Original Article

Patient Dose Estimation from Digital Radiography Repeat Rate

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Effective Dose;

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Abstract

Purpose: This research aimed at estimating the patient effective dose from digital radiography repeat rateand evaluating the factors that contribute to the repetition of radiographic procedures in two referral hospitals in Sari, Iran.

Materials and Methods: Entrance skin dose and effective dose per common radiography procedures in digital radiography were measured. 1724 X-ray exposures were investigated prospectively. The annual number of each radiography procedure was obtained from the archives of the digital radiography department. The patient cumulative dose was the calculation from annual exposures Repeat Rate (RR) and effective dose per digital radiography procedures.

Results: The mean exposure RR per examination was 1.12% and the total percentage of a repeat of all examination was 8.9%. Annual cumulative dose (man-mSivert) resulted from radiographic RR was 449.2.The chest and lumbar spine radiography had the highest annual number and the highest radiation dose, respectively; therefore, these procedures transfer the largest annual dose from repeated radiographic images to the patients. The factors leading to the repetition included the radiographer error (69%), the X-ray tube and equipment error (10.4%), the patient related error (16.1%) and other cases (4.1%). The average effective dose for each examination was 0.36 mSv.

Conclusion: Digital radiographic repeat rate increases a 1.1 % annual patient effective dose from the base level that receives from the current radiographic examination. Inconsistency of the center of the digital panel and the central axis of the X-ray beam and error in the selection of the upright or table digital panel are among the most important factors in the repetition of digital radiography.

1. Introduction

Patients in radiology departments are severely exposed to high radiation doses due to multiple diagnostic radiographic examinations. The relationship between human radiation exposures at different ages and the incidence of cancer has been proven [1, 2]. Patient dose information provides an acceptable indicator of the incidence of late effects of radiation exposures. One of the important goals in radiography is to provide images with high quality and the lowest radiation dose to the patient. Reducing image quality can lead to repetitive radiography images [3]. The repeat rate of radiography images is considered as a quality control indicator, which is very useful in the study of processes such as image quality evaluation, optimization of imaging protocol, determination of knowledge level and skills of radiographers and evaluation of unnecessary radiation dose rate in patients [4]. To accurately calculate the dose of radiography procedures, the number of exposures per patient must be calculated [5]. In radiographic imaging, a percentage of exposures are repeated because of staff

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or system errors. Obviously, the higher is the percentage of repetitions, the more unnecessary the dose is. Some studies have assessed the radiographic repeat rate and related factors in digital radiography systems [6-8], and a number of studies have calculated the patient dose from each radiographic procedure and investigated the factors that lead to increased patient dose [9-12]. Patients' dose values from repeated radiographic images are obtained by multiplying the number of repeated exposures and patient dose from each radiographic procedure, so this quantity is a very important index that considers both the reasons for the repetition and the image quality and dose level of the patients. Accordingly, it can be a very important qualitative indicator. There is little information about the patient's radiation doses from digital radiography repeat rate. In this study, the dose rate in the current radiographic procedures in the digital system and the number of repetitions of images in each examination was measured and the patient doses from repeated digital radiographic tests and the factors leading to repetition were studied.

2. Materials and Methods

In this study, the following steps were performed to measure the patient dose resulting from repeating the images in digital radiography in the most common procedures:

2.1. Measurement of Radiation Dose Level

To calculate the average skin dose and effective dose for the most common radiographic procedures, the patient's demographic information (patient body thickness, weight) and radiographic conditions (kV, mAs, and digital panel to X-ray tube distance) from two referral governmental hospitals, Sari, were obtained. The X-ray tube output was obtained from the latest calibration report of the X-ray systems. The Skin Entrance Dose (ESD) in mGy, which is the absorbed dose of the skin in the central axis of the radiation field, was calculated using the following equation [10 -11]:

