

Original Article

The Evaluation of Conventional X-ray Exposure Parameters Including Tube Voltage and Exposure Time in Private and Governmental Hospitals of Lorestan Province, Iran

Mehrdad Gholami^{1*}, Fataneh Nemati², Vahid Karami³

Abstract

Introduction

In radiography, dose and image quality are dependent on radiographic parameters. The problem is caused from incorrect use of radiography equipment and from the radiation exposure to patients much more than required. Therefore, the aim of this study was to implement a quality-control program to detect changes in exposure parameters, which may affect diagnosis or patient radiation dose.

Materials and Methods

This cross-sectional study was performed on seven stationary X-ray units in six hospitals of Lorestan province. The measurements were performed, using a factory-calibrated Barracuda dosimeter (model: SE-43137).

Results

According to the results, the highest output was obtained in A Hospital (M1 device), ranging from 107×10^{-3} to 147×10^{-3} mGy/mAs. The evaluation of tube voltage accuracy showed a deviation from the standard value, which ranged between 0.81% (M1 device) and 17.94% (M2 device) at A Hospital. The deviation ranges at other hospitals were as follows: 0.30-27.52% in B Hospital (the highest in this study), 8.11-20.34% in C Hospital, 1.68-2.58% in D Hospital, 0.90-2.42% in E Hospital and 0.10-1.63% in F Hospital. The evaluation of exposure time accuracy showed that E, C, D and A (M2 device) hospitals complied with the requirements (allowing a deviation of $\pm 5\%$), whereas A (M1 device), F and B hospitals exceeded the permitted limit.

Conclusion

The results of this study showed that old X-ray equipments with poor or no maintenance are probably the main sources of reducing radiographic image quality and increasing patient radiation dose.

Keywords: Quality Control, X-ray Output, kVp Accuracy

1- Department of Medical Physics & Radiation Sciences, School of Para medicine Sciences, Lorestan University of Medical Sciences, Khorram Abad, Iran

*Corresponding author: Tel: 09166616814, E-mail: mhrgh@yahoo.com

2- Science & Research Branch, Islamic Azad University, Tehran, Iran

3- Department of Medical Physics, School of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

1. Introduction

Dose optimization is of high significance for the quality and quantity of quality-control tests on X-ray equipments. The widespread use of X-ray in the diagnosis and management of patients has led to increased radiation exposure. Although the clinical use of X-ray is governed by dose optimization and as-low-as-reasonably-achievable (ALARA) principle, more invasive methods have been proposed [1].

Quality-control programs in diagnostic radiology aim to ensure the optimal performance of all imaging components. These programs lead to the production of images with the highest quality and the lowest possible radiation dose to patients and operators, while maintaining a high diagnostic value. The goal of quality-control programs is to help reduce costs through eliminating unproductive imaging, caused by the inefficiency of devices or materials, which may occur in a complex chain leading to the finished product. [2, 3].

All medical facilities using X-ray devices, including simple intraoral dental units and image-intensified systems will benefit from adopting a quality assurance program. Such programs can monitor the imaging process from the beginning to the end and reveal potential problems and errors which may otherwise go unrecognized. [4]

A number of recent studies have evaluated dose optimization. Some of these studies have evaluated image quality and patient dose in radiographic examinations in different countries [5-9]. Some researchers have only focused on patient dose optimization [10-13], whereas some have examined both patient dose and image quality in radiographic devices [14-16].

Some studies have presented reference values for clinical X-ray examinations by measuring phantom dose [17]. However, no previous research has evaluated dose optimization during the implementation of quality-control

programs on X-ray devices. Therefore, the aim of this study was to implement a quality-control program to detect changes in tube voltage and exposure time as conventional X-ray exposure parameters.

2. Materials and Methods

In the present study, radiographic measurements were performed on seven conventional stationary X-ray units at six governmental and one private hospital (B Hospital). All hospitals were located in Lorestan province, Iran. Overall, Italray, Varian, Genius and Toshiba X-ray units were evaluated in this study. A Hospital was equipped with two functional X-ray units, denoted as M1 (Italray, 400) and M2 (Varian, 300).

