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# Radiation Doses in Diagnostic Radiology and Method for Dose Reduction

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## Abstract

**Objective:** The current research study aims to calculate entrance surface air kerma for skull, chest, cervical spine, lumbar spine, and pelvic X-ray examinations in interior posterior and posterior interior positions and generate a method for chest dose reduction to decrease radiation risk. **Materials and Methods:** The indirect dose measurement was used in the current research. The X-ray tube output was measured using RAD-CHECK Plus ionization chamber and the indirect entrance surface air kerma was calculated via applying physical acquisition parameters such as a focus on skin distance, tube current times exposure time (mAs), and applied tube voltage (kV), and applying a mathematical model. **Results:** The main findings were obtained from comparing the radiation doses with the reference levels of International organizations such as the American College of Radiology and the International Atomic Energy Authority. The mean entrance skin dose for the skull (AP), skull (PA), skull (LAT), cervical spine (PA), cervical spine (LAT), lumbar spine (AP), lumbar spine (LAT), pelvis (AP), and pelvis (LAT) of adult X-ray examinations was within the diagnostic reference dose level values obtained by ACR (2018) except for the ESD for chest (AP) which was 0.88 mGy. **Conclusions:** The results of the study concluded that by adjusting the applied tube voltage, kV, and tube current product time, mAs decreased the radiation dose to the chest X-ray by 58%.

## Keywords

Radiology, Entrance Skin Dose, Chest X-Ray, Dose Minimization

## 1. Introduction

Optimization of radiation dose delivered to patients is the main objective of radiation protection principles. The shortage in the entrance skin dose database and the probability of delivering an excess dose to patients lead to calculating the Entrance Skin Dose (ESD) for patients undergoing diagnostic X-ray examinations and optimizing the dose delivered to the chest. Studying some factors affecting on patient doses should be made as a means to ensure the accuracy of the operating physical parameters and minimize a dose to a certain organ. Ionizing radiation in the medical field contributes significantly to the source of exposure of the population [1]. Dose measurements are required to comply with some international guidelines and regulations. The need for radiation dose assessment of patients during diagnostic X-ray examinations has been highlighted by the increasing knowledge of the hazards of ionizing radiation. In today's diagnostic radiology, there is a growing concern about radiation exposure. This can be seen in the recommendations of the International Commission on Radiation Protection. The guiding principles for setting a Diagnostic Reference Level (DRL) are: 1) the regional, national, or local objective is clearly defined, including the degree of specification of clinical and technical conditions for the medical imaging task; 2) the selected value of the DRL is based on relevant regional, national, or local data; 3) the quantity used for the DRL can be obtained practically; 4) the quantity used for the DRL is a suitable measure of the relative change in patient tissue doses and, therefore, of the relative change in patient risk for the given medical imaging task; and 5) how the DRL is to be applied in practice is clearly illustrated. All these recommendations advise that X-ray examinations should be conducted using techniques that keep patients' doses as low as compatible with the medical purposes of the examinations [1]. The ESD is a measure of the radiation dose absorbed by the skin where the X-ray beam enters the patient. The application of radiation physics in medicine includes three medical practices: diagnostic X-ray, nuclear medicine, and radiotherapy. Diagnostic X-ray practice is one of the medical applications of radiation in medicine [2]. Ofori *et al.* (2014) calculated the mean ESD and effective dose of seven different examinations using Cal Dose software [3]. The results showed that the mean patient Entrance Surface Doses (ESDs) were 0.27 mGy, 0.43 mGy, 1.31 mGy, 1.05 mGy, 0.45 mGy, 2.10 mGy, 3.25 mGy and the mean effective doses were 0.02 mSv, 0.01 mSv, 0.09 mSv, 0.05 mSv, 0.03 mSv, 0.13 mSv, 0.41 mSv for thorax (PA), thorax/chest (RLAT), pelvis (AP), cervical spine (AP), cervical spine (LAT), thoracic spine (AP) and lumbar spine (AP) respectively. Mor *et al.* (2018) estimated doses for chest X-ray examinations for adult patients using the indirect method and compared them with the Diagnostic Reference Levels (DRLs) [4]. Abubaker *et al.* (2017) estimated the Entrance Surface Dose (ESD) for adult patients who underwent diagnosis via X-ray examinations in one of the radiographic centers in Sebha city. The ESD has been estimated indirectly using exposure factors for patents. The results showed that the mean patient Entrance Surface Doses (ESDs) were 41.73 ± 5.84 mGy, 7.43 ± 2.58 mGy, 103.7 ± 125.53 mGy, 7.25 ± 4.32 mGy and 11.24 ± 16.18 mGy respectively for pelvis (AP), chest (AP), lumbar spine (AP), cervical spine (AP) and skull (AP). In the present investigation, the authors conducted a study to assess the entrance skin dose for ten types of X-ray examinations: skull, chest (PA), chest (AP), skull and pelvic of patients (adult) Radiology Unit in the Nuclear Research Center (NRC) using the indirect method and created a new method for dose reduction [5]. Mohamadain *et al.* (2013) estimated the effective doses and body organ doses due to chest examinations in infants and pediatrics. Two examination incidences, AP and PA for chest X-ray exposures were evaluated and compared with respect to the radiographic technique employed [6]. Komarskiy *et al.* (2014) reduced Pulse X-ray diagnostics is capable of reducing radiation exposure considerably [7]. Njiki *et al.* (2019) investigated how accurate are TASMICS and TASMIP models in predicting the X-ray output of some Conventional Radiology X-ray Units with high-frequency generators [8]. Bope *et al.* (2022) studied the knowledge and practices of health professionals on the optimization of radiation protection in diagnostic radiology in children and adults in the general referral hospitals of Bukavu in South Kivu, DRC [9].

