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Full Length Research Paper

Patient Dose-Area Product (DAP) Monitoring in Digital Radiography

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Abstract
The objective of this study was to determine the Dose Area Product (DAP) for sample of 70 patients (40 Females and 30 Males) undergoing different types of digital radiography (DR) examinations at King Abdul-Aziz University Hospital (KAUH), Saudi Arabia. This study was done through implementing a quality control (QC) program initiated by The Center for Training and radiation protection, KAU. It was found that, the majority of the examinations carried out at the university hospital were Chest (46%), lumbar spine (13%), knee (10%), wrist lateral (6%) projection, and the rest for the other projections. For the most frequent value in this survey (Chest PA) the measured dose area product ranged from 0.12 to 0.42 Gy.cm^2 with an average value of 0.24 Gy.cm^2, for Chest lateral, it ranged from 0.18 to 1.48 Gy.cm^2 with an average value of 0.65 Gy.cm^2. For Cervical spine the observed DAP values ranged from 0.1 to 0.38 Gy.cm^2 with an average value of 0.23 Gy.cm^2. For Lumbar spine the value of the DAP ranged from 2.14 Gy.cm^2 to 2.93 Gy.cm^2 with an average value of 2.44 Gy.cm^2. The highest average DAP value (2.44 Gy.cm^2) was obtained from lumbar spine projections. The results indicate that, the results of this survey were within the corresponding international values available from the literature. Some additional measures needed to reduce the dose without loss of image quality especially for lumbar spine protocol. Monte Carlo technique was used to calculate the conversion factors that estimate the effective dose used for measuring the DAP or entrance skin dose.

Keywords: *Dose area product, digital radiography, Quality control in diagnostic radiology, Patient dose*

Introduction

Patients can certainly derive huge benefit from radiography examinations, although the ionizing radiation such as diagnostic X-rays means that their use in medical field usually associated with some risk. For this reason, all exposures diagnostic X-rays need to be justified and optimized in terms of risk and benefit. One of the basic requirements for such optimization is knowledge of patient doses, regular patient dosimetry is recommended to evaluate the potential for optimization of radiation protection of patients (Olivera C., et al. 2005, ICRP 1991, Sniureviciute M. et al. 2005). Although individual patient dose in radiography is relatively low, its contribution to the collective dose is significant due to the frequent use of this examination. Patient dosimetry is now regarded as an integral part of a quality assurance program (Faulkner K. et al. 1999, Menglong Z. 2012, NRPB 1990). DAP is a product of surface area of patient that is exposed to radiation at the skin entrance multiplied by the radiation dose at this surface. Measurement of dose area product is suitable to attain optimum degree of safety during radiological examination of patient. It is a useful radiation dose descriptor because radiation-induced bio effects are directly related to both the magnitude of the radiation dose and the total amount of tissue that is irradiated (Nickoloff E.L. 2008). Measurement of dose-area product (DAP) or entrance skin dose are the common methods for patient dosimetry and effective doses are then estimated by multiplication of the measured quantity by conversion factors that have been calculated by Monte Carlo techniques (Bor D. et al 2004, Pinto N. et al 2007, Ernest K. 2013). Dose-Area-Product (DAP) meters are large-area, transmission ionization chambers and associated electronics. In use, the ionization chamber is placed perpendicular to the beam central axis and in a location to completely intercept the entire area of the X-ray beam. The DAP, in combination with information on X-ray field size can be used to determine the average dose produced by the X-ray beam at any distance downstream in the X-ray beam from the location of the ionization chamber (Stephen B. et al 2002, Hart D. et al 2002). It is generally recommended that dosimetry should be performed regularly to evaluate the potential for optimization of radiation protection of patients (ICRP 1990). Also the assessment and control of the performance characteristics of X-ray generators and tubes is an essential part of a quality assurance program for radiological equipment. Since the radiation output is a measurable quantity it gives an overall impression about the status of the X-ray tube and generators (Hamed, A. A et al 1999). In This study the dose area products received by some group of adult patients (70 patients) were determined for different common DR projections categories (Chest, Lumbar Spine, Pelvis and Knee) after applying quality control program.

