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Estimation of the Effective Dose for Patients Undergoing PA Chest X-Ray Examination in Selected Hospitals of Al Najaf Governorate-Iraq

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Abstract

The effective dose (ED) was estimated for 90 patients (male and female) undergoing PA chest radiography using CALDose-X.5 Monte Carlo software. The ED calculations were based on the measurements of X-ray tube output and from the knowledge of exposure factors. The X-ray output was measured using Rad-Check ionization chamber for each X-ray tube. In total, seven X-ray tubes were used to estimate the patients' ED. Exposure factors (e.g. tube potential (kVp), tube loading (mAs) and X-ray source to image detector distance-SID (cm)) were recorded for each patient together with patient demographic data (weight(kg) and height(m)). Five main hospitals were considered in this research. The average ED for PA chest X-ray examination was ranged from 0.012±0.010 mSv to 0.13±0.0.029 mSv; across all hospitals. The overall average of the ED of all X-ray units is 0.053 mSv. The corresponding (kVp) set for PA chest X-ray was ranged from 69.13±3.61 to 100.23±8.98 kVp; (mAs) ranged from 2.24±1.25 to 35.33±2.21 mAs and for the SID, the range was between 100±0 and 202.30± 4.21. According to the resulted data, a clear variation in the ED together with the corresponding exposure factors was seen. The values of the ED were seen to be high when compared with the UK values (i.e. PA chest: 0.02 mSv); and were comparable to those reported by some developing countries (e.g. Nigeria, Iran and Palestine).

Keywords: Effective dose; Chest X-ray; Patient dosimetry; Radiation safety; Radiation protection.

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Introduction

The demand for utilizing medical X-ray examinations becomes increasingly high worldwide. Using ionizing radiation for diagnostic purposes has been ranked as the second main source of human exposure after the natural sources of radioactivity [1].

In this context, a marked increase in the number of X-ray examinations performed has been reported all over the world. This fact is specifically true especially when considering the huge increase in the number of digital X-ray systems that recently used. In Iraq and specifically in Al Najaf governorate, the film-screen system has been replaced by digital X-ray systems [2].

In the UK, using the X-ray for medical diagnosis is reported to constitute an about 90% of people exposed to ionizing radiation when compared with other man-made sources of radiation [3]. In this regard, despite the fact that using the X-ray has improved the diagnostic capabilities of medical professionals, but its use in medicine can increase the probability of cancer incidence [4]. For this reason, the International Commission on Radiation Protection (ICRP) organization has recommended that the radiation dose received by patients should be justified and followed the ALARA principles. The ALARA imposes that patient dose should be kept as low as reasonably achievable. Therefore, protecting patients from unnecessary radiation is highly imperative [1].

Following the international standards and regulations in diagnostic radiology necessitate that patient dose should be assessed and monitored regularly. The reason for this is to make sure radiation dose is within the recommended levels set by international organizations/bodies (e.g. ICRP, IAEA and NCRP) [5]. Additionally, the surveillance of the radiation dose is a key for attaining the assurance programs in every X-ray center [6]. In diagnostic radiography there are different X-ray examinations that can be conducted for patients with different clinical situations. These examinations, in fact, are imposing a variety of radiation dose and therefore variable risks. In the last two decades, there are dose surveys which have been conducted to assess patient doses across many countries worldwide [3,7,8].

It is well recognized that some of the X-ray examination that are conducted more frequently than other. For example, chest X-ray examination is considered to be the most conventional diagnostic X-ray radiography because it can assist in diagnosing of a wide range of health issues. The chest radiography is characterized by having many advantages over cross sectional imaging techniques. This includes its lower cost, lower dose, speed of acquisition and diagnosis [9]. The chest X-ray examination can be utilized in screening programs for large

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populations, taking into account the significant effect on the overall collective dose [10].

Finally, it has been estimated that chest radiography is accounted for approximately 30 to 40% of all X-ray examinations performed, irrespective of the level of health-care delivery [11]. Patient dose during chest X-ray examination has been considered by many researchers in many countries (i.e. developed and developing) [5,12-18].

In this work, an attempt was conducted to assess the effective dose that patients received when examined for PA chest X-ray in selected hospitals of Al Najaf governorate, Iraq.

