

Patient effective dose evaluation for chest X-ray examination in three digital radiography centers

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Background: The radiation doses resulting from diagnostic X-ray examinations are routinely measured in terms of entrance surface dose (ESD) and effective dose (ED). In this study, for the purpose of radiation protection, the radiation doses received from Digital chest X-ray examination were evaluated in terms of ESD and ED. **Material and Methods:** The ED was calculated by using the MCNP Monte Carlo code and an adult hermaphrodite mathematical phantom. The effects of both operating high voltage and projection geometry on the effective dose were investigated. The absolute values of the ED were calculated for digital and conventional Posterior-Anterior (PA) and Lateral (LAT) projections of chest radiography. **Results:** The results show ED for PA projection in digital chest radiography in some major hospitals is higher than National Diagnostic Reference Level (NDRL). **Conclusion:** Therefore optimization process should be considered seriously at national level to reduce patient exposure in digital chest radiography in Iran. Iran. J. Radiat. Res., 2012; 10(3-4): 139-143

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INTRODUCTION

Chest X-ray examination is one of the most frequently required diagnostic procedure used in clinical practice and it may also be implemented in screening programs for large populations, with a significant impact on the collective dose⁽¹⁾. According to ICRU report 70 the chest radiography is responsible for approximately 25% of all X-ray examination performed⁽²⁾. Since the use of digital techniques in radiographic imaging are rapidly growing, it is important to assess and review the exposure settings, for example the tube voltage, used to obtain the images⁽³⁾. Digital technology has not only

the potential to reduce patient doses, but also the risk to increase the number of exposures and the dose required to obtain images of enough quality. Experience has shown that many radiology departments have made the transition to digital equipment, patient doses have been measurably increased⁽⁴⁾. In Iran, uses of digital radiography systems are growing very fast and different digital radiography systems have been used. Some studies have been carried out to evaluation of exposure parameters and ESD of chest and other routine conventional X-ray examinations in Iran^(5,6).

Effective dose, a weighted sum of organ doses⁽⁷⁾, is considered the best dosimetric quantity for estimating the risk of exposure to ionizing radiation⁽⁸⁾. In 2005 Bahreyni Toosi *et al.* calculated the ED of some routine conventional radiography procedures using MCNP4C Monte Carlo code. They used the mathematical ORNL phantom to measure effective dose based on ICRU 60 definition of tissue weighting factors (w_t)⁽⁹⁾. They found that the MCNP4C is a useful tool to determine relative dose of organs exposed to X-ray tube.

In this study, for the first time in Iran, the radiation doses from digital chest X-ray examinations were obtained in terms of

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ESD and ED based on ICRU 103 tissue weighting factors. The results were compared with Iranian National Diagnostic Reference Level (NDRL) of chest X-ray examinations. This study is a pilot study to evaluate the patients ED in digital chest X-ray examinations in Iran.

MATERIALS AND METHODS

Mathematical phantom

The adult male phantom developed by Eckerman *et al.* ⁽¹⁰⁾ in Oak Ridge National Laboratory (ORNL) was used for the ED calculations. In this phantom all organs of the human body were represented with analytical equations of various three-dimensional geometrical bodies. Three types of tissues, skeletal, lung and soft tissue, with different densities and elemental compositions were present in ORNL phantom.

Digital X-ray unit

Three major and busy hospitals (out of six hospitals using digital X-ray) were selected. They have been using digital radiography for 5 years. The X-ray machines that are used in hospitals are Axiom Aristos VX plus (Siemens) ⁽¹¹⁾. Before measurements, an initial quality control check was done on the X-ray equipment using a Barracuda multimeter instrument (RTI Electronics, M^olndal, Sweden). The instrument was calibrated with a calibration traceable to a standard laboratory. Five basic quality control tests (timer a kVp accuracy, kVp repeatability, filtration check and output repeatability) were performed.

Calculations method

The calculation of organ equivalent doses with high accuracy is necessary for calculating ED. Direct measurements are very difficult if possible at all. The Monte Carlo transport code MCNP4C ⁽¹²⁾ was used to simulate chest X-ray examinations evaluating absorbed doses in various organs

within the ORNL phantom. The energy deposited tally F6 (assuming the existence of secondary electron equilibrium) was used to calculate the absorbed doses for each organ ⁽¹³⁾. For each technique to obtain the entrance surface dose, air-kerma were measured at the entrance surface of the ORNL phantom using an air filled cylinder with 100 cm² surface and 180 cm³ volume positioned on the surface of phantom in the middle of the radiation field. The MCNP F6 tally was used for calculating air kerma within the cylinder model. Considering charged particle equilibrium, the air kerma was obtained through the air-absorbed dose ⁽¹⁴⁾. For the MCNP calculations, 10⁷ photons were traced. This number ensured that the relative standard deviation calculated with MCNP was smaller than 5% for all organs. The photon cut-off energy was set at 10 keV.