Materials and Methods

The study was undertaken of dose area product for different digital radiographic examinations performed at radiology department-KAU hospital during the period from December 2009 to January 2010. After applying a quality control test procedures for the examined X-ray machine, information was collected from patient logbook (age, sex, and weight), the clinical physical parameters such as kVp, mAs, output of X-ray machine, and, the number of X-ray projection in addition to the registered DAP for each type of X-ray projection by the machine itself. All projections and measurements were performed on a Kodak X-ray machine model Direct View DR 7500. A calibrated X-ray test device NERO-mAx model 8000 was used to measure the performance of the examined X-ray machine. The test devices were calibrated for X-ray tubes with tungsten target, Aluminum filtration anode (W/Al) and molybdenum filtered molybdenum (Mo/Mo) anode. Digital images were acquired by complete automatic system. The beam quality was measured by investigating the HVL thickness (mm Al). The radiation beam quality was checked by measuring the half-value layer (HVL) at clinically used physical parameters by using the NERO-mAx model 8000 X-ray test device with some various aluminum attenuators. Different Al thickness (high purity 99.0 %) was used to carry out the beam quality. Depending on the exposure reading, there were added or taken filters until the measured exposure was smaller than half of the initial value. The examined X-ray machine was provided with a flat transmission ion chamber installed with the system in order to measure the DAP for every single radiographs after the exposure of each patient. The flat ionization chamber mounted directly on the light beam diaphragm housing. The flat chamber is almost transparent to X-rays for the simultaneous measurement of DAP during the exposure. The value displayed in decigray square centimeters and was converted to gray square centimeters.

Results and Discussion

Quality control test results

a. Results of tube potential (kVp) Accuracy and consistency

The average, effective and peak tube potential was measured using NERO-mAx model 8000 X-ray test device for a number of dial tube potential settings between 55 and 95 kVp at constant tube current. It was found from Table 1 that, the measured tube potential has an acceptable error from the nominal value by about 2.7%. The measured tube potential consistency has an acceptable value by about 10.8. The acceptable value for the consistency in the measured time ranged from 1 to 4%.

Table 1. Results of quality control tube potential accuracy and consistency

Type of Tests	Settings			Measured values			
	kVp	Exposure time (msec)	mAs	kVp avg.	% RD (kVp)	Exposure time (msec)	% RD (msec)
Accuracy (kVp)	55	10	1.6	55.4	0.7	10.1	1.0
	65	10	1.6	65.0	0	10.3	3.0
	75	10	1.6	76.7	2.2	10.1	1.0
	80	10	1.6	80.9	1.1	10.3	3.0
	85	10	1.6	87.4	2.7	9.6	4.0
	95	10	1.6	97.4	2.5	10.3	3.0
	Settings			Measured values			
	kVp	Exposure time (msec)	mAs	kVp avg.			% RD (kVp)
Consistency (kVp)	85	250	100	89.1			4.8
	85	250	100	89.2			4.9
	85	250	100	88.8			4.5
	85	250	100	89.0			4.7
	85	250	100	94.2			10.8

The examined exposure time has an acceptable deviation from the nominal by about 4.5% as indicated in Table 2.

Table 2. Results of exposure time accuracy

Exposure. No.	Set Exposure time (msec)	Measured time (msec)	% RD
1	10	10.1	**0.9**
2	15.6	14.9	**4.5**
3	50.0	49.2	**1.6**
4	100	100.4	**0.4**
5	156.3	155.4	**0.6**
6	**312.5**	**311.4**	**0.4**

b. Results of Beam Quality (HVL) Measurements

The beam quality (HVL) was estimated to be 3.54 mm Al at 80 kV, 20 mAs, 100 cm source to image distance, and 20×20 cm^2 field Size using some various aluminum attenuators (high purity 99.0 %) and NERO-mAx model 8000 system X-ray test device. The total filtration is 4.14 mm Al. Our results passed the test by comparing with the corresponding recommended value at the same tube potential (>2.3 mm Al).

c. Variation in Radiation Output with Tube Current

The X-ray tube output during the exposure should ideally be constant in quantity, but in practice it varies considerably depending on, rectification, current and voltage settings. At constant tube potential (kV= 85), the ratio of mR/mAs was determined at different value of tube load (mAs) and was found to be nearly constant with deviation of 0.3% as shown in Table 3.

