion: This study uncovered that most of the radiology rooms in Yazd province are in an adequate situation based on the QC tests; however, more than half of the units do not satisfy the timer reproducibility criteria. Hence, more supervision needs to be directed at these systems by qualified radiation safety officers who are responsible for the protection of the population against ionization radiation.

Keywords: Quality Control; Conventional Radiology; Shahid Sadoughi University of Medical Sciences; Yazd.

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1. Introduction

Since the discovery of the x-ray by Wilhelm Conrad Roentgen in 1895 [1], its utilization in medicine has undergone a dramatic rise. As asserted by several investigators, the public exposure to man-made sources primarily stems from diagnostic examinations [2-6]. This, coupled with the radiological exposure linkage to cancer risk, has raised concerns about the health of the population [7-10].

It cannot be denied that at the individual level, the benefits of these exams by far outweigh their risks; nevertheless, this remains a fact as far as the imaging facility functions satisfactorily [8-11]. The repeat exposures as a consequence of radiographic system malfunctioning are one such example. Thus, it appears to be imperative to evaluate the imaging equipment on an ongoing basis to avoid poor functioning and somewhat total breakdown of the unit. This continual and periodic assessment of unit operation is known as QC. Motivated by the concerns mentioned above, this study was conducted to provide a report on the status of the radiographic systems and hence, to ascertain the cost-effectiveness of radiological examinations performed in Yazd province by conducting the most critical QC tests. The impetus for this study came from the fact that acceptable radiographs can be obtained if individual elements in the system (generator, image receptor, and processor) are operated inside acceptable limits. To the best of the authors' knowledge, this is the first survey aiming to investigate the Quality Control (QC) status among Yazd radiographic systems.

2. Materials and Methods

A total of 11 out of 62 radiology rooms located in Yazd province and affiliated with Shahid Sadoughi University of Medical Sciences and Health Services were included in this survey. These institutions were selected for their relatively high referral rates. The most critical QC tests were accomplished, including light/ radiation field alignment, the accuracy of kilovoltage and exposure time, reproducibility of kilovoltage, exposure time, output, and linearity of output against exposure time and milliamperage; a concise explanation of each test will be provided later. The kilovoltage, exposure time, and output measurements were performed by a Barracuda package and Multi-Purpose Detector (MPD) (RTI Electronics, Sweden) (Figure 1).

Figure 1. Measurement Setup; Barracuda package and Multi-Purpose Detector (MPD)

2.1. Light/Radiation Field Alignment

The light/radiation field alignment checks the congruency of the collimated and irradiated fields to ensure their discrepancy lies within tolerable limits. The unconformity of the beam and light field affects the image contrast due to increased scatter radiation. Moreover, it can cause unnecessary exposure of a body region to X-ray and occasionally may compel the radiologist to repeat the exposure. With reference to the QC criteria published by the Atomic Energy Organization of Iran (AEOI) [12], the misalignment should not exceed 10 mm at each individual border of the field.

In order to test the adequacy of the alignment between light and radiation field, a collimator template (PTW-Freiburg, Germany) was placed on the tabletop at a distance of 100 cm from the source. As illustrated in Figure 2a, the light field was visually collimated to the inner borders of the template and exposed to relatively low technical parameters (regularly, 50 kilovolts, and 2 milliampere-seconds [mAs]). In this context, no film was implemented, and the images were interpreted digitally by ImageJ software (v. 1.52a, National Institutes of Health, USA). To this end, a rectangular Region Of Interest (ROI) was plotted beyond the middle to the margins to cover more than 90% of the border, and then the profile of gray value was drawn for the ROI (Figure 2b).