## 2. Materials and Methods

The current X-ray Toshiba model delta ray (E7239X) has the following features: Specially processed Rhenium-tungsten faced molybdenum target of 74 mm diameter. The tubes have foci 1.0 mm and 2.0 mm and are available for a maximum tube voltage of 125 kV with a single phase or three-phases accommodated with IEC 60526 type high voltage cable receptacles. Questionnaires were distributed to radiographers in charge of diagnostic facilities. Each radiographer was asked to provide information with respect to his X-ray Radiography Unit, including manufacturer, model, year of installation, physical half-value layer and X-ray exposure parameters such as kVp, mA, mAs, and Focus on Skin Distance (FSD). The ESD was assessed by the indirect method, using the data on the radiation output of the X-ray tubes and exposure factors (kVp and mAs). The detector was placed at a one-meter focus detector distance on the top of the table at 80 kVp setting. For minimizing the influence of the heel effect, the detector should be placed as close to the central axis as possible. The Focus Film Distance (FFD) and radiographic exposure factors (kVp and mAs) used for X-ray examinations were recorded on a self-designed questionnaire sheet. Datasheets were collected on a weekly basis, and the exposure factors recorded were cross-checked against actual practice with the radiographers who recorded exposure factors. The ESD was calculated in the present work via entering parameters which are focal to skin distance, FSD, mAs, and kV in mathematical Equation (1) used by Davies *et al.* (1997) [10].

$$\text{ESD} = \text{O/P} \times \left(\frac{100}{80}\right)^2 \times \left(\frac{100}{\text{FSD}}\right)^2 \times \text{mAs} \times \text{BSF} \tag{1}$$

where: O/P is the output in mGy/mAs of the X-ray tube at 80 KV at a distance 100 cm normalized to 10 mAs. BSF is backscatter factor for a particular examination at the required potential and was taken (IAEA, 2014) mAs. The Output was measured using RAD-CHECK Plus ionization chamber, Nuclear Associates Division of Victoreen, Inc., USA with serial number 103008 and model 06-526.

## 3. Results

Ten routine types of X-ray examinations were studied: skull (AP), skull (PA), skull (LAT), chest (PA), cervical spine (AP), cervical spine (LAT), lumbar spine (AP), lumbar spine (LAT), pelvis (AP) and pelvis (LAT). The X-ray tube potential (kVp) and tube loadings (mAs) selected for the adult patients focused on skin distance are presented in **Table 1**. The distributions of the mean values of ESD for patient exposures for individual patient's exposures for the ten projections are shown as in **Table 2**.

