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Original Article

Quality Control Assessment of Radiology Devices in Kerman Province, Iran

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Abstract

Introduction
Application of quality control (QC) programs at diagnostic radiology departments is of great significance for optimization of image quality and reduction of patient dose. The main objective of this study was to perform QC tests on stationary radiographic X-ray machines, installed in 14 hospitals of Kerman province, Iran.

Materials and Methods
In this cross-sectional study, QC tests were performed on 28 conventional radiographic X-ray units in Kerman governmental hospitals, based on the protocols and criteria recommended by the Atomic Energy Organization of Iran (AEOI), using a calibrated Gammex QC kit. Each section of the QC kit incorporated different models.

Results
Based on the findings, kVp accuracy, kVp reproducibility, timer accuracy, timer reproducibility, exposure reproducibility, mA/timer linearity, and half-value layer were not within the acceptable limits in 25%, 4%, 29%, 18%, 11%, 12%, and 7% of the evaluated units (n=28), respectively.

Conclusion
As radiographic X-ray equipments in Kerman province are relatively old with a high workload, it is recommended that AEOI modify the current policies by changing the frequency of QC test implementation to at least once a year.

Keywords: Diagnostic X-ray, Quality control, Radiology Device

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1. Introduction

X-rays play an important role in modern technology, particularly in medical imaging. Sources of ionizing radiation are regarded as the largest contributor to the population dose emitted from artificial sources, and diagnostic X-rays account for a major share of the received radiation [1]. Overall, provision of high-quality healthcare services is the main purpose of using medical devices. To meet this objective, implementation of some technical examinations on diagnostic radiological equipments can be helpful.

The World Health Organization (WHO) has increasingly highlighted the importance of quality assurance (QA) programs, directed at equipments in order to reduce radiation exposure, decrease the imposed medical costs, and improve the available diagnostic information [2]. QA programs include both quality control (QC) techniques and quality administration procedures. In fact, implementation of QC tests on diagnostic radiographic equipments can ensure the optimal status of imaging systems and help provide high-quality images [3].

X-ray generators constitute the largest share of radiographic units and contain high-voltage transformers, milliampere (mA) and peak kilovoltage (kVp) selectors, rectifiers, and timing circuits [4]. Since, these devices are subject to producing beam variability, it is important to verify the calibration of X-ray generators. In fact, measurement of technical parameters in generators is necessary for ensuring its long durability and reliable system performance, based on periodic programs.

Various studies have been conducted on QC of diagnostic radiographic units, and some guidelines have been established for QC tests [5-8]. In Iran, QC tests are not performed on a regular basis. Some studies have revealed that QC parameters of radiographic equipments are unacceptable, based on QC regulations of diagnostic radiology, suggested by the Atomic Energy Organization of Iran (AEOI) [9-14].

Many studies have been performed on the QC of diagnostic radiographic equipments in some cities of Iran. In 1999, Saghtchi et al. performed QC tests on diagnostic X-ray units in Zanjan, Iran. The obtained results showed 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 [11].

Khoshbin Khoshnazar A. et al. in 2013 performed QC assessments of radiographic equipments in Golestan province, Iran. The findings showed that timer accuracy was a common problem of X-ray units [10]. Furthermore, in 2014, Gholamhosseinian-Najjar et al. reported the QC status of radiology centers in Khorasan, Iran. They observed that the status of 27% and 45% of apparatuses was unacceptable in terms of kVp accuracy and timer accuracy, respectively [9]. Also, Rasuli et al. in 2014 and Gholami et al. in 2015 evaluated the performance of radiographic X-ray equipments in Khuzestan and Lorestan provinces, respectively [13, 14].

To the best of our knowledge, no comprehensive local programs have been implemented in Kerman province for QC assessment of diagnostic radiology devices. Therefore, it is necessary to perform QC tests and periodically fix technical problems. The aim of this study was to perform QC tests on conventional radiographic X-ray generators, installed in radiology centers of hospitals, affiliated to Kerman and Rafsanjan universities of medical sciences in Kerman, Iran.

