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Original Article

Estimation of Entrance Surface Dose and Dose Area Product in Most Frequently Used Radiography Examinations in Hamadan

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Abstract
Background: Radiation dose in C-arm procedure and radiography may lead to late complications such as cancer. Entrance surface dose (ESD) and dose area product (DAP) are two practical indicators for patient dose estimation. This study aimed to calculate ESD and DAP based on exposure parameters for the most common radiographic examinations in educational hospitals of Hamadan.
Methods: This work was conducted in three radiography centers in Hamadan in 2020. ESD was determined using a standard equation. Radiation parameters, including maximum kilovolt and milliampere-seconds (mAs), were obtained from the device console, and the output factor was obtained from the calibration certificate. Eventually, ESD and DAP were computed for the head, chest, abdomen, and pelvic radiography examinations.
Results: Means of ESD and DAP were 0.68 ± 0.44 mGy and 274.03 ± 179.84 mGy.cm^2 for head, as well as 0.13 ± 0.07 mGy and 117.64 ± 70.07 mGy.cm^2 for chest. In addition, the corresponding values were 1.31 ± 0.82 mGy and 1187.17 ± 738.3 mGy.cm^2 for the abdomen, as well as 0.84 ± 0.83 mGy and 764.84 ± 753.59 mGy.cm^2 for the pelvic. The difference in ESD and DAP for all examinations between centers was significant ($P < 0.05$).
Conclusion: Several factors affect radiation exposure and patient dose in radiography. Some of these factors are subjective and depend on technician knowledge. It is possible to reduce the patients' dose while maintaining image quality by regular training of technicians.
Keywords: Digital radiography, Radiation dosages, Radiation protection

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Introduction

Today, medical imaging plays an important role in diagnosing many diseases (1-3). Exposure of patients to X-ray irradiation may lead to late complications such as cancer. Several studies have shown that low doses of radiation in the diagnostic range can cause an increased risk of cancer, the possibility of chromosomal damage, and genetic mutations due to DNA damage (4-9). Applying radiation protection principles is mandatory for patients and staff. Keeping a suitable distance and shielding are used for personnel during imaging, but patients are directly exposed to X-rays. In recent years, extensive studies have been conducted to reduce patient exposure. Adjustment of exposure parameters such as maximum kilovolt (kVp) and milliampere-seconds (mAs) to a low level while considering image quality, precise collimation, and accuracy in performing radiography is highly important for patients. In 1996, the diagnostic reference dose level was introduced by the International Commission on Radiation Protection for the purpose of dose optimization in medical imaging (10). Extensive patient dose variations for a specific radiography test have been reported in various centers. The diagnostic reference level takes into account both the patient's dose and image quality (11,12). The advent of digital radiography in the 1980s created a major transformation in radiology (13). Despite the advantages, the wide dynamic range of digital systems in response to radiation allows for more errors in exposure parameters, causing a higher radiation dose to patients. Therefore, applying dose optimization methods seems to be of higher importance than conventional radiography (13). Exposure information is displayed on the console immediately after irradiation. If the devices are properly calibrated, this information can be used to calculate the values of entrance surface dose (ESD) and dose area product (DAP). Thus, the patient dose can be observed subsequently. This study sought to estimate ESD and DAP for most common radiographic tests in educational hospitals of Hamadan in 2020.

Materials and Methods

This work was conducted as a descriptive cross-sectional study in three educational centers of Hamadan with the ethics code of IR.UMSHA.REC.1398.393. Three digital radiography units, including one Shimadzu (0.6/1.2P324DK-85) and two Toshiba (E7252X), underwent investigation. All radiography units had a calibration certificate attached to them. Four commonly used radiographies, including the head, chest, abdomen, and pelvis, were chosen after refereeing to the registry of radiographic examinations. The head and chest examinations were performed in posterior-anterior projection, and the abdomen and pelvic radiographs were obtained in anterior-posterior projection. The ESD was calculated using the standard equation as follows (14):

$$ESD(mGy) = OP.\left(\frac{kV}{80}\right)^2.mAs.\left(\frac{100}{FSD}\right)^2.BSF \quad (1)$$

The parameters of kV and mAs were obtained from the device console. OP is the output of the device in order of mGy/mAs and is obtained from the calibration certificate. Since the output has been determined in specific kilovolts, to obtain the output in kilovolts used in radiographic examinations, the relationship was created in Excel software. The focal spot-to-surface distance (FSD) is equal to the adjusted distance for each radiograph in centimeters. The backscattered factor (BSF) has been obtained from the study of Vijayam et al (15). The data of 100 patients were collected for each examination.