Table 3. The variation in output of X-ray tube at constant tube potential

Nominal mAs	Measured output (mR)	mR/mAs
1.6	13.1	8.2
5.0	39.9	7.9
16.0	139.3	8.7
50.0	469.9	9.4
100.0	**964.8**	**9.6**

d. Radiation Output reproducibility results

The output reproducibility was measured by repeated exposures at fixed tube potential as shown in Table 4. The measured values are accepted with standard deviation of 1.0 and coefficient of variation 0.072.

Table 4. The output reproducibility results of the used X-ray tube

Reading No.	Measured Output (mR)	mR/mAs	kVp Avg.	kVp Eff.	kVp Max.
1	13.2	0.132	89.1	87.2	89.1
2	13.2	0.320	89.2	87.2	89.2
3	13.5	0.135	88.8	87.2	88.8
4	15.5	0.155	89.0	88.0	89.1
5	**14.5**	**0.145**	**94.2**	**93.1**	**94.4**

KVp = 8 5, SID = 1m, Field size = 20×20 cm^2, mAs = 100 , Exposure time = 250 mSec.

Dose Area Product (DAP) Data Analysis

It was found that, the majority of the X-ray examinations carried out during the period of the survey was consisted of Chest projection (46%), 13 % for Lumbar Spine and Cervical Spine projection, 10% for Knee projection, 6% for Wrist projection, and the rest for other projections. The distribution of the total DAP values obtained for the investigated machine considered in this study for different examinations is shown in Figure1. Table 5 shows that, the observed DAP for Chest PA examination was found to be in the range from 0.12 Gy.cm^2 to 0.42 Gy.cm^2 with an average value of 0.23 Gy.cm^2 which is above the value of the reference level (0.12 Gy.cm^2) for Chest PA given in Table 6 . For Chest lateral the observed DAP was found to be in the range from 0.18 Gy.cm^2 to 1.48 Gy.cm^2 with an average value of 0.65 Gy.cm^2 and are therefore twice the reference value (0.3 Gy.cm^2) given in Table 6. For Cervical spine the observed DAP values ranged from 0.1 to 0.38 Gy.cm^2 with an average value of 0.23 Gy.cm^2. For Lumbar spine, the value of the DAP ranged from 2.14 Gy.cm^2 to 2.93 Gy.cm^2 with an average value of 2.44 Gy.cm^2. This average value higher than the corresponding reference value (1.6 Gy.cm^2) given in Table 5. For Knee AP projection, the value of the DAP ranged from 0.072 Gy.cm^2 to 0.3 Gy.cm^2 with an average value of 0.18 Gy.cm^2. For Knee Lateral projection, the value of the DAP ranged from 0.055 Gy.cm^2 to 0.77 Gy.cm^2 with an average value of 0.39 Gy.cm^2. For Wrist PA projection, the value of the DAP ranged from 0.01 Gy.cm^2 to 0.03 Gy.cm^2 with an average value of 0.021 Gy.cm^2. For Wrist Lateral projection, the value of the DAP ranged from 0.012 Gy.cm^2 to 0.051 Gy.cm^2 with an average value of 0.026 Gy.cm^2. For Pelvis AP projection, the value of the DAP ranged from 0.82 Gy.cm^2 to 1.88 Gy.cm^2 with an average value of 1.33 Gy.cm^2 and below the recommended reference value (3 Gy.cm^2) given in Table 6. For Ankle projection, the value of the DAP ranged from 0.018·cm^2 to 0.032 Gy.cm^2 with an average value of 0.028 Gy.cm^2. For Hand projection, the value of the DAP ranged from 0.02 cm^2 to 0.039 Gy.cm^2 with an average value of 0.03 Gy.cm^2. For Femur projection, the value of the DAP ranged from 1.08 cm^2 to 1.27 Gy.cm^2 with an average value of 1.17 Gy.cm^2, and for Femur Lateral projection the value of the DAP ranged from 0.20·cm^2 to 0.71 Gy.cm^2 with an average value of 0.49 Gy.cm^2. It is important to mention that all DAP reference values except for that given in Table 6 were not reported in the international recommended values. The variations in the recorded DAP's were due to different radiographic technique employed by each technician for the same X-ray projection**.** This technique includes choice of exposure factors due to patient situation (age, sex, weight, anti-scatter grid, field size, area exposed to radiation, kVp, mAs, and exposure time) especially for some kind of X-ray projection. The use of high mAs values and the high