The distance between the first relative maximum (representation of the midline of the template) and the last minimum (representation of the edge of the radiation a

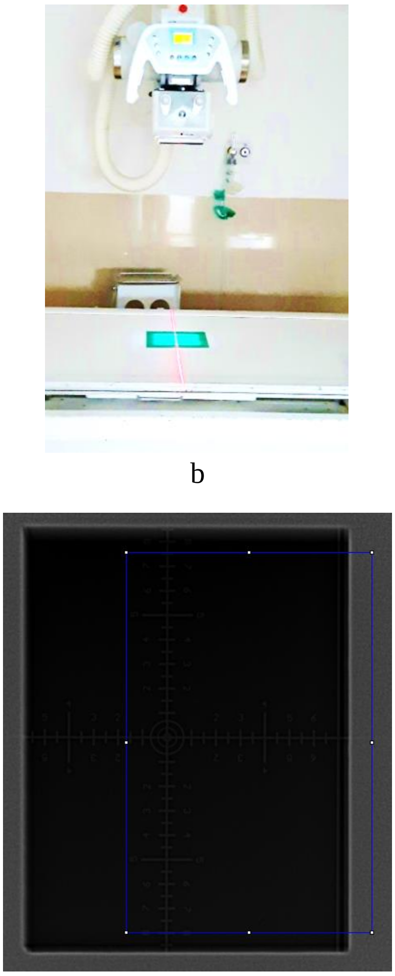

Figure 2. a) The setup of light/radiation field alignment test. The field was visually collimated to the inner borders of the test tool. b) The radiograph of the collimator template. The rectangular Region Of Interest (ROI) was drawn from beyond the midline to margins to cover over 90% of the border

field) was measured from the profile (Figure 3). Since the borderline of the template was somewhat imperceptible in the image, the start position of measurement was chosen as the midline. As evidenced by Figure 3, the penumbra has been excluded, and hence the measured distance fittingly represents the radiation field dimension. Thereafter, the measured distance was subtracted from the template dimension to indicate the field's misalignment. This procedure was carried out for each border of the image individually.

2.2. Kilovoltage Tests

As it is known, the X-ray energy spectrum, and subsequently, the radiograph contrast strongly depends on the adjusted peak KiloVoltage (kVp). Hence, the calibration of accuracy and reproducibility of kVp guarantee the stability of radiation output. These checks were accomplished on the basis of the national guidelines published by AEOI for four or more clinical kVp settings (regularly, from 60 to 90 with 10 kV intervals). For this purpose, the MPD detector was placed on the tabletop at a distance of 100 cm from the tube focal spot. In order to diminish scattered radiation resulted from air gap and in-detector interactions, the field was roughly collimated to the sensitive area of the detector. Based on the national standards, the tolerances of measured kVp from user-set value and the Coefficient Of Variation (COV) from three measurements at an identical user-set kVp (typically, 70 kV) fall within ±10% and ±5% limits, respectively. These are considered satisfactory to assure the stability of the radiographic system.

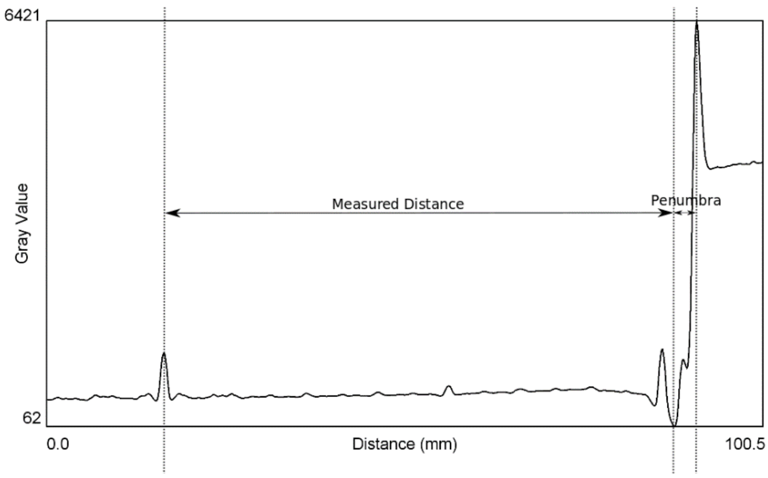

Figure 3. Profile of gray values calculated on the rectangular ROI; the first and second peaks represent the midline and borderline of the test tool, respectively. The overall minimum and maximum represent the boundaries of the field and penumbra, respectively