Next, the entrance surface area exposed to X-rays was determined using collimation. The ESDs multiplied by the area of the field size were considered as DAP. The Kruskal-Wallis test was performed to compare the ESD and DAP for each examination separately between centers.

Results

Radiography exposure parameters (i.e., kVp and mAs), as well as the characteristics of patients, including number, gender, and age, in order of examination type and center, are provided in Table 1. Centers' names are defined as A, B, and C.

The output factor (the output in terms of mGy/mAs) for each device was obtained from the calibration certificate. Output values were specified only in certain kilovolts. By plotting output versus kVp curves (Figures 1-3), the output values at desired kilovolts for each examination were obtained in centers A, B, and C.

The BSF values for the small field of the head and large field of other examinations were obtained from the study of Vijayam et al (15). Considering that the BSF values in the mentioned study are defined at specific kilovolts, curves in Figures 4 and 5 were used to obtain BSF values in the desired kilovolts.

Table 2 presents the calculated values of ESD (mGy) and DAP (mGy.cm^2) for each examination in different centers. Means of EDD and DAP for head and chest were 0.68 ± 0.44 mGy and 274.03 ± 179.84 mGy.cm^2, as well as 0.13 ± 0.07 mGy and 117.64 ± 70.07 mGy.cm^2, respectively. Moreover, they were 1.31 ± 0.82 mGy and 1187.17 ± 738.3 mGy.cm^2, as well as 0.84 ± 0.83 mGy and 764.84 ± 753.59 mGy.cm^2 for abdomen and pelvic, respectively. The differences of ESD and DAP for all examinations between centers were significant ($P < 0.05$).

Discussion

Given that there is no safe dose limit for ionizing radiation, three principles of radiation protection, including justification, optimization, and dose limit, should be employed in radiography practice to reduce the risk of radiation effects (16). In this study, the ESD and DAP

Table 1. Radiography Exposure Parameters, Including kVp and mAs, as Well as the Characteristics of Patients in Order of Examination Type and Centers

Center	Examination Type	Patients' Gender, Age, and Number				Exposure Parameters	
		Male		Female		kVp Mean ± SD	mAs Mean ± SD
		Number	Age (y) Mean ± SD	Number	Age (y) Mean ± SD		
A	Head	15	28 ± 14	11	38 ± 21	65.4 ± 2.35	20.3 ± 3.57
	Chest	12	40 ± 26	15	37 ± 25	68.4 ± 7.9	12.6 ± 8.12
	Abdomen	17	44 ± 14	8	29 ± 12	70.3 ± 5.73	33.5 ± 9.57
	Pelvic	20	48 ± 17	7	60 ± 20	65.4 ± 3.28	25.3 ± 5.13
B	Head	13	41 ± 16	13	44 ± 19	74.9 ± 4.45	22.8 ± 3.83
	Chest	12	57 ± 17	14	57 ± 22	69 ± 2.13	14.1 ± 4.09
	Abdomen	19	56 ± 14	8	49 ± 7	70.1 ± 2.05	28.6 ± 10.42
	Pelvic	13	58 ± 17	12	45 ± 14	66.5 ± 1.32	20.3 ± 2.94
C	Head	13	41 ± 16	12	39 ± 22	60.4 ± 7.44	17.44 ± 10.53
	Chest	14	53 ± 19	11	54 ± 22	83.16 ± 7.71	8.01 ± 2.14
	Abdomen	11	50 ± 12	15	58 ± 19	78.4 ± 6.07	30.2 ± 7.38
	Pelvic	14	52 ± 17	11	56 ± 22	78.4 ± 6.44	30.62 ± 4.1

Note. SD, Standard deviation; kVp, Maximum kilovolt; mAs, milliampere-seconds.

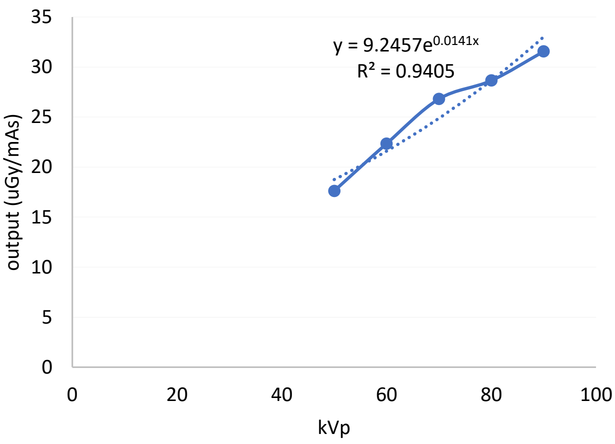

Figure 1. Output Factor Curve in Order of kVp for the Radiography Device in Center A. *Note*. kVp: Maximum kilovolt.