exposure time for Lumbar spine, Pelvis, and Femur X-ray examination could be responsible for the obtained high value of DAP (up to 2.93 Gy.cm^2). The DAP value for Chest lateral examination was not reported in the Australian reference report 2013. As a useful indication of the DAP spread, the frequency of occurrence of each DAP value for the majority of X-ray examination carried out in this study was given in Table 6. More than 53% of all DAP values are in the range between 0.3-0.4 Gy.cm^2 for Chest PA examination. About 45% of all DAP values are in the range between 0.3-0.6 Gy.cm^2 for chest lateral examination. So after applying some additional measure these values may be lie around the value recommended by the UK reference value (0.3 Gy.cm2). About 36% of all DAP values are in the range between 3.5-4.0 Gy.cm^2 for lumbar spine examination. The cervical spine examinations show 40% from the value of DAP lie in the range between 0.3 to 0.4 Gy.cm^2. Figure 2 and 3 show the relationship between the value of the mAs and DAP for Chest PA and Chest lateral projection respectively. It is clear that the relationship between the mAs and DAP is linear relation. Table 4 shows the clinical physical parameters in the applied protocol for the used DR machine in addition to the results of the registered DAP (Gy.cm^2).

Table 5. Technique factors used for digital radiography and the measured Dose Area Product (Gy.cm^2).

Type of Examination	kVp	mAs	Exposure time (mSec)	DAP (Gy.cm^2)
Lumbar Spine AP	80	41.9 (38.5-47.2)	77.3 (75-80)	2.44 (2.14-2.93)
Cervical Spine Lat	75	12.6 (6.4-20.8)	39.4 (20-65)	0.23 (0.1-0.38)
Lower leg	65	3.2	10	0.07 (0.053-0.1)
Pelvis AP	80	38.4 (22.6-58.5)	61.0 (36-93)	1.33 (0.82-1.88)
Knee AP	65	6.2 (1.9-16)	26.7 (6-50)	0.18 (0.072-0.30)
Knee Lat	65	16.4 (3.5-29.1)	50.7 (4-91)	0.39 (0.055-0.077)
Chest PA	125	5.0 (3-7.6)	35.3 (13-56)	0.24 (0.12-0.42)
Chest Lat	125	10.8 (4.8-21.6)	26.0 (9-54)	0.65 (0.18-1.48)
Hand	55	2.7 (1.6-3.2)	10.0	0.03 (0.02-0.039)
Ankle AP/ Lat	60	2.5	10.0	0.028 (0.018-0.032)
Wrist PA	55	3.2	10.0	0.021 (0.01-0.03)
Wrist Lat	55	4.1	13.0	0.026 (0.012-0.051)
Femur AP	70	34 (27-40.3)	54 (43-64)	1.17 (1.08-1.27)
Femur Lat	70	15.7 (11.2-21.4)	29.3 (23-35)	0.49 (0.20 -0.71)

AP = Antero posterior, PA = Poster anterior, Lat = Lateral

Table 6. Dose-area Product Readings High Frequent value as a percentage for Chest, Lumbar Spine, and Cervical Spine Examination.

Type of Examination	DAP Range (Gy.cm^2)	High Frequent Value (%) in every category
Chest PA	0.3-0.4	53
Chest Lateral	0.3-0.6	45
Cervical Spine	0.3-0.4	40
Lumbar Spine	3.5-4.0	36

Table 7. Average dose area product in this study and the corresponding reference levels for Australia and UK.