The measurements were performed using a factory-calibrated Barracuda dosimeter (Barracuda, SE- 43137 Sweden). This system determines tube voltage and exposure time with an accuracy of 5% and dose range of 15-1000 nGy. For measurements, the dosimeter was positioned on the central beam axis in a way that the focus-detector distance (FDD) was 100 cm.

In order to avoid possible scatter radiation to the dosimeter, the radiation field size was selected in a way that it could cover the dosimeter. X-ray tube output was determined as the ratio of dose reading to mAs setting. In order to determine the X-ray output at different currents, exposures were performed at a constant voltage (kVp=60), with gradually increasing currents (4, 8, 12 and 16 mAs). All readings were repeated three times at a distance of 100 cm.

To investigate the accuracy of kVp, 20 mAs and 50 kVp were selected. X-ray exposure was performed and the readout was recorded. This process was repeated at the same constant current (mAs) and different kVp settings (50, 70, 80 and 100 kVp).

Table 1. The specific information of the evaluated X-ray devices

City	Hospital (No of units)	Company	kVp _{max}	mA _{max}	Installation year
		Italray	150	400	2002
	A (2)	Varian	100	300	1982
1	C (1)	Varian	120	400	1990
	F (1)	Genius	150	400	1992
	B (1)	Toshiba	120	500	1987
2	D (1)	Italray	160	500	2000
3	E (1)	Italray	150	400	1997

In addition, to determine exposure time accuracy, a constant voltage (50 kVp) and different time settings (20, 40 and 80) were recorded. Time variation was set at $\pm 5\%$ for exposures greater than 10 msec and $\pm 20\%$ for exposures less than 10 msec. The measured exposure (mR) was converted into output (mGy/mAs) by being multiplied by a factor of 0.00877 [2].

3. Results

Seven X-ray units in six hospitals, including five governmental and one private hospital, were investigated. Table 1 presents the characteristics of radiographic equipments at different hospitals. As presented in this table, the years of unit installation ranged from 10 to 30 years.

3.1. X-ray tube output

The results of X-ray tube output are presented in table 2. The highest output value, which was obtained in A Hospital (M1 device), ranged between 107×10^{-3} and 147×10^{-3} mGy/mAs. The output values for M2 device at A Hospital were relatively lower than those obtained in M1. However, at other hospitals, with the same voltage (60 kVp), the highest and lowest output values were found in E (68.10×10^{-3} mGy/mAs) and D (5.50×10^{-3} mGy/mAs) hospitals, respectively.

3.2. Tube voltage accuracy

The results related to tube voltage accuracy in the investigated X-ray units are presented in table 3. This table shows the selected tube voltages, the measured tube voltages and the magnitude of deviation. It is evident that the extent of kVp deviation varies between different hospitals.

In A Hospital, the deviation of tube voltage ranged between 0.81% (M1) and 17.94% (M2). The deviation ranges at other hospitals were as follows: 0.30-27.52% in B Hospital (the highest in this study), 8.11-20.34% in C Hospital, 1.68-2.58% in D Hospital, 0.90-2.42% in E Hospital and 0.10-1.63% in F Hospital. Devices used in A (M1 device), F, D and E hospitals complied with the requirements ($\pm 5\%$), whereas A (M2 device), C and B hospitals exceeded the accepted range.

3.3. Exposure time accuracy

The results of exposure time accuracy for the evaluated X-ray units are presented in table 4. This table shows the selected time (ms), the measured time (ms) and the extent of deviation. In A Hospital, the deviation ranged between 0.50% (M2 device) and 10% (M1 device).