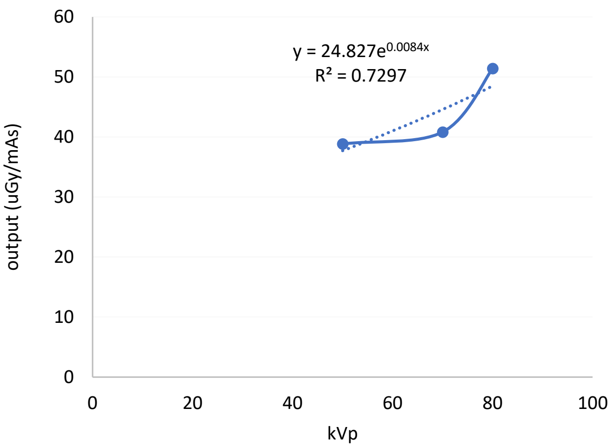

Figure 2. Output Factor Curve in Order of kVp for the Radiography Device in Center B. *Note*. kVp: Maximum kilovolt.

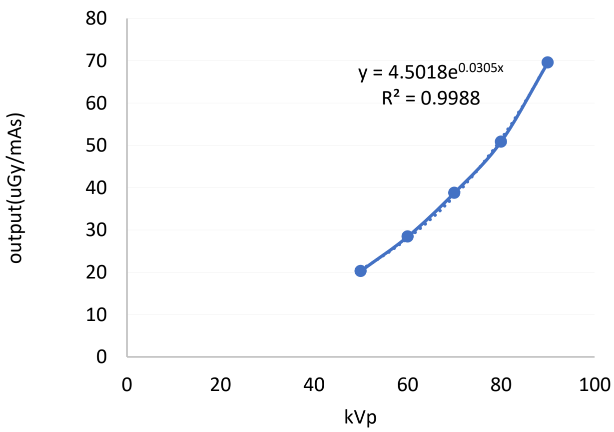

Figure 3. Output Factor Curve in Order of kVp for the Radiography Device in Center C. *Note*. kVp: Maximum kilovolt.

were calculated for head, abdomen, chest, and pelvic radiography examinations. These quantities depend on a number of factors that influence the patient's exposure. kVp has an effect on both the quantity and quality of the radiation beam. For all radiography devices, the output increased with increasing kVp, resulting in a higher dose to the patients. The exposure is directly proportional to the mAs parameter. The scattered radiation will increase with a larger field size and impose more surface doses. These mentioned parameters are selected by the operator. Therefore, the level of knowledge and commitment of the operator in applying the appropriate parameters is effective on the absorbed dose.

The ESD and DAP for abdomen radiography are higher than the other protocols. This is due to higher exposure parameters (i.e., kVp and mAs) than the other tests. Field size is another factor influencing the diagnostic reference level, which is larger for the abdomen than the other tests. The lowest ESD and DAP values are related to chest radiography for which exposure is less than the other examinations.

Table 3 compares the results of other studies with those of this study. ESD for all examinations in this study was less than others. In all studies, abdominal radiography had the maximum ESD, and the minimum ESD was related to chest radiography. This demonstrates that higher exposure parameters are used for abdomen radiography because of more thickness in this part of the body.

Based on the results of this study and those of other studies, variations in patient's dose for a specific radiography procedure between different centers are to some extent inevitable. However, it is important to prevent abnormal variations which in turn lead to extra doses to patients. In this study, the difference between centers was significant for all radiography procedures. The issue of dose variation with digital radiography units becomes more important due to more dynamic range responses to radiation, giving more maneuverability to technicians. Therefore, using an appropriate dose reference and regular training courses can help optimize

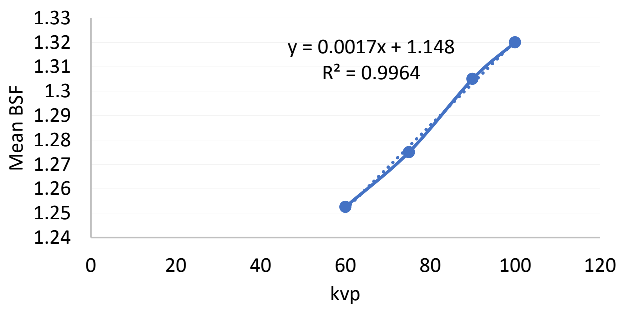

Figure 4. Backscattered Factor Curve for Head Field Size in Order of Different kVp. *Note*. kVp: Maximum kilovolt; BSF: Backscattered factor.