Examination	This Study	DAP per radiograph (Gy.cm^2)	
		Australian reference levels -2013	UK- 2005
Chest PA	0.24 (0.12-0.42)	0.12	0.12
Chest LAT	0.65 (0.18-1.48)	-	0.3
Lumbar Spine AP	2.44 (2.14-2.93)	1.6	1.6
Pelvis AP	1.33 (0.82-1.88)	3.0	3.0

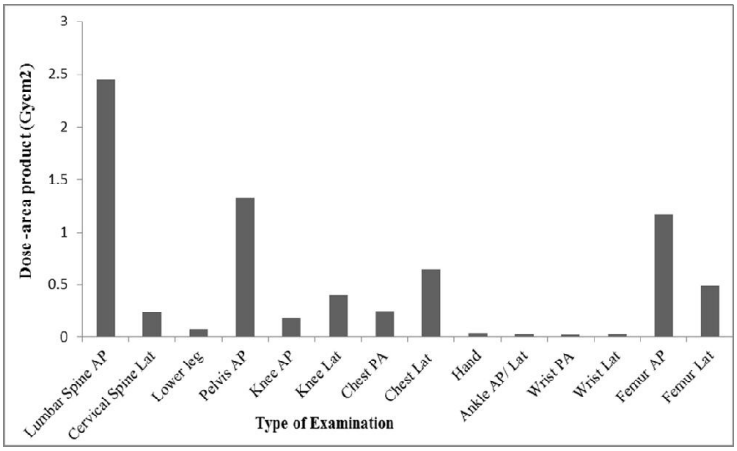

Figure1. Average dose- area products for digital radiography for different examination.

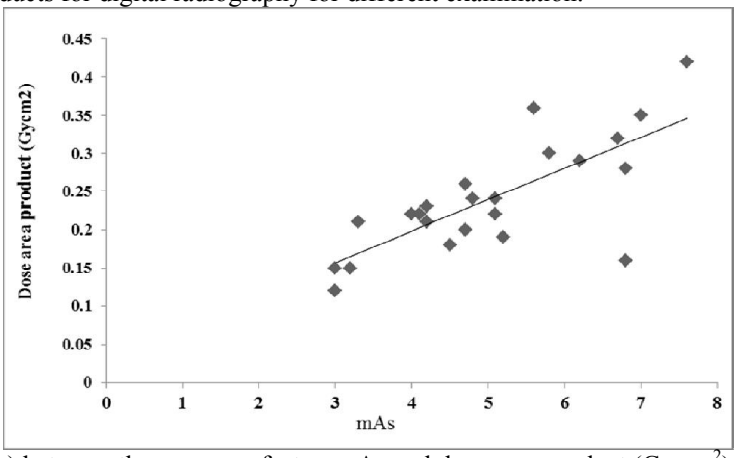

Figure 2. The relationship (linear) between the exposure factor mAs and dose area product ($Gy.cm^2$) for chest PA examination.

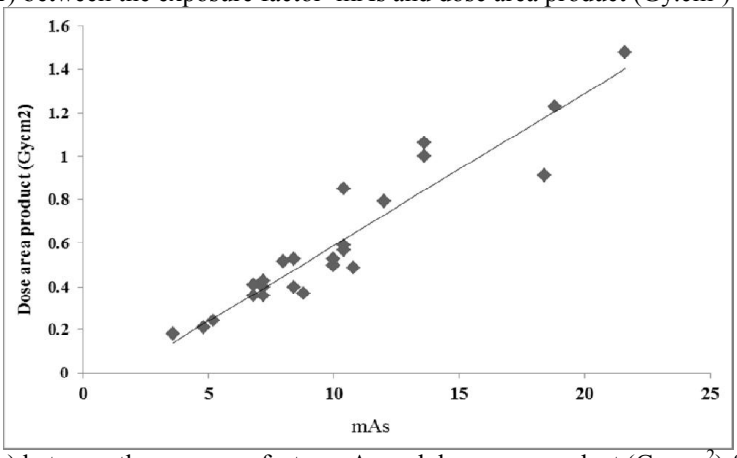

Figure 3. The relationship (linear) between the exposure factor mAs and dose area product ($Gy.cm^2$) for chest Lateral examination.

Conclusion

The results of the quality control test procedures show good agreement between the measured parameters and the recommended acceptance levels. From the results of this survey we are in need to optimize the clinical physical parameters selected by the technicians especially for lumbar spine projection. The observed dose area product received by patient for different projection was determined. The present study will provide a useful baseline data to establish the national diagnostic reference levels especially for those projections not found in the international recommended values. This study reflects the current situation due to the impact from using DR system in diagnostic radiology.

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