**Table 1.** Mean X-ray exposure parameters for each projection.

| Examination | Projection | kVp | mAs | Field Size, $cm^2$ | FSD, cm |
|---|---|---|---|---|---|
| Skull (AP) | PA | 59 | 20 | 24 × 30 | 85 |
| Skull (PA) | AP | 58 | 20 | 24 × 30 | 95 |
| Chest (PA) | AP | 62 | 20 | 24 × 30 | 80 |
| Chest (AP) | PA | 60 | 20 | 24 × 30 | 180 |
| Cervical Spine (AP) | AP | 61 | 10 | 24 × 30 | 85 |
| Cervical Spine (LAT) | LAT | 61 | 10 | 24 × 30 | 107 |
| Lumbar Spine (AP) | AP | 91 | 20 | 14 × 17 | 76 |
| Lumbar Spine (LAT) | LAT | 85 | 20 | 14 × 17 | 71 |
| Pelvis (AP) | AP | 74 | 10 | 14 × 17 | 74 |
| Pelvis (LAT) | LAT | 85 | 20 | 14 × 17 | 75 |

**Table 2.** The ESD (mGy) for adult patients and comparison with America College of Radiology, 2018 [11] (ACR, 2018), and International Atomic Energy Agency, 2001 [12] (IAEA, 2001).

| Protocol | Current Study | ACR, 2018 | IAEA, 2001 |
|---|---|---|---|
| Skull (AP) | 0.73 | | 5 |
| Skull (PA) | 0.75 | | 5 |
| Chest (PA) | 0.17 | 0.15 | 0.4 |
| Chest (AP) | 0.60 | 0.15 | 0.3 |
| Cervical Spine (AP) | 0.43 | | 5 |
| Cervical Spine LAT | 0.24 | | 10 |
| Lumbar Spine (AP) | 2.11 | 6 | 10 |
| Cervical Spine (LAT) | 2.56 | 15 | 10 |
| Pelvis (AP) | 1.50 | 3.4 | 10 |
| Pelvis (LAT) | 0.72 | 3.4 | 5 |

The mean entrance skin dose for the skull (AP), skull (PA), skull (LAT), cervical spine (PA), cervical spine (LAT), lumbar spine (AP), lumbar spine (LAT), pelvis (AP) and pelvis (LAT) of adult X-ray examinations were within the diagnostic reference dose level values obtained by ACR (2018). The good results given by Radiology Unit would be due to the regular monitoring that the radiology department receives except the ESD for chest (AP) which was 0.88 mGy that higher than the diagnostic reference levels.

**Dose minimization to chest AP (adult) compartment during X-ray imaging**

Dose reduction to chest X-ray examinations was carried out via increasing kVp by 15% and decreasing mAs by 50%. The indirect entrance skin dose is measured using the mathematical model as presented in Equation (1). The ESD for the chest X-ray examinations was reduced to 58% as shown in Table 3 and Figure 1. As the entrance skin dose to chest-AP decreases the effective dose the corresponding radiation risk will decrease too.

X-ray acquisition parameters for chest AP for adults were reviewed to optimize diagnostic reference dose levels. The mean dose reduction to the chest was 58% because of increasing high kVp by 15% and decreasing mAs by 50% without compromising the image quality. It is expected to enhance image quality with Digital Radiography (DR). Thus, the use of DR is associated with lower patient exposures because of very low imaging failure rates. The recommendation to avoid unnecessary radiation exposure is to apply the digital radiography to obtain image quality.

**Table 3.** ESD for chest and pelvic examinations before and after optimization.

| Examination | Before Optimization | | | After Optimization | | | Dose Reduction |
|---|---|---|---|---|---|---|---|
| | Group A | | | Group B | | | |
| | kV | mAs | ESD (mGy) | kV | mAs | ESD (mGy) | |
| Chest (AP) | 62 | 20 | 0.88 | 65 | 6 | 0.26 | 58 |