2. Materials and Methods

2.1. QC apparatus

QC tests were performed on 28 conventional stationary diagnostic X-ray equipments at Kerman and Rafsanjan universities of medical sciences, using a calibrated Gammex QC kit (Gammex RMI, USA). The QC kit included a kV meter (model: RMI 245), Rad-Check™ X-ray exposure meter (model: 06-526), digital X-ray pulse counter/timer (model: 07-453), and aluminum half-value-layer (HVL) attenuator set (RMI 115A).

The kV meter (range: 22-200 kV, accuracy: ±2%, reproducibility: ±0.5 kV) simplified the determination of actual kV values for radiographic X-ray systems. The Rad-Check™ X-ray exposure meter (reproducibility: 2%, energy response to photons: 30-150 kVp within ±7%) was used to measure X-ray exposure (output). The exposure time of either alternating current (AC) or direct current (DC) X-rays was measured, using the digital X-ray pulse counter/timer (X-ray detection accuracy: ±1 count). Also, the aluminum HVL attenuator set was used to determine the HVL of X-ray beams [15].

2.2. Description of QC tests

Specification of some conventional X-ray unit parameters, which were adopted in our study based on the basic criteria by AEOI, is presented in Table 1 [16]. In general, if the measured values comply with the exposure limits, no noticeable deviation in image quality or patient dose is expected. On the other hand, if the measurements fall within the action level, the technical parameter must be fixed by an expert engineer, and then, the parameter should be re-measured.

In the present study, in order to evaluate kVp accuracy (tube voltage), the focus-film-distance (FFD) was set at 100 cm and kV meter was placed on the radiography couch along the central axis of the X-ray beam. At fixed mA/mAs and time, four kVp stations (based on the technical chart for each unit) were selected from the control console, and X-ray exposure was performed three times for the selected kVp stations [16, 17]. Afterwards, the difference between the recorded reading and the selected kVp was calculated and compared with the criteria presented in Table 1.

The method applied for the assessment of timer accuracy was similar to that used for kVp accuracy, except for the fact that exposure time could be variable, whereas kVp and mA/mAs remained constant. For the evaluation of timer accuracy, the digital X-ray pulse counter/timer was used instead of the kV meter. Also, to determine kVp and timer reproducibility, three kVp and exposure timers were selected from the control console; for each station, X-ray exposure was performed three times. Then, coefficient of variation (CV) was calculated from the recorded readings [16, 17].

To evaluate radiation output reproducibility, the Rad-Check™ X-ray exposure meter was employed. The applied method was similar to the previously described method for kVp and timer reproducibility assessments. The only difference was that three diverse exposure conditions were selected for this parameter, and then, X-ray exposure was performed [16, 17].

Table 1. Technical parameters influencing the performance of X-ray generator unit with the accompanying the criteria (16).

Technical Parameters	Criteria		
	Acceptable Level	Action Level	Rejected Level
kVp Accuracy	Error ≤ 10%	10%<Error≤20%	Error>20%
kVp Reproducibility	CV≤5%	5%<CV≤20%	CV>20%
Timer Accuracy	Error ≤ 10%	10%<Error≤20%	Error>20%
Timer Reproducibility	CV≤5%	5%<CV≤20%	CV>20%
Output Reproducibility	CV≤5%	5%<CV≤20%	CV>20%
mA/mAs Linearity	L≤0.1	0.1<L≤0.2	L>0.2
Timer Linearity	L≤0.1	0.1<L≤0.2	L>0.2
Total Filtration (H.V.L) at kVp=80	≥2.3 mmAl	<2.3 mmAl	<2.3 mmAl

Table 2. kVp and timer accuracy/reproducibility results in Kerman and Rafsanjan hospitals