Table 2. The measured X-ray outputs at different currents (mAs) in different hospitals

Hospital	Selected Time	FFD	Selected KvP	Selected mA	mAs	Average dose (mGy)	Y(mGy/mAs)
A(M1)	40	100	60	200	8	134.40	147×10^{-3}
	40	100	60	300	12	170.26	124×10^{-3}
	40	100	60	400	16	195.76	107×10^{-3}
A(M2)	40	100	60	100	4	14.50	31.70×10^{-3}
	40	100	60	200	8	20.20	20.10×10^{-3}
	40	100	60	300	12	20.90	15.20×10^{-3}
	40	100	60	400	16	17.50	9.50×10^{-3}
C	40	100	60	100	4	7.40	14×10^{-3}
	40	100	60	200	8	21.00	21×10^{-3}
	40	100	60	300	12	48.00	32×10^{-3}
	40	100	60	400	16	74.00	37×10^{-3}
B	40	100	60	200	8	43.50	47.70×10^{-3}
	40	100	60	300	12	53.80	39.31×10^{-3}
	40	100	60	400	16	72.33	39.65×10^{-3}
E	40	100	60	200	8	62.00	67×10^{-3}
	40	100	60	400	16	124.30	68.10×10^{-3}
	40	100	60	500	20	154.00	67.50×10^{-3}
D	40	100	60	200	8	50.66	5.50×10^{-3}
	40	100	60	400	16	102.56	56.20×10^{-3}
	40	100	60	500	20	154.00	67.50×10^{-3}
F	40	100	60	100	4	11.26	34.60×10^{-3}
	40	100	60	200	8	19.20	21×10^{-3}
	40	100	60	300	12	28.03	20.48×10^{-3}

Table 3. The accuracy of tube voltages measured in different hospitals

City/Hospital	Selected Tube voltage (kVp)	measured Tube voltage (kV)	Magnitude of Deviation %
1/A (M1)	60	61.04	1.73
	70	71.01	1.44
	80	81.30	1.62
	100	100.81	0.81
1/A (M2)	60	50.87	17.94
	70	61.95	11.19
	80	71.35	12.12
	100	93.2	7.29
1/F	50	49.78	0.44
	60	59.94	0.10
	70	69.71	0.41
	80	81.31	1.63
1/C	50	60.17	20.34
	60	64.87	8.11
	70	76.94	9.91
	80	91.80	14.75
1/B	50	53.91	7.82
	60	47.05	27.52
	70	69.79	0.30
	80	77.77	2.86
2/D	50	50.84	1.68
	60	61.28	2.13
	70	71.35	1.92
	100	102.58	2.58
3/E	50	51	2.00
	60	61.45	2.41
	70	71.65	2.35
	100	103.90	0.90

Table 4. Exposure time accuracy in different hospitals

City/Hospital	Selected Time (ms)	measured Time (ms)	Magnitude of Deviation %
1/A(M1)	20	22	10
	40	42.33	5.82
	80	81.88	2.32
1/A(M2)	20	20.53	2.65
	40	40.30	0.75
	80	80.40	0.50
1/F	20	20.45	2.25
	40	49.10	22.75
	80	80.30	0.37
1/C	20	20.63	3.15
	40	41.50	3.75
	80	81.20	1.50
1/B	20	46.64	133.20
	40	71.33	78.32
	80	109.32	36.65
2/ D	20	20	0.00
	40	39.96	0.10
	80	78.73	1.61
3/ E	20	20.04	0.20
	40	40.43	1.07
	80	80.33	0.41

Table 5. The summary of quality-control test results at different hospitals

Parameter tested	Recommended variability	Results of QC tests						
		A (M1)	A (M2)	F	C	D	E	B
kVp accuracy	±5%	Within limit	Out of limit	Within limit	Out of limit	Within limit	Within limit	Out of limit
kVp consistency	±10%	Within limit	Out of limit	Within limit	Out of limit	Within limit	Within limit	Out of limit
Timer accuracy	±5% for exposure time>10ms, ±20% for exposure time <10ms	Out of limit	Within limit	Out of limit	Within limit	Within limit	Within limit	Out of limit
kVp Reproducibility	±10%	Within limit	Out of limit	Within limit	Out of limit	Within limit	Within limit	Out of limit
Timer Reproducibility	±10%	Out of limit	Within limit	Out of limit	Within limit	Within limit	Within limit	Out of limit

The deviation ranges at other hospitals were as follows: 36.65-133.20% in B Hospital (the highest in this study), 0.37-22.75% in F Hospital, 1.5-3.15% in C Hospital, 0.2-41% in E Hospital and 0.00-1.61% in D Hospital.