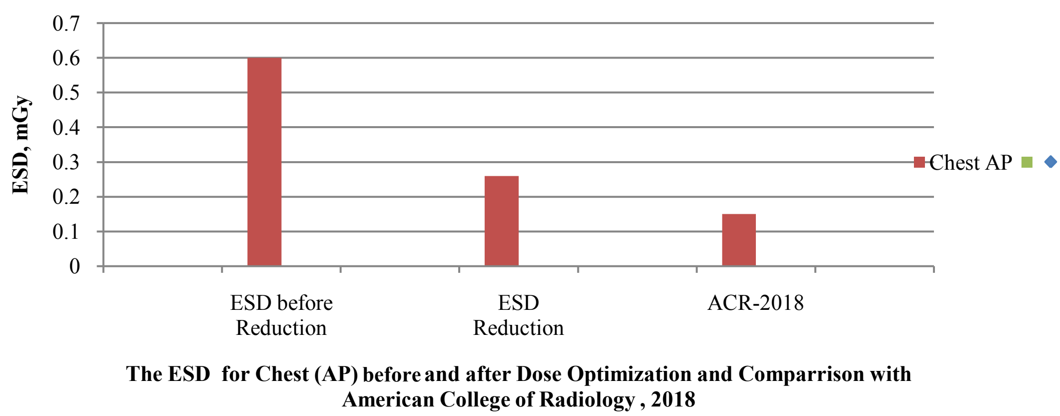


**Figure 1.** The ESD for chest (AP) before and after dose optimization.

## 4. Discussions

It can be seen in **Table 1** that the tube voltage used for different X-ray examinations varied with respect to the type of X-ray examination. The European Commission recommended the use of tube voltage values of 100 to 120 kVp for adults. In the current study, the tube voltage used for skull was 58 to 50 kVp and 20 mAs; for chest was ranged from 60 to 62 and 20 mAs; for cervical spine (AP) was 61 kVp and 10 mAs; for cervical spine (LAT) was 61 kVp and 10 mAs; for lumbar spine (AP) was 91 kVp and 20 mAs; for lumbar spine (LAT) was 85 kVp and 20 mAs; for pelvis (AP) was 74 kVp and 10 mAs and for pelvis ( LAT) was 85 kVp and 10 mAs [13]. Most X-ray conventional radiography was within the operating conditions of the kilo-voltage settings. The selected tube voltage for chest was lower than that reported by Akhdar (2007) by 62 kVp [14]. The tube loading (mAs) used in combination with tube voltage for different X-ray examinations are presented in **Table 1**. The range of mAs used for most X-ray examinations performed on patients was from 10 to 20 mAs. Generally, it can be observed that the exposure factors used for patients in the present study comprised of high voltage (58 to 85 kVp) and low mAs (10 to 20 mAs) similar to values reported by Akhdar (2007) [14] for all protocols and they were higher than value for chest AP protocol by 55 Kvp. In case of the current Pelvic-AP radiography imaging, 85 kVp is a fact so better use where photoelectric absorption is directly proportional with cube of atomic number and inversely proportional with triple of energy. Bones absorb more radiation because they contain a high amount of calcium [3]. As mentioned by many authors who stated that the absorbed dose in skin is directly proportional to tube current, the length of exposure time, and the square of peak kilovoltage [12] Cervical Spine. **Table 2** presents the mean entrance skin dose for the skull, cervical spine (AP/LAT), lumbar spine (AP/LAT) and pelvic (AP/LAT) of adult X-ray examinations were within the diagnostic reference dose level of IAEA (2001) and ACR (2018) except the ESD for chest which was 1.44 mGy (higher than the diagnostic reference levels). The ESD (mGy) for chest (PA) was higher than (ACR, 2018) by 13.33% and lower than that reported by the IAEA (2001) by 57.5%. The ESD (mGy) for chest (AP) was higher than ACR (2018) by 75% and higher than that reported by the IAEA, (2001) by 50%. Image quality is automatically controlled because the use of X-ray machine has an option of digital imaging and reduces the dose as a function of Automatic Exposure Control (AEC). It can be seen in **Table 2** that the ESD (mGy) for the AP skull was lower than reported by IAEA (2001) [12]. The ESD (mGy) for AP pelvic half that value recorded by the American College of Radiology, 2018 [11]. The measurement of the ESD for patients in the Radiology Department of the NRC was lower than the value of the international organizations except for chest (AP). It is expected to enhance image quality with digital radiography, and DR. Thus, the use of the DR is associated with lower patient exposures because of very low imaging failure rates. The recommendations to avoid unnecessary radiation exposure are could be implemented by applying digital radiography to obtain image quality.

## 5. Conclusion

The current research focuses on generating skin does baselines for diagnostic X-ray machines. The indirect entrance skin dose associated with X-ray examinations does not exceed that recommended by IAEA and ACR. The mentioned method for dose estimation can predict the ESD before X-ray imaging. The study concluded that by adjusting applied tube voltage, kV, and tube current product time, mAs the radiation doses to the chest X-ray was decreased by 58% and a high image quality could be obtained using digital radiography.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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