X-ray source

The relative intensities of the X-ray source photons, as a function of the energy, must be known for MC simulation. The X-ray spectra to be used in the MCNP simulations are generated with spectrum generator software SRS-78 ⁽¹⁵⁾, taking the X-ray voltage and Al filtration applied in the clinic as input parameters.

Effective dose calculation

Two routine projection geometries of the phantom were evaluated, namely, PA and LAT. The normalized organ absorbed doses relative to the ESD equivalents for hermaphrodite phantom were determined. The normalized effective doses to the ESD values were calculated according to the definitions that is given in ICRP publication 103⁽⁷⁾ that released new values for Tissue Weighting factors to calculating ED.

ESD measurement

To evaluate the effective dose in different digital chest radiography procedures, it's necessary to measure the ESD. The ESD of each projection was calculated as:

$$ESD = Y(kVp, FDD) \cdot mAs \cdot \left(\frac{FDD}{FFD - t_p} \right)^2 \cdot BSF \quad (1)$$

Where, Y is the air kerma at FDD (Focal Detector Distance) in certain kVp, t_p is the patient thickness, and BSF is the air kerma Back Scatter Factor that is provided in IAEA Technical Reports Series No. 457⁽¹⁶⁾. According to the ORNL phantom thickness, the t_p was set 20 and 40 cm for PA and LAT projections, respectively. For each system the air kerma, free-in-air, was measured by Barracuda multimeter Solid-state detector in fixed 100cm distance from focal spot in unit of mGy/mAs. Capability and accuracy of barracuda multimeter for measuring the air kerma in free air is investigated by Martin *et al.*⁽¹⁷⁾.

Patient information, exposure parameters and ESD values for each projection of conventional chest X-ray examination were obtained from Asadinezhad *et al.*⁽⁶⁾ as Iranian NDRL. This information was used for calculating the ED in conventional chest radiography.

RESULTS AND DISCUSSION

Exposure parameters from selected hospitals were collected in one month period. The results are summarized in table 1 compared with NDRL. As it can be seen, the operators in all hospitals prefer to use constant value for kVp and FFD for all adult patients and the mAs is adjusted by machine according to Automatic Exposure Control (AEC) operation. Fixed FDD, 120

cm, is used in two hospitals and one hospital prefer to use the high KVp technique with higher FDD, 180cm.

MCNP Air Kerma results are shown in figure 1. As it is indicated, the air kerma values were decreased with tube voltage. These results are comparable with Correa *et al.*⁽¹⁸⁾ study, but aren't compatible with practical measurements. The reason could be due to MCNP behavior, that all output tallies are normalized to total number of source particles. For correction, it is necessary to multiple the F6 tally results by the number of produced photon for each tube kVp that was acquired from the spectrum generator software SRS-78. These correction Air kerma values are shown in figure 1. Using the correction factor, it can be seen that modified MCNP Air kerma calculations are in good agreement with practical measurements.

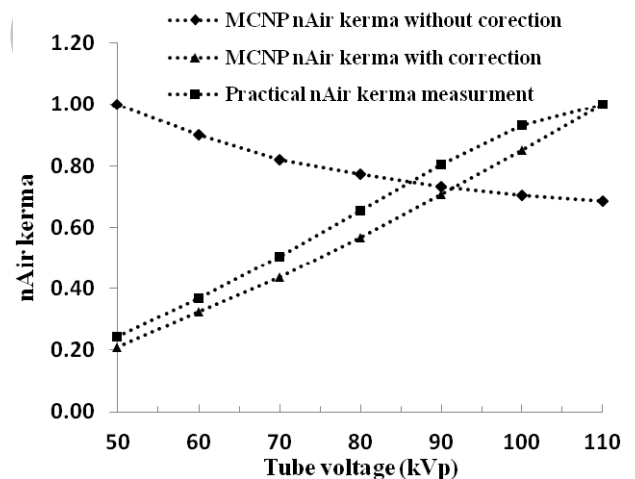


Table 1. Exposure parameters for digital chest radiography in three major hospitals compared with Iranian NDRL.