The devices used in E, C, D and A (M2) hospitals complied with the requirements

(±5%), whereas A (M2), F and B hospitals exceeded the permitted range. Table 5 provides a summary of quality-control test results related to X-ray units, used at different hospitals.

4. Discussion

As previously mentioned, this study was conducted on six X-ray units with various models in three cities of Lorestan province. At each hospital, one unit was studied except A Hospital, which was equipped with two units, denoted as M1 and M2. The oldest unit (Varian 300) was installed in 1982, whereas the newest unit (Italray 400) was installed in 2002 (Table 1). Given the fact that some of these units were installed about 30 years ago, the implementation of quality-control programs is essential at these hospitals.

Although today, advanced radiologic imaging systems do not employ conventional radiology, in most provinces of Iran, use of these devices may be fruitful. Consequently, output radiation measurements, which directly affect patient dose, are of great significance. As shown in table 2, the greatest output was measured in A Hospital (M1 device); it is evident that this device was the oldest evaluated unit. On the other hand, the lowest output was measured in D hospital, which was installed in 2000. It can be concluded that advanced age of units increases the final output.

Experience shows the lack of quality-control tests in most hospitals, unless the units need to be repaired. In the present study, the calculated average dose was different between M1 device and the unit installed in D city. These findings confirm the great significance of image quality, since images with no diagnostic features impose unnecessary exposure on patients. Furthermore, if devices are in good quality, the personnel should not damage the units by negligence and optimization methods should be employed.

The International Atomic Energy Agency (IAEA) recommended the use of a high kVp technique, which probably results in low patient dose [18]. On the other hand, radiologists prefer high-contrast chest radiographs, which are produced by low kVp. According to earlier reports, increasing the tube voltage (kVp) from 8-1 (Table 1) 3 in

lumbar spine and thoracic examinations results in a dose reduction of 26-36% [19].

The minimum and maximum deviations in tube voltage accuracy are presented in table 2. The minimum deviation was 0.1% in F Hospital and the maximum deviation was reported in B Hospital (27.52%); in addition, the rate of deviation was 20.34% in C Hospital. The greater extent of deviation in kVp, reported in C and B hospitals, may be caused by various factors. One of the main factors leading to differences between the measured and selected kVp values is poor or inadequate implementation of quality-test programs.

Moreover, the excessively large extent of deviation between the selected and measured kVp could reduce image contrast [20]. The unexpected increased value of technical parameters, which results from defective devices, could affect both patient dose and image quality [20]. Based on the findings, A (M2), C and B hospitals require regular and repeated quality-control tests. kVp accuracy tests showed compliance with the acceptable limits in A (M1 device), F, D and E hospitals, while A (M2 device), C and B hospitals did not meet the acceptable limit ($\pm 5\%$).

In terms of timer accuracy, exposure time is postulated to directly affect the total quantity of radiation, emitted from X-ray tubes. Therefore, an accurate exposure timer is critical for proper radiographic exposure and reasonable patient radiation exposure. A (M2 device), C, D and E hospitals met the acceptable limit. However, since the timer accuracy in A (M1 device), B and F hospitals was above the accepted limit, radiation dose delivered to the patient might be higher than the expected value required for producing the image.

As mentioned above, human factors significantly contribute to the enhancement of effective patient dose. Factors such as the personnel's negligence at radiology departments and resistance to the implementation of standard methods lead to an

increase in the frequency of imaging, increased exposure apparatus and rise in device temperature, resulting in the short life of the unit. Economic factors are also of great importance. Due to the high price of digital radiographic units, many hospitals are not able to purchase these devices and the same old system is frequently used. Economic problems also reduce image quality and increase patient dose.

5. Conclusion

The results of the present study showed that old X-ray equipments with poor or no maintenance significantly affect the quality of

radiographic images. In addition, proper selection of equipments, effective quality-control programs and accurate dosimeters can ensure patient radiation protection and high image quality.

Acknowledgments

We would like to thank all radiographers at radiology departments for their sincere cooperation.

