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PATIENT RADIATION DOSE FROM CHEST X-RAY EXAMINATIONS IN THE WEST BANK—PALESTINE

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Radiation doses to patients resulting from chest X-ray examinations were evaluated in four medical centers in the West Bank and East Jerusalem—Palestine. Absorbed organ and effective doses were calculated for a total of 428 adult male and female patients by using commercially available Monte Carlo based softwares; CALDOSE-X5 and PCXMC-2.0, and hermaphrodite mathematical adult phantoms. Patients were selected randomly from medical records in the time period from November 2014 to February 2015. A database of surveyed patients and exposure factors has been established and includes: patient's height, weight, age, gender, X-ray tube voltage, electric current (mAs), examination projection (anterior posterior (AP), posterior anterior (PA), lateral), X-ray tube filtration thickness in each X-ray equipment, anode angle, focus to skin distance and X-ray beam size. The average absorbed doses in the whole body from different projections were: 0.06, 0.07 and 0.11 mGy from AP, PA and lateral projections, respectively. The average effective dose for all surveyed patients was 0.14 mSv for all chest X-ray examinations and projections in the four investigated medical centers. The effect of projection geometry was also investigated. The average effective doses for AP, PA and lateral projections were 0.14, 0.07 and 0.22 mSv, respectively. The collective effective dose estimated for the exposed population was ~60 man-mSv.

INTRODUCTION

The need for using medical X-ray examinations is increasing around the world[(1)]. Medical applications of ionizing radiation are defined as the second source of exposure to man after the natural sources of radioactivity[(2)]. The exposure mainly comes from medical X-ray usage to patients in diagnosis and therapy. Researches on low radiation dose indicate that, there is an increase in the risk of stochastic detriment from diagnostic X-ray. Therefore, radiation dose to patient must be kept as low as reasonably achievable (ALARA)[(3)]. Many studies evaluated radiation doses from medical X-ray examinations and risk assessment from their collective doses. Organ dose, the absorbed amount of radiation in a radiosensitive organ is usually used for estimating radiation risks to the patients. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported an increase in the annual number of medical diagnostic examinations as well as the annual collective effective dose from diagnostic medical examinations[(4)]. Effective dose is a radiation protection quantity calculated with selected weighting factors to get a single number that represents the health detriment to the whole body. Effective dose has proved to be a useful tool in controlling exposures received by patients undergoing medical diagnostic and interventional procedures. However, its use to provide estimates of risk to individual patients goes beyond its intended use[(1, 5)]. Brenner[(6)] suggested that effective dose should be replaced by effective risk as a more scientifically based quantity.

X-ray imaging represents the main source of medical radiation exposure worldwide, and those examinations have high values in medical and diagnostic fields[(7)]. Low cost of using conventional X-ray imaging during the past century has made it a common daily diagnostic tool. However, it is important that radiation doses from X-ray examinations are being monitored, and kept at a minimum. Chest X-ray examination is considered as the most conventional diagnostic radiography examination because it has a high value for diagnosing a wide range of health issues. Although recent developments in cross sectional imaging of the thorax exist, particularly computed tomography, this examination provides very important information for diagnosis, treatment and follow-up procedures of many pulmonary diseases. Chest radiography has many advantages over cross sectional imaging, such as lower cost, lower dose, speed of acquisition and diagnosis[(8)]. Assessment and optimization of radiation doses received by patients are some of the most important tasks for radiation protection of patients in diagnostic radiology. Chest X-ray examination may also be implemented in screening programs for large populations, with a significant impact on the collective dose[(9)].