Hospital	City	Type of Unit/ Unit Notification	Selected kVp	kVp Accuracy (%)	kVp Reproducibility (%)	Selected Time	Timer Accuracy (%)	Timer Reproducibility (%)
A	Kerman	Shimadzu/A1	60	0.88	0.00	80	2.4	0.00
			80	0.54	0.38	110	0.3	0.00
			100	0.13	0.06	160	0.2	10.00
		Shimadzu/A2	60	3.17	0.17	70	8.81	2.37
			80	3.33	0.10	80	6.67	4.62
			100	0.57	0.89	120	9.42	2.63
			110	4.27	0.54			
		Shimadzu/A3	50	6.40	0.55	80	0.41	0.00
			60	0.22	0.42	100	0.99	0.00
			80	0.25	0.38	200	0.50	0.00
			100	0.33	0.10			
		Triplunix/A4	60	5.50	0.00	80	72.66	0.00
			80	13.88	3.06	100	54.64	4.72
			100	14.70	3.11	200	55.84	2.95
B	Kerman	Ketsomat/B1	60	1.89	0.53	20	23.81	3.69
			68	15.64	1.00	40	17.65	3.69
			-----	-----	-----	80	14.29	0.00
		Shimadzu/B2	50	8.73	0.55	80	1.23	0.00
			60	0.44	0.94	120	4.76	0.00
			80	0.04	1.13	200	0.17	0.28
			100	0.30	0.21			
C	Kerman	GE/C1	50	0.53	0.00	80	1.23	0.73
			60	1.22	0.47	100	0.33	0.00
			80	1.17	1.21			
			100	0.57	0.54			
		Shimadzu/C2	50	0.87	1.26	80	2.44	0.00
			60	0.22	0.26	100	1.96	0.56
			80	0.08	0.50	200	0.99	0.00
			100	0.10	0.10			
		Varian/C3	50	8.07	0.64	80	2.44	0.00
			60	0.17	0.34	125	1.57	0.50
			80	0.04	0.19	200	0.99	0.00
			100	0.13	0.63			
D	Koshkouiyeh (Rafsanjan)	IAE/D1	60	1.11	0.65	40	0.84	0.00
			70	1.14	1.47	60	0.56	0.97
			80	3.67	0.40	80	1.27	1.27
			100	4.97	0.70			
E	Rafsanjan	Shimadzu500/E1	60	0.06	1.33	50	2.74	1.19
			70	1.24	3.38	80	1.69	0.73
			80	0.04	0.51	100	3.81	3.17
			100	1.83	0.52			
		Shimadzu600/E2	60	1.56	0.09	40	0.00	2.27
			70	0.14	0.38	63	1.56	0.00
			80	0.58	0.29	80	0.42	0.00
			100	0.37	0.12			
		Varian/E3	70	0.52	0.48	40	6.98	0.00
			80	1.75	0.42	60	0.00	0.00
			100	4.70	0.00	80	3.61	0.00
F	Rafsanjan	Shimadzu500/F1	60	7.28	0.00	40	12.15	1.62
			70	8.90	0.21	60	11.11	0.00
			80	12.38	1.21	80	13.74	2.96
			100	1.17	0.08			
		Villa/F2	60	0.50	1.07	40	4.76	1.35
			70	0.76	0.83	60	3.23	0.00
			80	0.75	4.18	80	2.44	0.00
			100	0.60	0.06			
G	Jahanabad (Rafsanjan)	Comet/G	60	0.22	0.26	100	4.15	0.31
			70	2.29	0.67	120	1.93	0.25
			80	1.13	0.07	160	0.29	1.05
			100	5.03	0.27			

Table 3. kVp and timer accuracy/reproducibility results in different hospitals of Kerman province (Except Kerman and Rafsanjan hospitals)