References

1. Korir GK, Wambani JS, Korir IK. Establishing a quality assurance baseline for radiological protection of patients undergoing diagnostic radiology. *SA Journal of Radiology*. 2011;15(3):70-9.
2. Oluwafisoye PA, Olowookere CJ, Jibiri NN, Bello TO, Alausa SK and Efunwole HO. Quality control and environmental assessment of equipment used in diagnostic radiology. *International Journal of Research and Reviews in Applied Sciences*. 2010; 3 (2):148-58.
3. John B. Weaver, John W. Rushford, Kevin Cameron, Robert G. Cross, Neal M. Boucher. *Quality Control Manual (X ray equipment procedure manual)*, Lebanon New Hampshire, June 2009
4. John Winston PA, Debra Jackson et al . *Quality control recommendations for diagnostic radiography. Volume 3: radiographic or fluoroscopy machines*. Conference of Radiation Control Program Directors, Inc. 2001
5. Bouzarjomehri F. Patient dose in routine X-ray examinations in Yazd state. *Iran J Radiat Res*. 2004; 1(4):199-204.
6. Ciraj O, Markovic S, and Kosutic D. First results on patient dose measurements from conventional diagnostic radiology procedures in Serbia and Montenegro. *Radiation Protection Dosimetry*. 2005; 113(3):330-35.
7. Ramanandraibe MJ, Andriambololona R, Rakotoson E, Tsapaki V, Gfinter H, Rehani M, editors. *Survey of image quality and patient dose in simple radiographic examinations in Madagascar: Initial results*. World Congress on Medical Physics and Biomedical Engineering, September 7-12, 2009, Munich, Germany; 2009: Springer.
8. Papadimitriou D, Perris A, Molfetas M. Patient dose, image quality and radiographic techniques for common X-ray examinations in two Greek hospitals and comparison with European guidelines. *Radiation Protection Dosimetry*. 2001; 95(1):43-8.
9. Shahbazi-Gahrouei D. Entrance surface dose measurements for routine X-ray examinations in Chaharmahal and Bakhtiari hospitals. *Iran J Radiat Res*. 2006; 4(1):29-33.
10. BriX G, Nekolla E, Griebel J. Radiation exposure of patients from diagnostic and interventional X-ray procedures. *Radiology*. 2005; 45(4):340-9.
11. Vano E, Fernandez SJ. Patient dose management in digital radiography. *Biomed Imaging Interv J*. . 2007; 3(2):e26.
12. Seibert A. Tradeoffs between image quality and dose. *Pediatr Radiol*. 2004; 34(3):183-95.
13. Williams J and Catling M. An investigation of X-ray equipment factors influencing patient dose in radiography. *Br J Radiol*. 1998 Nov;71(851):1192-8.
14. Gholamhosseinian-Najjar H, Bahreyni-Toosi M T, Mohammad- Zare M H, Sadeghi H R, Hamid-Reza Sadoughi. *Quality Control Status of Radiology Centers of Hospitals Associated with Mashhad University of Medical Sciences*. *Iran J Med Phys*. 2014; 10 (4): 1182-7.

15. Schaefer-Prokop C, Neitzel U, Venema HW, Uffmann M, Prokop M. Digital chest radiography: an update on modern technology, dose containment and control of image quality. *Eur Radiol.* 2008 Sep;18(9):1818-30.
16. Khoshbin Khoshnazar A, Hejazi P, Mokhtarian M, Nooshi Sh. Quality Control of Radiography Equipments in Golestan Province of IRAN. *Iran J Med Phys.* 2013; 10 (1): 37-44.
17. Gray J, Archer B, Butler P, Hobbs B, Mettler F. Reference values for diagnostic radiology: Application and impact. *Radiology.* 2005; 235(2):354-8.
18. International Atomic Energy Agency. Radiation Doses in Diagnostic Radiology and Methods for Dose Reduction. IAEA-TEC DOC-796 (Vienna. IAEA). 1995
19. Martin CJ, Darragh CL, McKenzie GA, Bayliss AP. Implementation of a programme for reduction of radiographic doses and results achieved through increases in tube potential. *Br J Radiol.* 1993 Mar;66(783):228-33.
20. Livingstone RS, Koshy CG, Raj DV. Evaluation of work practices and radiation dose during adult micturating cystourethrography examinations performed using a digital imaging system. *Br J Radiol.* 2004 Nov;77(923):927-30.