Palestine is a country that has shown an increase in the use of radiation in medical diagnosis. This increase is accompanied with a lack of information about the radiation dose received by patients. Moreover, there is a lack of quality control, which should be undertaken to get better diagnostic information with minimal X-ray exposure to patients. According to the Palestinian Medical Imaging Association (PMIA), in 2013, there were 176 hospitals and medical centers in the West Bank with X-ray Departments. About 134 plain X-ray and portable machines can be found in those hospitals and centers[(10)]. The total number of utilization of plain X-ray in governmental hospitals was about 803,913 images in the West Bank, which forms ~83.5% of all medical X-ray usage, and ~53% constitutes the total number of chest X-ray images[(11)]. Scientific studies on patients doses from X-ray examinations are in Palestine. Practical regulations lack clear instructions for radiation protection and safety guidelines. The knowledge of radiation protection is quite poor. Radiation protection and quality control programs are not available in many healthcare centers in the country. Estimating the organ and effective doses is a solution to get a view of medical radiation exposure to patients. In routine radiological procedures, it is not practical to conduct *in vivo* measurements of organ doses. The possible practical methods for deriving the organ doses are measurements in a phantom, i.e. an artificial object representing a patient, or computer calculations. An important method applicable to a wide range of applications is Monte Carlo (MC) simulation, MC uses phantoms, which are defined as artificial objects, representing a patient or computer calculations[(12, 13)]. As stated above, effective dose should not be used to assess risks to individual patients of specific age, sex and nationality, an application for which it was not intended. It can, however, be a valuable tool for comparing the doses (and risks of aggregated detriment) to a reference person (of 'average' age, gender and nationality) from different medical diagnostic procedures and from other sources of radiation exposure[(14)]. The aim of this work is to evaluate the organ doses and effective doses for patients undergoing chest X-ray radiography in different projections.

MATERIALS AND METHODS

Data concerning a total of 428 male and female adult patients undergoing chest X-ray examination in different projections were collected from four medical centers between November 2014 and February 2015. Investigated medical centers utilize plain X-ray radiographic systems as well as portable, while one center uses computed radiography (CR). Radiographic systems used in the four medical centers and exposure factors for all projection geometries are summarized in Table 1.

Evaluation of organ absorbed doses and effective doses was performed theoretically using two commercially available softwares based on MC simulations: CALDose_X (Calculation of dose for X-ray diagnosis) is a software tool that provides the possibility to calculate incident air Kerma (INAK) and entrance surface air Kerma (ESAK), two important quantities used in X-ray diagnosis, based on the output of the X-ray equipment[(15)]. The second used software is PCXMC, which is a code for calculating patient doses in diagnostic radiology developed at the Medical Radiation Laboratory of the Finnish Radiation and Nuclear Safety Authority. The first version PCXMC (PC program for X-ray Monte Carlo) was released in 1997 for calculating patient organ dose and estimating effective dose in medical diagnostic X-ray examinations. It allows a free adjustment between the X-ray projections from many X-ray examination types.

The phantoms used in PCXMC are computational hermaphrodite phantoms representing human beings of various ages: new-born, 1, 5, 10, 15 years old and adult patients. The phantoms include expressions describing various organs and body parts. These phantoms have been specified by Cristy and Eckerman (1987) with

Table 1. Exposure factors in the four selected medical centers H1, H2, H3 and H4.

Medical center	H1			H2			H3	H4	
Radiographic system	Plain X-ray			Plain X-ray			Plain X-ray	Computed radiography	
Exposure factors	AP portable	PA	LAT	AP portable	PA	LAT	PA	PA	LAT
kVp (KeV)	50–75	100–120	105–125	62–74	75–95	88–105	70–95	109–133	120–133
mAs	5–15	1–4	4–12	5–8	5–6	16–25	10–25	3–9.5	4–14
FID (cm)	100	180	180	100	180	100	180	180	180

FID: focus image distance, CR: computed radiography, AP: anterioposterior projection, PA: posterioanterior projection, LAT: lateral projection, mAs: milliamperage second, kVp: kilovoltage peak, AP portable: anterioposterior projection in portable radiography.

further modifications; (modification of the head, correction of some apparent errors in the data of Cristy and Eckerman and inclusion of some new organs: extrathoracic airways, oral mucosa, prostate and salivary glands). These modifications of the phantom enable the calculation of the effective dose using the tissue weighting factors introduced in ICRP Publication 103 (2007). Also, the program has organized doses for patients with different ages and sizes and for different projections. In the calculation, the user can specify whether the arms of the phantom are included at the sides of the trunk or whether they are removed (which may simulate the real situation better, e.g. for lateral projections). Trunk width is given for both of these conditions[16, 17].

Initially, for effective dose calculations, the Entrance Skin Air Kerma (ESAK) and the Incident Air Kerma INAK have to be estimated from the X-ray tube output parameters. Personal data and X-ray tube exposure parameters were recorded for all patients. These factors are: kVp, mAs, the FFD, patient age and gender. The ESAK and INAK values were estimated from the X-ray tube geometry parameters by using (CALDose_X) software, while PCXMC was used to calculate organ and effective doses. PCXMC software calculates the effective dose using tissue weighting factors of ICRP 103 and ICRP 60, and gives the average absorbed doses in the whole body.