$$ESD(mGy) = \frac{Y_D.mAs.D^2}{\left(L-(d+b)\right)^2} \times BSF \qquad (1)$$

Where, Y_D is the output of the X-ray tube in µGy /mAs at a distance D, mAs is the product of time in mA, L is the distance from focal spot to the digital panel, and b and d are the distance between the digital panel to the table and the patient's thickness, respectively. Back Scatter Factor (BSF) is a conversion factor that is used for conversion of air kerma to the ESD [13]. In order to calculate the ESD, the output of X-ray tube, Y_D, at a distance of 1 meter for voltages from 60 to 80kV, with 5 kV intervals, was measured using the BARACUDA RTI R100 Dose Probe and the X-ray tube output (µGy / mAs) was plotted versus kilovoltage (kV) and appropriate conversion factors were used to calculate ESD to Effective Dose (ED) [14, 15]. In this study, the radiation doses of the most common radiographic procedures, including upper limb, lower extremity, pelvis (AP), neck (Lat), lumbar spine (AP and Lat) and lung (PA) were investigated.

2.2. Measurement of the Radiographic Image Repeat Rate

From the two referral hospitals in Sari, 1,724 exposures (with 10% repeat rate from previous studies, 95% confidence interval and 2% statistical accuracy) were investigated prospectively. Total number of repetitive exposures, number of repetitions for common radiography procedures in the digital system, and factors leading to repetition (including patient positioning errors, inappropriate restriction of the radiation field size, error in the central point of radiation, inappropriate selection of radiation conditions, patient motion, failure of digital radiographic system in production of X-ray, image artifact and other items) were recorded in predesigned sheets. Samples were analyzed for calculating radiographic repeat rate in descriptive statistics using Excel software.

2.3. Estimation of Patient Doses from Repeated Radiographic Images

In this study, the effective annual dose of patients was calculated from the total number of digital radiography images and also for each procedure. The annual number of each radiographic procedure was obtained from the archives of digital radiography departments in each hospital. The following equation was used to calculate the effective dose from radiographic repeat rate:

$$effctivedose(ED)(mSv) = \sum \frac{Rexm.i}{Nexp} \times Nti \times \frac{exposure\ number}{patient} \times ESDi(mGy) \times \left(\frac{ED}{ESD}\right) i \quad (2)$$

where ED / ESD, is the conversion factor of the doses of the skin to the effective dose for each procedure (R_{exm}.i is the number of repetition for each procedure, N_{exp}.is the total number of exposures (1724), N_{ti} is the total number of each radiographic examination per year, and ESD_i is the entrance skin dose (mGy) for each procedure (Equation 1). To calculate the total number of exposures per year, the annual number of patients was multiplied by the average number of exposures for each patient.

3. Results

The ESD (mGy) was calculated using the X-ray tube output (Y_D) and the kVp and mAs were selected for each radiographic procedure. In Table 1, the patient's demographic information and radiographic conditions are shown.

In Table 2, the ESD (mGy) and ED (mSv) for each digital radiographic examination, the annual number of radiographic examinations and annual cumulative patient effective dose (man-Sivert) from radiographic repeat rate are shown.

The mean exposure number (X-ray shooting) per patient in the two hospitals was 1.9. The mean exposure repeat rate per examination was 1.12% and the total percentage of the repeat of all examination was 8.9% (154/1724). The factors leading to the repetition of radiographic images in the digital system were divided into four groups, which include the radiographer errors, the X-ray tube and equipment errors, the patient related errors, and other cases. In Figure 1, the share of each of these factors is shown.