2.3. Exposure Time Tests

Since the beam quantity is directly affected by exposure time, to guarantee the consistency of output and hence the adequacy of image quality and transferred dose to the patient, one needs to ensure the timer accuracy and reproducibility. These checks were performed in line with AEOI recommendations by an error margin of 10% and 5% for accuracy and reproducibility tests, respectively. When exposure time turns out to be lower than 100 ms, the agency considers the errors of up to 20% satisfactory when it comes to the accuracy test. The accuracy of the timer was assessed at a clinically standard level of kVp and mA by measurements made by the Barracuda package at various exposure times. Referring to the national protocol, the exposure times were categorized into two groups: above or equal to 100 ms, and below 100 ms. In each condition, three sets of measurements were performed, and hence the COV was calculated to check the timer reproducibility.

2.4. Output Tests

In practice, the tube output determines the patient dose and greatly influences the radiograph. The non-reproducibility of output results in erratic exposures, which may cause poor and improper radiographs and in some cases a repetition of exposure. Moreover, the consistency of the linear dependency of output on tube milliampere and exposure time permits the radiologist to determine the best exposure parameters based on the patient thickness to yield a practicable radiograph. Under national standards, the reproducibility of output should be within a COV lower than 5%. Concerning the linearity test, it considers 10% as the margin of error for Linearity coefficient (L), which is described in Equation 1:

$$L = \frac{\left|\left(\frac{mGy}{mAs}\right)_1 - \left(\frac{mGy}{mAs}\right)_2\right|}{\left(\frac{mGy}{mAs}\right)_1 + \left(\frac{mGy}{mAs}\right)_2} \qquad (1)$$

Where mGy/mAs represents the tube output normalized by mAs, and the subscripts refer to each measurement.

2.5. Data Analysis

The indicators of descriptive statistics were derived by Excel (v. 2019, Microsoft, Redmond, Wash, US). To assess whether there is a correlation between the QC results and radiographic system age, Pearson correlation was implemented by SPSS (version 16, SPSS Inc., Chicago, IL). The normality checks of data sets were performed by a Shapiro-Wilk test. A 95% confidence level was considered significant.

3. Results

The characteristics of the investigated radiographic units, including vendor, model, maximum kilovoltage, total filtration, anode angle, age of tube as well as the duration between the last two QC checks are presented in Table 1. The oldest unit, serving more than ten years (124 months) is a Shimadzu radiographic system, installed in room H. The duration between the last two QC checks by an authorized organization was, on average, 14 months (range, 12 to 16 months).

Table 1. Characteristics of the investigated radiographic systems

Room	Vendor	Model	Max kVp	Total Filtration (mm Al)	Anode Angle	Age (months)	QC Interval (months)
A	Varex Imaging	RAD-14	150	2.4	12°	9	NA*
B	IAE SpA	RTC 600 HS	150	3.5	13°	56	16
C	Toshiba	E7252X	150	1.8	12°	89	16
D	IAE SpA	RTC 600 HS	150	3.5	13°	50	16
E	Shimadzu	1/2P13DK	150	2.5	12°	46	13
F	IAE SpA	RTC 600 HS	150	3.5	13°	50	13
G	Toshiba	E7252X	150	2.9	12°	49	12
H	Shimadzu	1/2P13DK	150	2.5	12°	124	13
I	IAE SpA	RTC 600 HS	150	3.5	13°	47	13
J	IAE SpA	RTC 600 HS	150	3.5	13°	50	12
K	Toshiba	E7254FX	150	2.8	12°	56	NA*

* NA: Not Available

3.1. Light/Radiation Field Alignment

Table 2 yields the misalignments of light and radiation fields at each individual border among participating radiology rooms. The negative sign indicates the smaller radiation field compared to the light field and vice versa. Only room A was rejected with regard to the congruency of collimated and irradiated fields. However, there were a couple of units (rooms G and the oldest system, H) where the fields' misalignment had reached the rejection limit. No significant relationship was found between the total absolute misalignment and unit age (P-Value=0.664).