Materials and Methods

This work was conducted in the main hospitals of Al Najaf governorate, Iraq; these include Al Sadder teaching hospital (ASTH), Al Hakeem general hospital (AHGH), Al Manzrah Hospitals (AMH), Al Furat Al Ausit hospital (AFAH) and Middle Euphrates cancer center (MECC). These hospitals were selected since they are the largest hospitals in term of work load. Seven X-ray units were included in this study. Prior to starting the work, an ethical approval was obtained from Al Najaf Health Administration of Al Najaf governorate. The work began with recording information on the X-ray units. This includes the manufacturer of X-ray tube, model, year of installation and the type of the X-ray system (i.e. computed or digital radiography-CR/DR). These data are listed in the below table (Table 1).

Table 1: X-ray systems information considered in this work.

Hospital	Manufacturer	Model	Year of installation	System types (DR/CR)
ASTH (1)*	Toshiba/Japan	E7254FX	2017	DR
ASTH (2)**	Shimadzu/Japan	R-20J	2006	CR
AHGH (1)	Toshiba/Japan	E7254FX	2017	DR
AHGH (2)	Shimadzu/Japan	R-20J	2006	CR
AFAH	Shimadzu/ Japan	R-20J	2005	CR
AMH	Toshiba/ Japan	E7254FX	2017	DR
MECC	Shimadzu/Japan	R-20J	2016	CR
Note: * and ** Refer to the room numbers in a given hospital				

After that, demographic data on each patient were collected. This data includes patients' weight (kg), height (cm) and gender (male/female). The latter data were used to calculate the body mass index (BMI = kg/cm^2) for each patient. Ten patents as a minimum number (≥18 years) was considered [19]. As a result, 90 patients in total of both male and female were recorded.

In order for the effective dose to be estimated, exposure factors (physical parameters) were recorded for all patients undergoing PA chest radiography. These include kVp (tube voltage), mAs (milliamper. second) and X-ray source to image detector distance-SID (cm).

The effective dose was calculated using windows based computer program called CALDose_X 5.0. It has been developed by Kramer et al. The CALDose_X 5.0 is a tool that enables the researcher to calculate Incident Air Kerma (INAK) and Entrance Surface Air Kerma (ESAK), two keys quantities used in diagnostic X-ray. This software provides the possibility to assess human body tissues and organs doses and the effective dose for different radiographic examinations [20]. The above measurable quantities of this software, have been calculated using the FAX06 and the MAX06 phantoms and for thirty four X-ray projections of ten frequently and commonly conducted X-ray examinations.

This software provides a combination of 40 kVp (50 to 120 kVp) and filtration range (2.0 to 5.0 mm Al) together with various focuses to detector distance (FDD) [20]. Based on the exposure factors that set by the user, the software demonstrates images of the phantom as well as the position of the X-ray beam (Figure 1) [21].

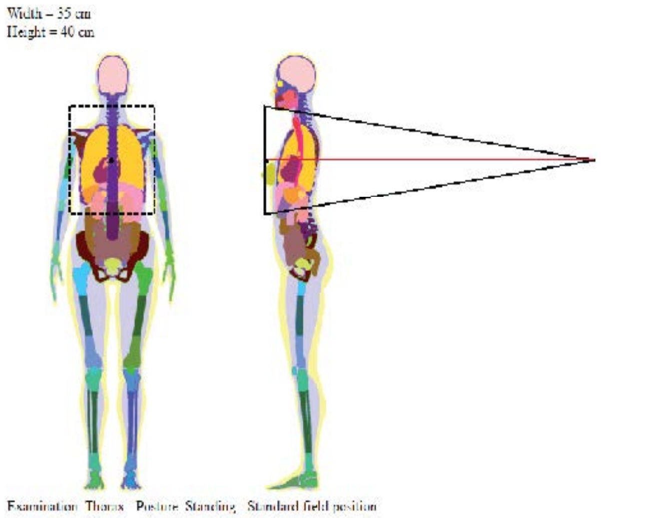

Figure 1: This image represents the CAL Dose software modeling of the PA chest X-ray examination.