Hospital	City	Type of Unit/ Unit Notification	Selected kVp	kVp Accuracy (%)	kVp Reproducibility (%)	Selected Time	Timer Accuracy (%)	Timer Reproducibility (%)
H	Sirjan	Shimadzu500/H1	60	7.50	2.38	40	31.87	7.53
			70	8.37	0.25	60	28.57	1.40
			80	14.38	0.76	80	21.83	4.80
			90	14.52				
		Varian/H2	50	6.87	1.39	40	4.76	0.00
			60	1.83	0.00	60	3.23	0.00
			80	2.25	0.00	80	2.43	0.00
I	Bardsir	Shimadzu630/I1	50	5.13	0.25	40	0.00	0.00
			60	0.06	0.40	63	0.00	0.00
			80	0.04	0.17	100	1.64	0.00
			100	0.00				
		Shimadzu500/I2	60	0.22	7.60	70	25.00	0.00
			70	5.43	1.11	100	22.45	2.55
			80	4.71	0.56	120	20.81	1.54
J	Sirjan	Toshiba/J1	70	17.91	2.09	40	26.32	1.82
			76	21.40	0.64	60	28.57	3.27
			80	22.67	0.91	80	32.60	6.70
		Toshiba/J2	70	13.29	4.04	40	50.00	8.66
			80	16.08	3.89	60	59.29	7.66
			90	14.11	2.53	80	57.89	0.00
K	Baft	Shimadzu/K1	60	0.28	0.69	20	4.76	0.00
			70	0.33	0.22	40	2.44	0.00
			80	0.04	0.14	80	0.83	0.00
			100	0.00				
		Varian/K2	60	1.33	0.34	20	9.09	2.28
			70	0.10	0.78	40	4.76	0.00
			80	0.08	0.07	80	2.04	0.00
			100	0.53	0.46			
L	Ravar	Shimadzu/L	60	0.39	0.19	40	6.98	0.00
			70	0.19	0.08	80	3.61	0.00
			80	0.29	0.07	100	2.91	0.56
			100	0.10	0.10			
M	Zarand	Shimadzu500/M	70	12.67	0.74	30	199.32	8.31
			80	17.13	0.67	60	71.43	0.00
			90	19.52	0.64	70	81.03	5.59
N	Shahrbabak	Shimadzu/N1	60	1.17	0.26	20	2.43	0.00
			70	3.00	0.17	40	5.89	0.00
			80	2.17	0.39	80	8.05	0.00
			100	2.43	0.87			
		Shimadzu/N2	60	0.72	0.10	20	5.26	0.00
			70	0.10	0.74	40	2.57	0.00
			80	0.17	0.22	80	1.27	0.00

Exposure linearity with respect to mA/mAs and exposure time was investigated, using Rad-Check™ X-ray exposure meter. The exposure meter was placed on the radiology bed along the beam central axis at FFD=100 cm. Then, at a fixed kVp, by selecting two different mA and exposure time stations, exposures (in mGy) were recorded by the exposure meter and divided by mAs in each station. The linearity coefficient (L) was measured, using the following equation:

$$Linearity\ \text{Coefficient} = \frac{|X_2 - X_1|}{|X_2 + X_1|} \quad (1)$$

where X_1 is $Dose/mAs$ for the first selected mA or time station, and X_2 is $Dose/mAs$ for the second selected mA or time station [16, 17].

In order to determine the HVL of X-ray beams, the exposure meter was positioned at FFD=100; afterwards, X-ray exposure was performed and the radiation output was recorded.

Table 4. Exposure reproducibility results in Kerman and Rafsanjan hospitals

Hospital	City	Type of Unit/Unit Notification	Selected Time	Selected mA	Selected kVp	Exposure Reproducibility (%)
A	Kerman	Shimadzu/A1	20	160	60	19.25
			200	200	83	22.40
			18	125	55	0.00
		Shimadzu/A2	80	200	80	0.93
			70	300	60	0.00
			100	150	100	6.37
		Shimadzu/A3	20	125	50	0.00
			60	125	55	2.44
		Triplunix/A4	360	200	73	0.00
			20	200	50	0.00
			80	300	80	0.00
			500	200	80	2.85
B	Kerman	Ketsomat/B1	60	300	85	14.85
			70	300	95	2.53
			40	400	76	3.65
			20	500	68	0.00
		Shimadzu/B2	80	200	80	3.67
			40	500	80	0.80
			50	400	60	0.00
C	Kerman	General Electric(GE)/C1	80	200	60	0.00
			100	400	80	0.00
			50	600	100	0.00
		Shimadzu/C2	100	400	80	0.29
			50	500	100	2.59
			80	200	60	0.00
		Varian/C3	80	200	60	1.27
			125	400	80	0.59
			50	500	100	0.30
D	Koshkouiyeh (Rafsanjan)	IAE/D	30	300	71	0.00
			120	300	67	73.93
			80	300	58	3.23
E	Rafsanjan	Shimadzu500/E1	80	200	60	2.99
			120	200	70	0.00
			200	200	65	6.44
		Shimadzu600/E2	80	200	60	0.00
			50	200	65	0.00
			56	200	60	0.00
		Vriana/E3	400	200	70	0.38
			400	200	60	0.00
			80	300	6	0.00
F	Rafsanjan	Shimadzu500/F1	300	200	80	1.08
			400	200	90	2.85
			500	200	100	2.36
		Villa/F2	250	200	70	3.72
			300	200	80	1.30
			400	300	100	0.45
G	Jahanabad (Rafsanjan)	Comet/G	100	100	50	0.73
			160	100	70	1.12
			200	100	100	0.81