RESULTS AND DISCUSSION

The absorbed organ doses were calculated for 29 body organs for every patient. The average organ doses were evaluated from all patients in anterior posterior anterior (AP), posterior anterior (PA) and lateral projections. PA and lateral projections in chest radiography account for more than 75%, of chest X-ray examinations. In case of incapacitated patients, AP projection was performed by portable X-ray machine. Calculations of organ and effective doses were conducted while a patient is positioned with arms in PA and AP projections and without arms in lateral projections. The highest average organ dose was 0.56 mGy and received by breasts in LAT projection. Breasts received also the highest dose in AP projection, ~0.56 mGy. While the highest average dose in PA projection was found for lungs, ~0.23 mGy. Relatively high doses were received by spleen in both PA and LAT projections, while heart receives high doses in AP and LAT projections. Skeleton is exposed approximately to the same radiation dose in the all three projections. The organs exposed to the lower doses in all projections of chest X-ray were brain, testicles, urinary bladder and uterus. Figure 1 presents the average organ doses for all surveyed patients.

The average effective dose was also calculated for all routine projections of chest radiography in the participating medical centers. Figure 2 shows the average effective doses evaluated for all patients. Table 2 presents the average absorbed doses, effective doses and ESAK, calculated for different projections for a number of patients from medical center H1.

Higher average ESAK in lateral projection compared to PA projection means high amount of

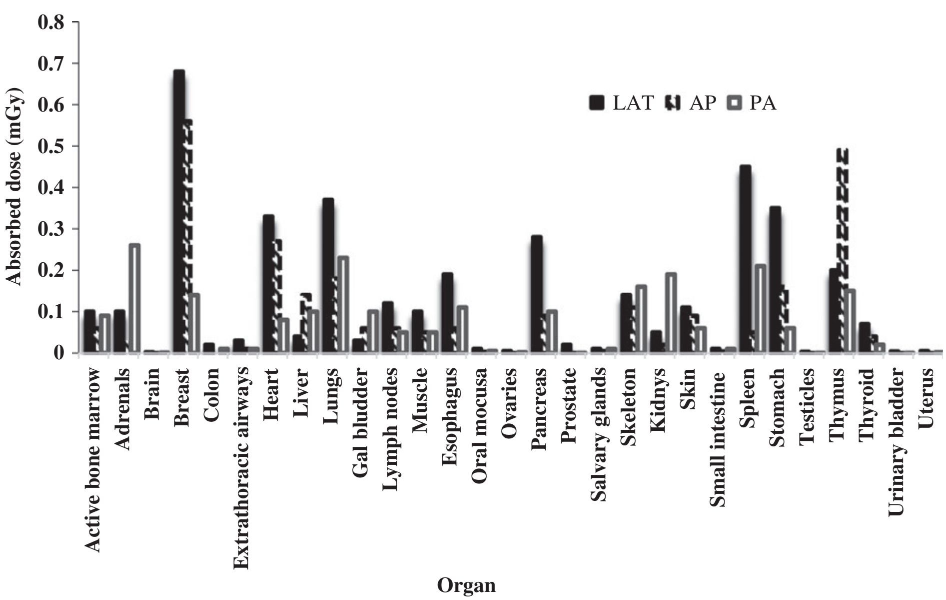

Figure 1. Average absorbed organ doses for all patients from chest X-ray in AP, PA and LAT projections.

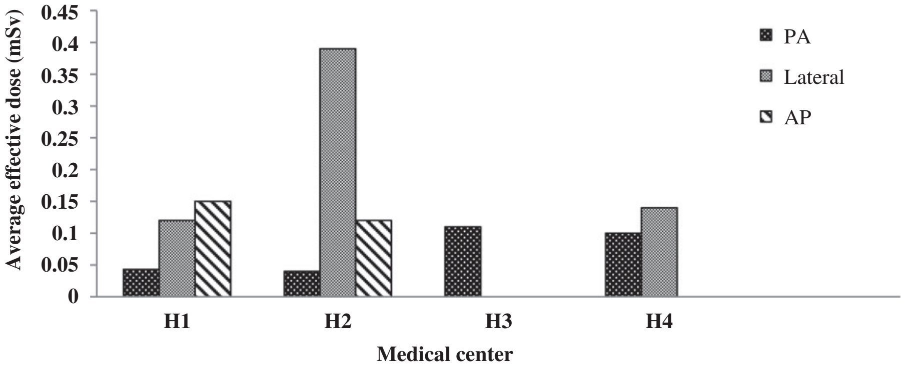

Figure 2. Average effective doses evaluated for patients from all medical centers.