Table 3. Collimated and irradiated field misalignments at each border for each radiology room; the negative values represent a smaller radiation field than the light field and vice versa

Room	Across Table (mm)		Along Table (mm)	
	Left	Right	Top	Bottom
A	2	-13	-3	-9
B	-6	-5	-6	-8
C	-4	-6	-2	-4
D	-1	-3	-3	2
E	6	-7	-7	-2
F	4	-4	-1	1
G	-9	-8	1	-10
H	-10	-7	-4	-10
I	-6	3	-7	-7
J	-3	-8	-6	-3
K	-5	-4	-4	-7

3.2. Kilovoltage Tests

Table 3 gives the QC results regarding the accuracy and reproducibility of kVp. The highest error from user-set kVp was documented for room F at 3.31%, being lower than the maximum tolerable level. As to the reproducibility test, the highest COV was recorded for the measurements performed in room C being equal to 0.37%; this is far below the acceptable level of error. No significant correlation was identified between the factors and age of the system.

3.3. Exposure Time Tests

The results of timer QC are displayed in Table 4. All the devices passed the exposure time accuracy test in both categories (≥100 ms and <100 ms); however, 7 rooms failed to meet the standard criteria for reproducibility test with COVs slightly higher than 5%. Against all the odds, the accuracy of exposure times <100 ms showed a statistically significant and strong reverse correlation with the device age (P-Value=0.029, Pearson Correlation Coefficient=-0.655). For the two others, no significant relation was identified with the unit age.

Table 2. The results of accuracy and reproducibility tests of kVp among 11 radiology rooms

Room	kVp Accuracy	kVp Reproducibility
A	1.60%	0.18%
B	1.68%	0.22%
C	1.91%	0.37%
D	0.59%	0.16%
E	0.77%	0.14%
F	3.31%	0.22%
G	3.14%	0.24%
H	1.91%	0.15%
I	0.95%	0.14%
J	2.10%	0.29%
K	1.77%	0.21%

3.4. Output Tests

The COVs of output measurements and the linearity coefficients against time and milliampere for each radiography system are presented in Table 5. All the units met the output reproducibility, where the highest COV was 1.59%, much lower than the standard limit. The linearity coefficients were roughly near zero for all the devices, indicating a proper relation of output to time and mA. The Pearson correlation test failed to prove any relation between the factors above and theage of the system.

4. Discussion

The purpose of this survey was to check the condition of the radiographic systems installed in Yazd province and thus to provide an overview of their performance. To achieve this goal, the highly referred-to radiology rooms, including 11 units, were investigated through seven critical QC tests. The interval periods between QC tests depend on several factors, including the elements' inherent variability, unit age, equipment stability, and patient load

[13]. The AEOI requires performing annual measurements of kilovoltage, exposure time, and output to have a logical assertion that the unit operates properly. Since the alignment of the light/radiation field plays a critical role in the patient dose and radiograph quality, AEOI recommends monitoring the congruency of the fields monthly.

In the collimator and beam congruency test, the check was performed quantitatively by measuring the distance on the gray value profile and calculating the misalignment. Here, it is important to note that a quantitative assessment eliminates user-induced error factors during the interpretation of images compared to the conventional screen-film approach. Furthermore, there is no way to exclude the penumbra from the border of the x-ray field in the qualitative assessment (screen-film) contrary to the quantitative method. All the included units, with just one exception, met the criteria regarding the light and radiation field alignment.

Unit A revealed the discrepancy of 13 mm on the left border; the regulation requires that discrepancy between fields be within ±10 mm at each border. Hence unit A failed to meet the limits. Interestingly, unit A possesses the most recently-installed tube among all (9 months old). The rejection of unit A regarding the alignment test may be attributed to the lack of or insufficient implementation of QC checks.