Aluminum absorbers were placed in the beam (typically in 0.5- or 1-mm increments), and then, X-ray exposure was performed. In general, through dividing each exposure reading by the exposure with no absorbers, we can determine the extent of entrance for each thickness of the absorber. The absorber thickness corresponding to an entrance value of 0.5 (50%) specifies the total filtration of the radiology unit or the so called "HVL" [16, 17].

Table 5. Exposure reproducibility results in different hospitals of Kerman province (Except Kerman and Rafsanjan hospitals)

Hospital	City	Type of Unit/Unit Notification	Selected Time	Selected mA	Selected kVp	Exposure Reproducibility (%)
H	Sirjan	Shimadzu500/H1	60	100	65	17.32
			200	200	80	0.00
			150	200	75	0.00
		Varian/H2	60	100	60	5.59
			160	200	65	2.07
			200	200	65	2.74
I	Bardsir	Shimadzu630/I1	32	320	63	11.95
			100	200	65	0.00
			40	320	66	0.00
		Shimadzu500/I2	100	200	64	4.03
			80	200	60	0.00
			120	200	68	0.00
J	Sirjan	Toshima/J1	40	320	64	0.00
			140	200	60	0.00
			140	160	60	0.00
		Toshiba/J2	40	320	64	0.00
			140	200	60	5.97
			140	100	66	0.00
K	Baft	Shimadzu/K1	20	200	50	19.25
			32	200	65	0.00
			16	320	70	0.00
		Varian/K2	20	200	60	7.87
			40	200	65	1.22
			25	200	70	3.33
L	Ravar	Shimadzu/L	20	200	100	0.00
			20	250	90	0.00
			25	200	80	0.00
M	Zarand	Shimadzu500/M	200	300	70	0.72
			200	300	80	0.00
			100	300	90	0.00
N	Shahrbabak	Simadzu/N1	80	200	80	0.68
			63	300	60	1.67
			100	100	100	0.00
		Shimadzu/N2	80	200	80	0.79
			71	320	60	0.00
			100	125	100	0.74

3. Results

In this study, 28 X-ray units, installed in 14 governmental hospitals of Kerman province, were investigated. Tables 2 and 3 present the results of kVp accuracy/reproducibility and timer accuracy/reproducibility of X-ray units. The kVp accuracy and reproducibility values ranged from 0.00 to 22.67 and 0.00 to 7.60, respectively. Also, the kVp accuracy of J1 unit (kVp=80; hospital J) was greater than others (12% higher than the reject limit).

Minimum error was observed in I1 unit (hospital I), K1 unit (hospital K), and N2 unit (hospital N). Furthermore, the kVp accuracy of 75%, 21%, and 4% of X-ray units fell in the acceptable, action, and reject limits, respectively. The kVp reproducibility met the standard criteria in all cases, with the exception of I2 unit at kVp=60 (34% higher than the acceptable level), which was within the action limit.

The timer accuracy and reproducibility were in the range of 0.00-199.32 and 0.00-10.00, respectively. Also, the results showed that the status of 71%, 4%, and 25% of the units was within the acceptable, action, and reject limits, respectively. Furthermore, in 18% and 82% of the units, timer reproducibility was within the action and acceptable limits, respectively.

The results related to exposure reproducibility in the investigated X-ray units are presented in Tables 4 and 5. Evidence showed that the extent of exposure reproducibility deviation varied between different units. Based on the results presented in these tables, exposure reproducibility of 61%, 18%, and 21% of units fell in acceptable, action, and reject limits, respectively.