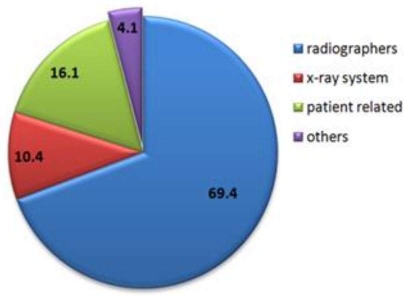

Figure 1. The factors leading to the repetition of digital radiography images and the contribution of each of them

Table 1. Patient's demographic information and radiographic conditions in two referral hospitals, Sari, Iran

Radiographic Procedures	Number of Patient	Patient Weight (kg)	Thickness of Anatomical Region (cm)	kVp	mAs	FFD
Upper Extremity	34	73.5 14-108	8.7 4-13	59 50-75	10 4-25	100
Lower Extremity	56	60 27-90	8.8 3-16	58 51-80	10 5-20	100
Lung	20	62 10-110	21 13-32	68 60-85	14 8-28	130
Lumbar Spine (AP)	10	75.5 60-85	24.8 18-32	75 68-90	43 25-56	100
Lumbar Spine (Lat)	10	75.5 60-85	32.5 30-38	86 80-100	69 40-90	100
Pelvic	10	59.5 13-86	21.5 12-30	74 55-90	30 20-36	100
Neck	10	62 16-80	11.5 9-13	70 57-83	20.5 14-28	100
Abdomen	10	67 23-85	26.5 14-32	72.5 60-90	32 25-40	100

Table 2. Cumulative effective dose (man-Sivert) from annual repeated of exposure in radiographic procedures in two referral hospital, Sari

Radiographic Procedures	Annual Number of Exposures	Repeat Rate (%)	Annual Repetition of Exposure	Mean ESDi (mGy) per Exam.	Mean EDi (mSv) Per exam.	EDi Annual (man-mSv) From RR
Upper Extremity	53204	1.86	990	0.70	0.0035	3.5
Lower Extremity	60589	1.33	806	0.69	0.0030	2.4
Lung	59981	1.68	1008	1.13	0.1450	146.2
Lumbar Spine (AP)	11164	0.87	97	7.48	0.8950	86.8
Lumbar Spine (Lat)	11164	0.87	97	20.10	0.5400	52.4
Pelvic	13779	0.46	63	4.88	0.5000	31.5
Neck	5625	0.35	20	1.46	0.0350	0.7
Abdomen	11283	1.55	170	5.59	0.7400	125.8
Total						**449.2**

Radiographer errors that lead to repetition of exposures in the digital system and ultimately lead to patient doses included inconsistency of the center of the digital panel and the central axis of the X-ray beam, error in selection of the upright or supine panel, patient position, inappropriate selection of radiation conditions, inappropriate technique, external object, error in reading of patient's request, mistake in the patient's name and deleting the images before saving them. Factors such as the lack of X-ray production after exposure, equipment failure and imperfect exposure are related to X-ray system errors. The movement of the patient and his lack of cooperation are factors that relate to the patient errors that lead to repetition of the radiographic exposures. The effective dose of patients with repeat radiographic images was 449.2 man-mSv for all radiographic procedures. The cumulative annual dose was 40521 man-mSv from the routine radiographic examinations listed in Table 2. The findings of this study showed that repetition of radiographic images adds 1.1% (449.2 / 40521) unnecessary doses to the population.