To run the software, it is necessary to provide it with the output in mGy/mAs, of all X-rays units used in the estimation of effective doses. For the effective to be calculated, the software provides calculated weighted MAX06 and FAX06 whole body absorbed doses separately. The latter represent the sex specific contributions to the effective dose [1]. Once the doses of the each of the organs and tissues are defined, the effective dose can be calculated using equation 1.

$$E = \sum_T wT \sum_R wR.DT,R \text{ , } E = \sum_T wT.HT \quad (1)$$

Where HT or wR DT, R is the equivalent dose in a tissue or organ, T, and wT is the tissue weighting factor. The effective dose is measured with the same unit used for absorbed dose, J kg^{-1}, and its common and specific name is Sievert (Sv). Based on CALDose_X 5, the ED can then be calculated from averaging the sex-specific weighted doses using the following equation 2 [22].

$$E = \sum \frac{WT[H(female)+H(male)]}{2} \quad (2)$$

The output (R/mAs) of the X-ray tube was measured using Rad-Check Plus model 06-526 X-ray ionization chamber (Nuclear Associates, Victoreen Division, NY, USA) at 80 kVp, 10 mAs and 100 cm distance from tube focus (see figure 2). Three measurements were taken for each kVp setting to allow the calculation of average value, and to reduce random error. A 8.7 mGy/R conversion factor was applied to convert the output from R (Roentgen) to mGy in air (i.e. 1 R = 8.7 mGy) [23].

Results and Discussion

A total number of 90 patients, who examined for PA chest X-ray, were recorded in this study. Patient demographic data are presented in table (Table 2). From this table, it can be seen that the average patients' weight (kg) is ranged from 73 to 80 for seven X-ray units. Regarding patients' height, it is clear that it is almost comparable at an average of about 1.67 m for 6 X-ray units except one unit where the height is 1.70 m at AHGH.

The BMI for all patients of this study is seen to have a range of (25 to

Table 2: This table presents the information of the patients examined for PA chest X-ray examinations in this research.

Hospital Code	Patients demographic data		
	Weight (kg) Average (SD)	Height (m) Average (SD)	BMI (kg/m²) Average (SD)
ASTH (1)*	77.46 (10.2)	1.66 (7.4)	28.03 (4.1)
ASTH (2)**	76.83 (8.6)	1.68 (5.2)	27.08 (2.6)
AHGH (1)	80.38 (10.5)	1.65 (5.8)	29.3 (4.2)
AHGH (2)	73.53 (7.4)	1.70 (5.3)	25.44 (2.8)
AFAH	70.84 (8.9)	1.64 (8.6)	26.24 (2.8)
AMH	76.92 (10.4)	1.66 (2.5)	27.6 (3.4)
MECC	78.54 (11.55)	1.64 (7.1)	29.03 (5.1)

Note: * and ** represent the number of the room in a given hospital

29 kg/m²) which would reflect the required relative homogeneity of the taken sample when considering the weight and length. Nevertheless, the variation in each of weight (kg) and height (m) is expected when considering the natural variability of the population of the current country and the governorate in specific.

By contrast, the average weight (kg) of sample that has been considered in the UK was around 70 kg. This would reflects the cultural variability of different population [2,20]. The tube outputs as normalized to 10 mAs of the seven X-ray units are presented in table (Table 3), where it can be noticed that the highest tube output was reported at ASTH room (2) at 0.067 mGy/mAs while the lowest value was 0.037 mGy/mAs that recorded at AMH.

Table 3: Lists the X-ray tube output factors measured at the seven X-ray units of the five hospital.

Hospital code	X-ray tube output (mGy/mAs)
ASTH (1)*	0.044
ASTH (2)**	0.067
AHGH (1)	0.044
AHGH (2)	0.049
AFAH	0.060
AMH	0.037
MECC	0.047