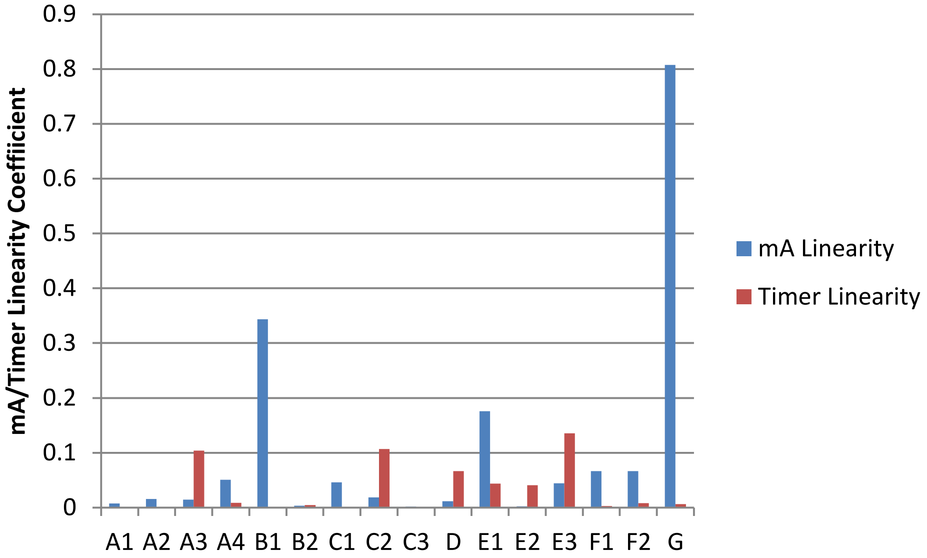

Figure 1. Tube current (mA) and timer linearity coefficients in Kerman and Rafsanjan hospitals

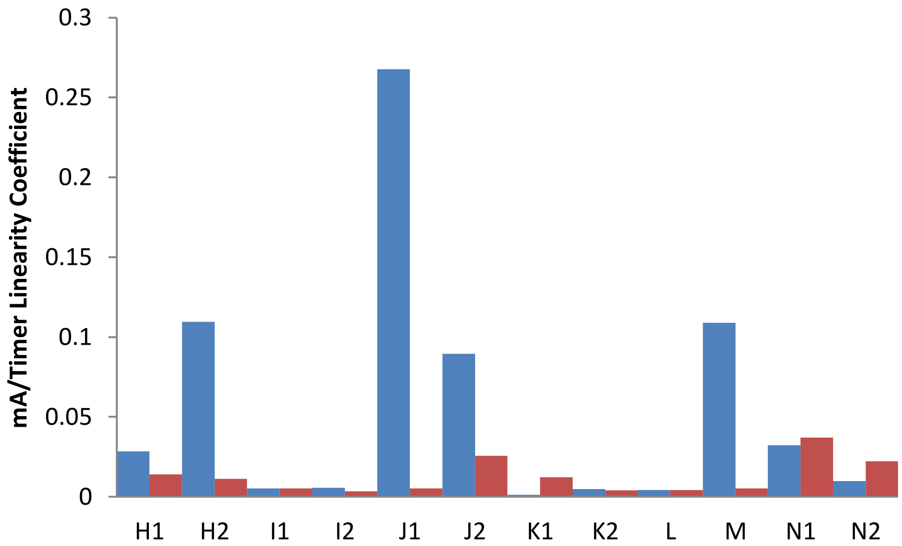

Figure 2. Tube current (mA) and timer linearity coefficients in different hospitals of Kerman province (with the exception of Kerman and Rafsanjan hospitals)

The mA and timer linearity coefficients are presented in Figures 1 and 2. Based on mA linearity tests, performance of 11% and 89% of X-ray units was within the action and acceptable limits, respectively. Also, according to the presented data for timer linearity, 13% of the units were in the action level, while 87% were within the acceptable limit.