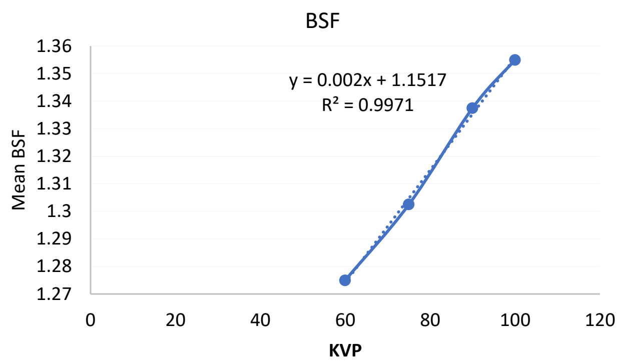

Figure 5. Backscattered Factor Curve for Large Field Sizes in Order of Different kVp. *Note*. kVp: Maximum kilovolt; BSF: Backscattered factor.

Table 2. Values of Entrance Surface Dose (mGy) and Dose Area Product (mGy.cm²) for Each Examination in Different Centers

Center	Examination Type	ESD (mGy)			DAP (mGy.cm²)			*P* Value
		Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum	
A	Head	0.395 ± 0.08	0.19	0.57	158 ± 34.73	77	230.23	< 0.05
	Chest	0.09 ± 0.06	0.01	0.24	84.63 ± 55.81	13.69	216.27	< 0.05
	Abdomen	0.86 ± 0.29	0.14	1.43	774.74 ± 264.19	130.53	1294.93	< 0.05
	Pelvic	0.37 ± 0.116	0.13	0.769	333.62 ± 104.84	117.40	692.41	< 0.05
B	Head	1.2 ± 0.29	0.54	1.46	483.93 ± 118.93	218.78	584.8	< 0.05
	Chest	0.09 ± 0.06	0.01	0.24	84.63 ± 55.81	13.69	216.27	< 0.05
	Abdomen	1.16 ± 0.55	0.67	2.95	1046.39 ± 499.19	608.32	2657.34	< 0.05
	Pelvic	0.37 ± 0.11	0.13	0.76	333.62 ± 104.84	117.40	692.41	< 0.05
C	Head	0.450 ± 0.309	0.047	0.81	180.17 ± 123.62	19.15	327	< 0.05
	Chest	0.204 ± 0.05	0.12	0.33	183.64 ± 45.76	112.73	302.94	< 0.05
	Abdomen	1.93 ± 1.02	0.42	5.58	1740.38 ± 918.23	383.14	5023.26	< 0.05
	Pelvic	1.80 ± 0.83	0.51	3.45	1627.27 ± 752.88	462.46	3105.9	< 0.05

Note. SD, standard deviation; ESD, entrance surface dose; DAP, dose area product.

Table 3. Means of Entrance Surface Dose (mGy) and Local Diagnostic Reference Levels of This Study in Order of Third Quartile of ESDs (mGy) Compared With Other Studies

	ESD (mGy)			
Examination	Head	Chest	Abdomen	Pelvic
This study	0.68 ± 0.44	0.13 ± 0.07	1.31 ± 0.82	0.84 ± 0.83
Mohsenzadeh et al (17)	0.97 ± 0.41	0.6 ± 0.31	1.65 ± 0.79	1.43 ± 0.69
Gholami et al (18)	2.98 ± 2.87	0.56 ± 0.46	5.58 ± 4.56	3.34 ± 3.31
Bahreyni Toosi (19)	Not reported	0.67	2.56	2.93
Gyan et al (20)	1.77 ± 0.3	0.93 ± 0.7	3.15	2.31 ± 0.4

Note. ESD, entrance surface dose.

radiation dose when performing radiography with mentioned equipment.

Conclusion

According to the obtained results, several factors could affect radiation exposure to patients. Some of these factors such as kVp, mAs, FSD, and field size are subjective depending on the technician's opinion and knowledge. Other parameters are objective, including radiography device model, regular calibration of the device, and detector type. By regular training of technicians, it is possible to prevent patients from irradiating unnecessary dose.

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Authors' Contribution

Conceptualization: Faeze Heidari.
Data curation: Salman Jafari.
Formal analysis: Salman Jafari.
Funding acquisition: Salman Jafari.
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Methodology: Salman Jafari.
Project administration: Salman Jafari.
Resources: Faeze Heidari, Maedeh Saiedi.
Software: Faeze Heidari, Maedeh Saiedi.
Supervision: Salman Jafari.
Validation: Salman Jafari.
Visualization: Salman Jafari.
Writing–original draft: Salman Jafari.
Writing–review & editing: Salman Jafari.

Competing Interests

There is no conflict of interests.

Ethical Approval

This study has been approved by the Research Ethics Committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1398.393).

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