4. Discussion

In this study, the annual effective dose of patients from repeat rate of routine radiographic procedures in digital system was evaluated. Equation 1 and Table 1 were used to calculate the patients' skin dose from each radiographic procedure, and Equation 2 was used to calculate the patient's effective dose from repeated radiographic images. The highest dose of patients with repeated radiographic images was related to the procedure that had the highest number of annuals or that had the highest dose of radiation deliver to the patient. In the national study of the reference dose level in Iran [9], the highest ESD (mGy) was related to the lateral projection of the lumbar spine, with an average value of 7.38 mGy. In our study, patients' skin dose from this projection was 20.10 mGy, which was the highest. The cumulative annual dose due to repeated radiographic images in lateral lumbar radiographs was 52.4 man-mSv, whereas only 5% of the annual number was related to this projection. Our study showed that patients received the lowest dose from radiographic repeat rate of cervical spine (0.7 man-mSv) and the highest dose was related to lung radiography (146.2 man-mSv). The highest number of radiographic examinations in a year was related to chest radiography (26%). In our study on average 68 kV as X-ray photon energy was selected for chest radiography. This kV value is low for chest radiography. The Commission of European Communities proposes a value of 110 kV for this procedure [16,17]. High kV voltage techniques have an effective role in reducing patient dose [18]. The annual cumulative dose (man-mSv) for all digital radiographic examination, in the two referral hospitals in Sari, was obtained (40521), and annual cumulative dose resulted from radiographic repeat rate was 449.2 (Table 1). This means that digital radiographic repeat rate increases 1.1 % annual patient effective dose from the base level that receives from current radiographic examination. In a study conducted by Monfared *et al.* [3], the radiographic repeat rate in the film-screen system was 11.3%, and the average dose per radiographic examination was obtained as 0.92 mSv. In our study, the rate of repetition in digital system was 8.9% and the average effective dose for each examination was 0.36 mSv, which shows that the average dose per examination in digital systems is less than that of film-screen systems, which is due to the higher DQE of digital panels than to film based receptors. Due to the short dynamic range of film-screen systems, inappropriate selection of irradiation conditions has the highest contribution to radiographic repeat rate. In a study by Jabari *et al.* [19], the most frequent reason for repeat rate with 54.13% was due to inappropriate selection of radiation conditions. In our study, inappropriate selection of radiation conditions was 8.7% of the cases of repeat rate, which appear in the image as increased noise or no image formation. The response of digital panels to multiple irradiation conditions is linear, so the likelihood of duplicate images is poorly selected. Therefore, inappropriate selection of radiation conditions in digital systems does not lead to repetition of procedures. However, inattention to the appropriate selection of radiation conditions can be associated with increased patient dose [20]. In our study, the mean number of exposures per examination was obtained as 1.9. In some studies, this value has been reported between 1.5 and 4 [19, 21, 22]. Increasing the number of exposures per examination means that the treatment teams use more projections to diagnose the disease. Obviously, as the number of exposures increases, the percentage of repeat rate increases, which is associated with an unnecessary dose to the patients. For radiographic procedures that have high ESD (mGy), fewer projections should be used to diagnose. The radiographic repeat rate in Florian *et al.* study [4], in digital radiography system for DR and CR system was 13% and 3.6%, respectively, which is more than the repeat rate in film- screen system. In Fallah Mohammadi's study, the radiographic repeat rate in film-screen system was reported as 5.9% [23]. More research is needed to compare the annual effective dose resulting from the repetition of radiographic images in the film-screen system and the digital system. The most contribution of this unwanted dose, as shown in Figure. 1, was related to radiographer performance error. The most common cause of the radiographer error in digital systems was related to the inconsistency of the center of the digital panel and the center of the radiation field, and then the error was in the supine or upright panel selection. In some studies, the error in the positioning of the patient by the radiographer (51.3%) was introduced as the most common cause of repeated radiographic images [24]. In our study, the positioning of the patient errors was 9.3%. Because staff performance errors are the most common cause of the radiographic repeat rate, increasing skills and training of personnel will play a major role in reducing repeat rate, reduction of loss of resources, improved methods, and reduce unwanted doses to the patients.

5. Conclusion

Regarding the fact that radiographer's performance in digital radiography techniques has the most important contribution in radiographic repeat rate and patient doses, the continuing training of personnel and development of their skills in the radiology department should be considered seriously.

To prevent errors in the selection of the standing and table digital panel in radiography, use the X-ray collimator angle sensors to automatically select the digital panel. Entrance skin dose in the abdominal and the lumbar vertebra digital radiography are very high, so care should be taken as much as possible to avoid repeating these radiographic procedures. Use high kV voltage technique in chest radiography.

Use the least number of radiographic views to diagnose diseases, especially those with high doses. Imaging systems should be periodically and regularly monitored to ensure the correct operation of radiation conditions. Inconsistency of the center of the digital panel and the central axis of the X-ray beam and error in selection of the upright or table digital panel are among the most important factors in the repetition of digital radiography.

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