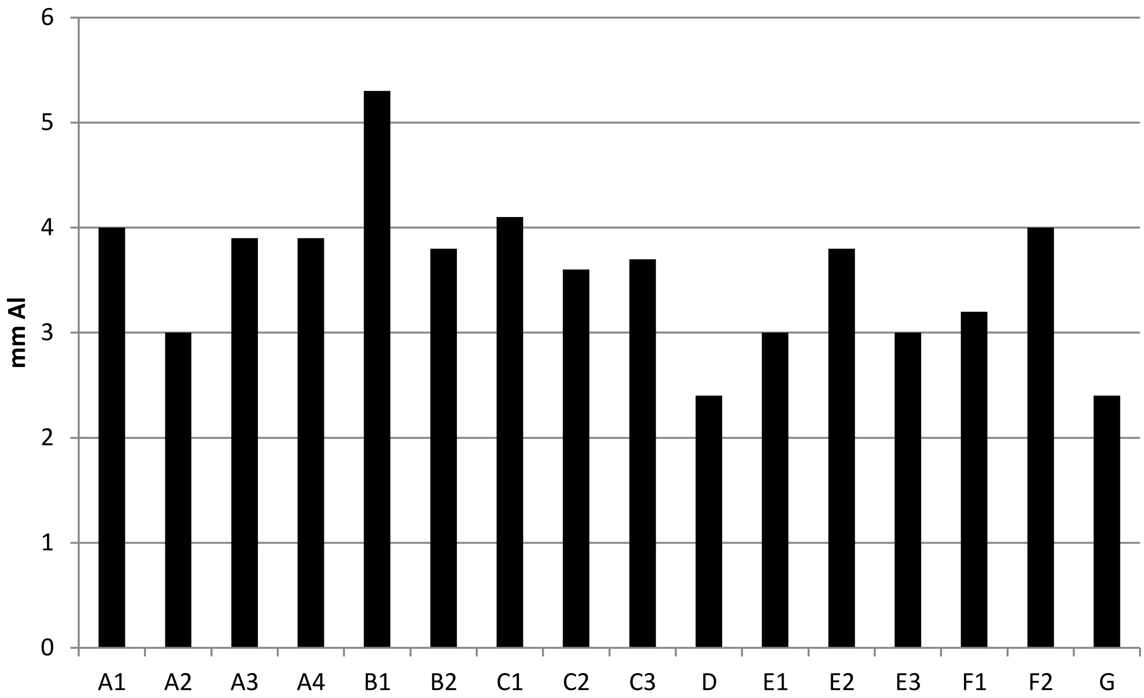

Figure 3. Half-value layer (HVL) of X-ray units in Kerman and Rafsanjan hospitals