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Chest projection	parameters	Hospital			Iranian NDRL**
		No. 1	No. 2	No. 3	
PA	kVp	68	60	110	66
	Mean mAs*	7.1 (5-8)	9.9(8-13)	1.5(1-2.1)	18(1.5-90)
LAT	kVp	77	70	110	72
	Mean mAs*	4.2 (3-5)	9.8(7-11)	1.8(1.3-2.5)	41(4-75)

* The range from minimum to maximum is given in brackets.

**Data from Asadinezhad *et al.*⁽⁶⁾

Figure 2 shows the Variation in ED with tube voltage calculated by MCNP simulation. The figure shows the effective dose increased with increase in tube voltage and it also indicates that effective dose of the PA projection is about 3 times as much as LAT projection. The increment of effective dose in the lower tube voltage domain is larger than in the higher tube voltage region.

ESD values for each hospital were calculated based on equation 1. Table 2 shows the ESD and corresponding effective dose for each hospital and for NDRL in both PA and LAT chest radiography.

The value of ED for LAT projection in three hospitals is about 22% of Iranian NDRL of ED. In PA projection, which is more often used, both ESD and ED values for hospital No. 1 and No. 2 are higher than Iranian NDRL. It might be because of lack of medical physicist, improper kVp and FDD setting and incorrect AEC system calibration. But in hospital No.3, that adopting the high kVp technique and higher FDD, the effective dose for both PA and LAT projection is lower than Iranian NDRL.

There are some studies on evaluation of patient dose undergoing digital radiography in different countries. Compagnone *et al.*⁽¹⁹⁾ calculated the ED in PA and LAT chest digital radiography in one hospital in Italy by Monte Carlo simulation technique. Their

results showed the ED for PA and LAT chest digital radiography was about 20 and 13% of Italian national diagnostic reference level respectively. The routine kVp for both PA and LAT chest digital radiography was 125 kV according to European guidelines. Another study on patient dose in digital radiography was performed in Germany by Schuncke *et al.*⁽²⁰⁾ in term of Kerma Air Product (KAP) and Entrance Air Kerma (EAK). The mean dose levels were far below the diagnostic reference levels for all except chest PA radiography in one hospital. They concluded the patient dose monitoring is essential and optimization should be performed in digital radiography.

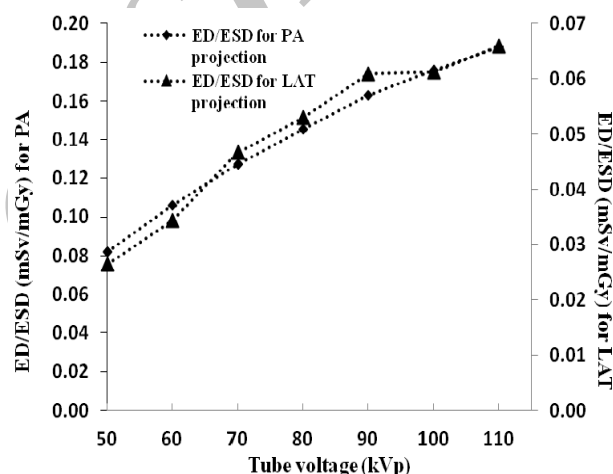


Figure 2. Variation in ED with tube for PA and LAT digital chest radiography.

Table 2. The ESD and ED values for different digital chest radiography in three major hospitals compared with Iranian NDRL.

Chest projection	parameters	Hospital			Iranian NDRL
		No. 1	No. 2	No. 3	
PA	Mean ESD (mGy)	0.45 (0.32-0.52)	0.53 (0.42-0.69)	0.095(0.063-0.13)	0.35 (0.5-2.59)**
	Mean ED (μSv)	55	71.5	19.5	44.1
LAT	Mean ESD (mGy)	0.53 (0.4-0.66)	0.53 (0.42-0.69)	0.15(0.11-0.21)	1.58 (0.39-3.89)**
	Mean ED (μSv)	14.5	29.6	12.8	87

* The range from minimum to maximum is given in brackets.

**Data from Asadinezhad *et al.*⁽⁶⁾

In digital radiography it is unacceptable to increase the patient effective dose in comparison with conventional method. Therefore, according to the ICRP recommendations⁽²¹⁾, it is necessary to optimize the patient dose in digital radiography especially for the countries moving from analog to digital radiography.

CONCLUSION

Our study shown that, even for the same type of modern digital equipment, the average applied patient dose at different hospitals can vary widely. Moreover it was found that the ED in PA projection of digital chest radiography in two major hospitals is higher than NDRL. The data available in this study cannot allow a judgment of the image quality. Further work is necessary to define appropriate procedures for optimization both in image quality and patient dose and adopting correction actions in digital radiology centers.

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