Table 4. The results of exposure time accuracy and reproducibility among 11 radiology rooms. Based on the national standards, the timer accuracy was assessed under two categories: exposure times above or equal to 100 m, and exposure times below 100 ms

Room	Timer Accuracy (ms>100)	Timer Accuracy (ms<100)	Timer Reproducibility
A	2.51%	16.95%	4.79%
B	1.26%	3.35%	2.68%
C	3.99%	5.30%	7.71%
D	3.21%	7.83%	7.62%
E	0.18%	1.06%	0.39%
F	3.88%	4.70%	7.77%
G	4.14%	4.46%	6.86%
H	0.21%	1.39%	1.19%
I	2.37%	7.33%	7.50%
J	1.96%	8.51%	7.12%
K	2.56%	4.57%	5.32%

Table 5. The results of output accuracy and linearity vs. time and mA among 11 radiology rooms

Room	Output Reproducibility	Output Linearity vs. Time	Output Linearity vs. mA
A	0.50%	0.00%	0.00%
B	0.00%	0.00%	0.00%
C	0.00%	0.02%	0.00%
D	1.59%	0.02%	0.01%
E	1.27%	0.01%	0.02%
F	0.32%	0.01%	0.00%
G	0.00%	0.01%	0.02%
H	0.92%	0.00%	0.00%
I	0.17%	0.01%	0.00%
J	0.16%	0.01%	0.00%
K	0.42%	0.03%	0.00%

It is intriguing to note that all the units passed the rest of the assessed QC tests except exposure time reproducibility. In exposure time reproducibility, 64% of units failed to meet the standard limit (5%), albeit with low deviations of COV from 5% (max COV, 7.77%). Accordingly, these systems are classified into the action level, i.e. they can continue functioning, but the unit needs to be modified at the earliest opportunity by a qualified expert.

The results linked the reproducibility of exposure time to the age of the unit, unexpectedly with a strong reverse correlation; however, it has commonly been assumed that the more the system ages, the more its reliability and stability degrade [13]. The authors admit that the small number of units investigated by this study makes the generalizability of the results difficult. Moreover, the age of the systems was calculated by the production date, and not the installation date, whereas the period between these two dates may vary by case and thus can be regarded as a source of error.

Compared to other studies, it appears that the radiographic systems installed in Yazd province are in a reliable situation. For instance, the assessment performed by Jomehzadeh *et al.* [14] in Kerman province revealed 25% of units being substandard regarding the kVp accuracy, timer accuracy, and reproducibility tests. The measurements performed by Gholamhosseinian-Najjar *et al.* [15] in Mashhad is another example, where the authors claim 27%, 54%, and 45% of the units failing to meet the criteria regarding kVp accuracy, exposure linearity, and timer accuracy tests, respectively. The reason may be ascribed to the fact that all the included institutions are affiliated with the university, which requires them to perform the QC tests periodically, no matter what the cost would be (on average, QC tests were performed every 14 months). Therefore, it is suggested to perform a comprehensive analysis by selecting the radiology rooms on a random basis to stand as a good representation of all radiographic systems installed in Yazd, related to either the government or private sector. In addition, the shorter age of installed facilities in Yazd is a remarkable factor.

5. Conclusion

Medical services have recently undergone significant development, and malpractice suits have been reduced thanks to diagnostic procedures. Conventional radiography is considered one of the most prominent and highly demanded diagnostic tools. Hence, particular attention should be devoted to effectively maintaining the units to ensure the cost-effectiveness of performed examinations. In this respect, the most practical strategy seems to be performing QC tests on an ongoing basis. The more precisely and periodically QC checks are performed, the more the unit stays in shape, also the less the misdiagnoses or failures in diagnosis occur, and the less the patient is exposed to hazardous ionization radiation. This study revealed that most of the radiology rooms in Yazd province are in an adequate situation. However, more than half of the units fail to satisfy the timer reproducibility test. Accordingly, more supervision should be administered by qualified radiation safety officers who are responsible for public health against ionization radiation.

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