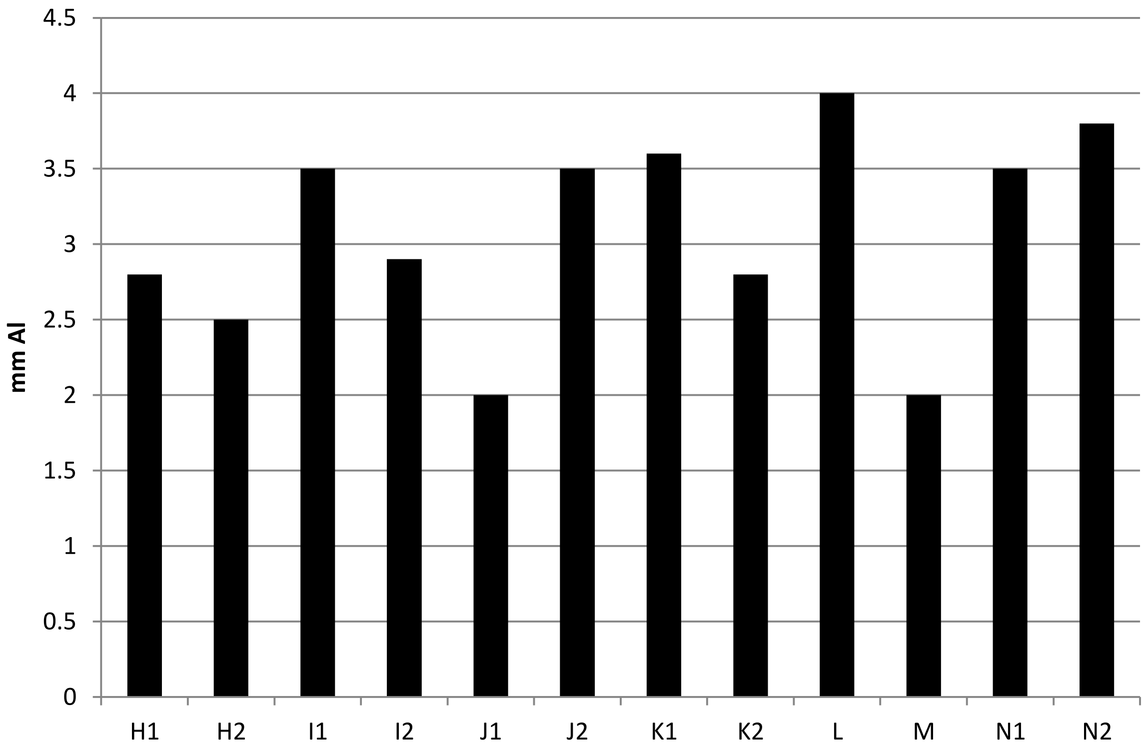

Figure 4. Half-value layer (HVL) of X-ray units in different hospitals of Kerman province (with the exception of Kerman and Rafsanjan hospitals)

The HVL values (at kVp=80) of all X-ray units in Kerman hospitals are presented in Figures 3 and 4. Based on the data presented in the figures, HVL was within the acceptable limit, except for J1 (hospital J) and M (hospital M) units; also, HVL in 13% of the units fell below the acceptable level.

4. Discussion

The current study focused on the performance of X-ray generators in governmental hospitals. The assessments on 28 X-ray units of Kerman hospitals (Tables 2 & 3) showed that kVp and timer accuracy/reproducibility was within the acceptable range in 75% of the units, based on the kVp accuracy tests (unacceptable in 25% of the units).

In general, the extent of KVp accuracy is dependent on various factors. One of the main factors leading to differences between the measured and selected kVp is poor or inadequate implementation of QC programs. The kVp accuracy measurements in the present study were more acceptable than the findings reported by Khoshbin Khoshnazar et al. [10], Saghatchi et al. [11], and Gholamhoseinian et al. [9], while the results reported by Rasuli et al. were more satisfactory than the present findings.

Also, the present results showed that the kVp accuracy of J1 unit at two kVps (76 and 80) fell in the reject limit, which might be caused by the high ripple voltage. In terms of kVp reproducibility, the results demonstrated that I1 unit was out of the acceptable range and within the action limit. Since deviation was found at just one selected kVp (60 kVp), this difference could be neglected.

In the present study, findings related to timer accuracy/reproducibility were not as satisfactory as kVp accuracy/reproducibility. As exposure time is one of the most important parameters in patient dose [1], regular and frequent QC tests are required in nearly 25% of X-ray units in Kerman hospitals. Based on our evaluations, the timer accuracy/reproducibility results reported by Rasuli et al. were slightly more satisfactory than the present findings.

In terms of exposure reproducibility, the percentage of defective equipments in our study was 39%, whereas in studies by Khosbin Khoshnazar et al. and Rasuli et al., 16.7% and 0.00% of the devices were flawed, respectively [10, 14]. This difference may be related to the examination of older X-ray equipments in our study, compared to the mentioned studies.

The present results indicated that timer and mA linearity in nearly 12% of the units was out of the acceptable limit (in the action level). Our results were more satisfactory than the findings reported by Khoshbin Khoshnazar et al. and Rasuli et al. [10, 14]. Also, based on the calculated HVL values (Figures 3 & 4), two units (J1 and M units) were out of the acceptable limit, which is mainly due to the inadequacy of added filters to the collimators, frequent repairs, or filter displacement. The current findings on HVL were slightly more satisfactory than the results reported by Khoshbin Khoshnazar et al. and Rasuli et al. [10, 14].

5. Conclusion

Most of X-ray generators assessed in this study indicated an acceptable performance, and few units required re-calibration for some parameters such as timer accuracy/reproducibility and exposure reproducibility. Regular QC tests, together with routine equipment maintenance services, are essential for promoting the performance of radiology departments. Therefore, as radiographic X-ray equipments in Kerman province are relatively old with a high workload, it is recommended that AEOI modify the current policies by changing the frequency of QC test implementation to at least once a year.

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