Note: * and ** represent the number of the room in a given hospital

The exposure factors which were applied to patients undergoing PA chest X-ray examinations can be seen in table (Table 4). It is clear that that the minimum average kVp used was at AHGH (2) with 69.13 kVp, whereas the highest average value was reported in AMH at 100.23 kVp. It should be noted that the range of kVp reported in this study is almost comparable to those reported by UK survey [3] and previous literature [12-18]. The minimum and the maximum average tube loadings (mAs) which were set for PA chest X-ray are 2.24 and 35.33 mAs, respectively (Table 4). By way of comparison, The reported average values of the mAs can be considered as slightly lower than those set in literature and international survey [3,12,14 and 15] except the mAs values set at AHGH where it can be classified as comparable to those high mAs (e.g. 35 mAs) that reported in above mentioned reports. The minimum average SID set for PA chest radiography in this study was 100 cm while the maximum SID was 202 cm. When taking the European guidelines into account the recommended distance for PA chest X-ray is almost 180 cm, 5 X-ray units out of 7 were set SID value lower than 180 cm [19]. So, this means that the X-ray intensity will be high as it inversely related to the square of the distance between the X-ray source and patient surface [24]. Thus, the values of the SID used PA chest X-ray are almost lower than the recommended level which may result in an increase in the patient dose.

Table 4: This table presents the average, minimum and the maximum values of the exposures factors (kVp, mAs and SID) applied for PA chest X-ray projection across the studied hospitals.

Hospital code	Tube potential (kVp)	Tube loading (mAs)	SID (cm)
ASTH (1)*	87.69 (70-110)	2.24 (1.6-6)	138.07 (110-145)
ASTH (2)**	84.08 (78-88)	14.85 (11.2-16)	100(100-100)
AHGH (1)	98.07 (70-110)	7.25 (2.4-17.9)	189.23 (185-190)
AHGH (2)	69.13 (63-76)	35.33 (30-40)	125.33 (110-135)
AFAH	69.38 (53-82)	9.66 (8-12.6)	100 (100-100)
AMH	100.23 (89-110)	5.62 (2.5-8)	202.30 (200-210)
MECC	85.90 (60-95)	9.09 (7.2-11.2)	123.18 (100-135)

Note: * and ** represent the number of the room in a given hospital

The patient ED that estimated for the patient's undergone PA chest X-ray radiography is presented in table (Table 5). According to this table, it can be seen that minimum ED value was reported at AHGH room (1) with a value of 0.004 mSv, whereas the maximum ED value was reported at ASTH (2) with 0.1665 mSv. The average value of the ED for PA chest radiography across the seven units was from 0.012 mSv to 0.134 mSv. Examining the data on the estimated ED reveals that there is a clear variability whether among different hospitals or even among different units of the same hospital as evidenced by the SD range (i.e. 0.007-0.029). Another evidence for the dose variability can be noticed via the data of the ratio of the maximum to minimum of the ED (Table 5). To illustrate, the ratio of max/min of the ED demonstrates that max value is around 25 times higher than that of the minimum at AHGH (1), while the lowest ratio is in AHGH (2) at 2.09 times.

Comparing the obtained results of the current study with those published internationally demonstrate that the average ED values for five out of seven X-ray units were higher than that reported for PA chest in UK survey [12], published report [25], Malaysia and Sudan (Figure 2). The reason for this could attribute to the adopted exposure factors with PA chest X-ray. To illustrate, the set SID with the majority of the X-ray units was clearly lower than the recommended SID (i.e. 180 cm) for PA chest X-ray. This would contribute to increasing the ED of the examined patients taking into account the inverse square law [24].

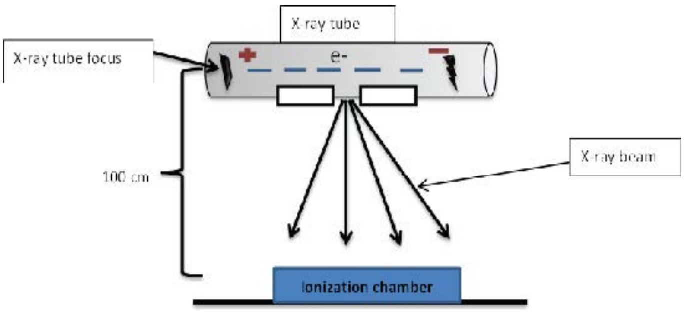

Figure 2: A schematic diagram illustrates the procedure of measuring X-ray output.

Nevertheless, the current study results were also found to be highly lower than that reported by Yacoob HY, et al. (2017) [13]. This is because, when examining Yacoob HY, et al. (2017) [13], it was found that mAs values used were high (e.g. 22 mAs) compared with mAs reported by the current study together with low SID the authors mentioned. Furthermore, comparing the current results with that of Nigeria [14] and Palestine [15] demonstrates that their results were slightly higher that reflects that the used exposure factors were almost comparable together with similar tube outputs.