Table 2. Average absorbed dose, effective dose and ESAK evaluated for 267 patients from medical center H1.

Dose	Projection		
	AP	PA	LAT
Average effective dose ICRP 103 (mSv)	0.15	0.04	0.12
Average effective dose ICRP 60 (mSv)	0.10	0.04	0.10
Average absorbed dose in the whole body (mGy)	0.07	0.04	0.07
Average ESAK (mGy)	1.16	0.28	1.08

backscatter radiation because the thickness of patient increases laterally. ESAK includes the backscattered radiation from the patient. However, the higher value of ESAK in AP projection is due to the use of portable radiographic system in which higher mAs and lower source to image distances (SID) are applied (the SID in portable radiography is ~100 cm, while in fixed installations is ~180 cm). Low doses in PA projection are because of the application of low mAs (tube current-exposure time product values range from 1 to 4 mAs, kVp range is 100–120 kV). PA projection is routinely used in chest radiography due to lower body thickness and it is also a better projection for radiation protection of the breast and thyroid. Calculations of effective dose based on ICRP 103 weighting factors in the case of chest X-ray provide slightly higher values than that based on ICRP 60. This is due to the differences in weighing factors. While the ICRP 60 recommend a weighing factor of 0.05 for the breast, which is an important organ in chest X-ray imaging, the ICRP 103 recommends 0.12, also in the ICRP 60 the recommended weighing factor for the reminders is 0.05, while its 0.12 in the ICRP 103. Results of effective dose calculations for all medical centers and projections are shown in Figure 2.

Lateral projections resulted in the highest radiation doses at all investigated medical centers, even while using CR. Exposure factors in LAT projection are higher than in PA and AP procedures. In LAT projection, the value of mAs is three to four times higher than mAs for AP and PA projections, depending on patient's size.

The highest value of effective dose (0.39 mSv) was found in medical center H2, where a short FID was applied (100 cm instead of 180 cm). The reason is not clear why this short FID was applied. Probably, it was a mistake provided by the radiation technologist. PA projection in CR resulted in higher or equal doses than plain X-ray in other medical centers. In this case, both mAs and kVp in CR PA projection are higher than those in plain radiography. Portable radiography in general, provides higher doses to the patients because of higher mAs values and shorter FID. However, all evaluated effective dose values in this work are comparable with results published in other countries. The effective dose from chest radiography was estimated in many regions of the world. Those doses can vary between different countries depending on the processing techniques, technical exposure factors, patient's geometry and biological features. Table 3 presents a comparison between effective dose values obtained in this study and those reported from different countries[18–23].

In general, the average annual effective dose to population from diagnostic medical X-ray examinations

Table 3. Comparison of effective doses from chest X-ray in different countries.

Country	Effective dose (mSv)				
	LAT	AP	PA	Range	Average
UK	0.04	0.02	N.A.	N.A.	N.A.
USA	0.04	N.A.	0.02	N.A.	0.1
Ireland	1.5	N.A.	0.3	N.A.	N.A.
Canada	N.A.	N.A.	N.A.	0.0012–0.33	0.06
EU	N.A.	N.A.	N.A.	0.01–0.26	0.10
This study	0.22	0.14	0.07	0.03–0.39	0.14

N.A: not available.

varies from <0.02 to 1.2 mSv depending on health care level. Worldwide average annual effective dose is 0.4 mSv[24]. The collective effective dose was estimated by multiplying the total number of patients and the average effective dose from all chest X-ray projections and found to be ~60 man-mSv.

CONCLUSION

Results obtained in this work are comparable with the results published from different countries. The average effective dose evaluated in this study is very close to those received by the European population. Many of the Palestinian medical centers dealing with medical applications of radiation does not have clear policies and strategies for radiation protection practices nor quality control programs. Furthermore, diagnostic reference levels do not exist in the country. Variation of organ and effective doses evaluated in this study suggested that there is a space for standardization of the radiological techniques and for optimizing radiographic procedures to reduce patient dose. We believe that this work will contribute to the establishment of a national radiation protection program with clear strategy and vision for minimizing the radiation doses received by the population from medical uses of radiation.

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