Table 5: This table presents, minimum, maximum, average and the standard deviation (SD) of the ED (mSv) for patients undergoing PA chest X-ray examination across the studied hospitals.

Hospital Code	Patient number	Minimum	Maximum	Average	±SD	Median	Max/Min
ASTH (1)*	13	0.004	0.0425	0.012	0.010	0.0095	12.14
ASTH (2)**	12	0.076	0.1665	0.134	0.029	0.1262	2.17
AHGH (1)	13	0.004	0.100	0.030	0.023	0.0295	25
AHGH (2)	15	0.075	0.156	0.099	0.027	0.092	2.093
AFAH	13	0.021	0.0825	0.043	0.018	0.0525	4.024
AMH	13	0.011	0.035	0.018	0.007	0.014	3.181
MECC	11	0.024	0.138	0.059	0.024	0.0535	5.75

Note: * and ** represent the number of the room in a given hospital; SD represents standard deviation.

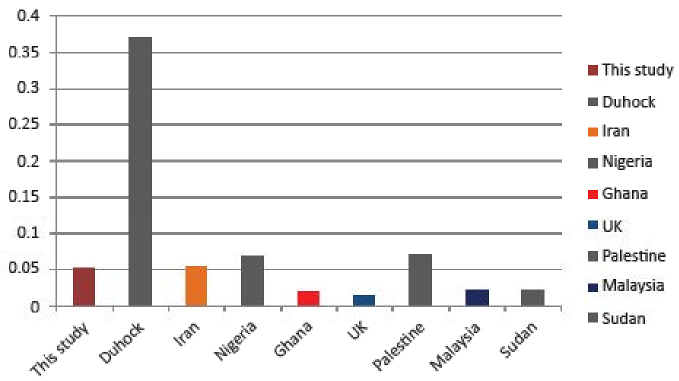

Figure 3: Comparison of the overall average ED reported for the seven X-ray units with those doses published by internationally for PA chest X-ray.

As it was mentioned earlier, a huge increase in the number of X-ray examinations that are conducting throughout the world. Perhaps, this due to the rapid improvement in the technology of medical imaging. Nevertheless, in developing countries, the utilization of this technology without a good training might lead to produce good quality image but on the expense of patient dose. Previous studies on this case had proven that patient dose is increasing throughout time without the awareness of radiologic operators. This case is what well known by 'dose creep' [26]. Further to this, the noted wide differences in the patient doses among hospitals and even among X-ray units of the same hospital is an issue that needs to be studied [19]. In this context, the variability in the patients doses should be reduced to the its lowest level aiming to achieve the quality assurance goals in the diagnostic radiology departments. One approach of achieving these goals is by periodically evaluating the radiation dose and then to find out the way of keeping it as low as reasonably possible [27]. In practice, there are many factors behind the noted variations. To illustrate, namely setting different tube potential and tube current with different X-ray units for the same X-ray examination would yield variable patient dose [28]. Different operators of different experience can lead to variable radiographic practice. Finally, patients' body habitus and their clinical situations may also impose some limitations that reflect on the patient radiation dose consistency across different X-ray units [29].

The high doses which were noted in this study can be attributed to a number of reasons. These could be related to the performance of the X-ray equipment. To illustrate, the efficiency of the equipment when considering the output, kVp and exposure time consistency [23]. The latter factors are supposed to be monitored regularly via conducting a periodic quality control checking. In this regards, training courses should be implemented among the operators/radiographers to upgrade their information regarding using the new technology and how they can manage to reduce patients dose while maintain the quality of the images.

A limitation that was identified in this work is the ranges of some of the exposure factors set in the software which in practice may go either beyond or before that set by developers.

Conclusion

The EDs were calculated for the patients undergoing PA chest X-ray examination at Al Najaf Al Ashraf main hospitals. According to the resulted data, the average EDs values were higher than those reported in UK survey, Ghana, Sudan and Malaysia and were comparable to some of the developing countries (e.g. Iran and Nigeria). A marked variation in the exposure factors used was identified. The results of this work can be used as a baseline for future dose estimation. Finally, conducting a quality control investigation together with conducting a training course is highly recommended.

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