Pertanika J. Sci. & Technol. 30 (4): 2509 - 2520 (2022)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Organ Dose and Radiation Exposure Risk: A Study Comparing Radiation Dose Using Two Software Packages

Abdullah Ali M Asiri

Department of Radiological Sciences, College of Applied Medical Sciences, Najran University, Najran, Saudi Arabia

ABSTRACT

With the rapid development of X-ray equipment, assessing the patient's radiation dose has become an important issue. This study uses DoseCal and PCXMC software to estimate the effective dose (ED) for 510 adult patients undergoing abdomen anteroposterior (AP) and chest anteroposterior/posteroanterior (AP/PA) X-ray examinations in Najran, Saudi Arabia. This study reported our experience with DoseCal and PCXMC software in calculating the ED and organ doses in abdomen and chest X-ray diagnostics. The mean ED values calculated using DoseCal were 0.051, 0.115, and 0.045 mSv for Abdomen AP, chest AP, and PA, respectively. Further, the mean ED calculated using PCXMC is 0.062, 0.132, and 0.047 mSv for Abdomen AP, chest AP, and PA, respectively. The dose results calculated by PCXMC were higher than DoseCal; however, we strongly recommended the dose surveyors utilize PCXMC because it uses the most recent tissue weighting factors (WTs) and offers a risk calculation.

Keywords: Abdomen, chest, DoseCal, effective dose, PCXMC

INTRODUCTION

Individuals are exposed to radiation from various sources, mostly natural and some that are artificial. These sources may include nuclear power plants and diagnostic or therapeutic medical applications. Radiography equipment is one of the human-made sources. As the number of diagnostic radiography applications grows, the health risks increase, and it becomes necessary to know the accurate doses received by patients undergoing such examinations.

The radiation dose that the patient absorbs during X-ray examinations is commonly evaluated using entrance skin

ARTICLE INFO

Article history:
Received: 21 September 2021
Accepted: 07 March 2022
Published: 15 September 2022

DOI: https://doi.org/10.47836/pjst.30.4.12

E-mail address:
aaalasmy@nu.edu.sa

ISSN: 0128-7680
e-ISSN: 2231-8526

dose (ESD) or effective dose (ED). An indirect method via X-ray output factors can be used to calculate the patient doses. Most dose surveyors have used software to perform the computational process. This software has become an important tool for reducing direct or in-vivo measurements for patients undergoing X-ray examinations. The radiation doses computed using these computer software packages may differ for the same patient model. Comparing estimated dose values to reference dose levels can help with dose optimization and dose audit in diagnostic protocols. Several publications have reported wide variations in patient doses arising from specific X-ray examinations at different places (Abdelhalim, 2010; Alsayyari et al., 2017; Mettler et al., 2008; Saeed, 2017; Osei & Darko, 2013; Osman et al., 2013; Rubai et al., 2018; Taha et al., 2016). The wide variations in patient dose in most of these studies may be attributed to the clinical condition, examination technique, radiographer skill, peak tube voltage (kVp), exposure current-time product (mAs), and focus-to-skin distance (FSD).

In Saudi Arabia, studies on radiation dose in routine X-ray examinations are scanty; therefore, in the present research, the authors were interested in evaluating the ED, comparing it with others, and obtaining risk factors that will be particularly useful for clinicians. This study uses DoseCal and PCXMC software to evaluate the EDs in different organs for abdomen anteroposterior (AP) and chest anteroposterior/posteroanterior (AP/PA) X-ray examinations in Najran University Hospital (NUH), Najran, Saudi Arabia. The additional aims include comparing the two software and estimating the radiogenic risk to patients during the abdomen and chest examinations. DoseCal software was produced by the Radiological Protection Centre of Saint George's Hospital, London. In contrast, PCXMC is a Monte Carlo tool kit developed by Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland.

In 1998, the program PCXMC was published by Servomaa and Tapiovaara (1998) and later was distributed from the STUK website. PCXMC performs Monte Carlo calculation according to the exposure parameters defined by the user using the hermaphrodite phantom models of Cristy and Eckerman (1987). This phantom family describes adult and pediatric patients and includes several pediatric ages such as newborns, 1, 5, 10, and 15-year-old. In addition, this software calculates the ED based on both tissue weighting factors (WTs) of the International Commission on Radiological Protection (ICRP) publication 103 (ICRP, 2007) and ICRP publication 60 (ICRP, 1991).

Later, Kyriou et al. (2000) published the program DoseCal which calculates the ED based on ICRP60 (ICRP, 1991). DoseCal calculates the organ and tissue doses for adult and pediatric MIRD5 phantom using the conversion coefficients reported by Jones and Wall (1985) and Hart et al. (1994). DoseCal has become very popular because it is easy to use and gives quick results. In addition, DoseCal could be obtained free of charge and used to assess the ESDs, dose area product (DAP), EDs, and organ and tissue absorbed doses (Ds) for X-ray examinations according to the exposure conditions defined by the user.

As opposed to DoseCal, which calculates the ED based on the output measurement and calculation of ESD, PCXMC gives the user the option to input the dose in different quantities such as incident air kerma (in mGy), DAP (mGy.cm^2), entrance exposure (mR), exposure area product (R.cm^2). The factors provided by the ICRP 103 have been modified slightly from those in ICRP 60, and this certainly will influence the results of ED calculated by DoseCal. The use of different sets of radiation weighting factors in this study could illustrate the range of disparity in the results of ED for patients undergoing chest and abdomen examinations. To the best of our knowledge, there is no comparison between PCXMC and DoseCal software; however, previous studies reported that each software is reliable in ED measurements and presents a few errors (Azevedo et al., 2006; Servomaa & Tapiovaara, 1998).

MATERIALS AND METHODS

Measurements and Calculation with DoseCal

This work was conducted in NUH using two X-rays units (Toshiba DRX-3724HD and GE AL01F). Both X-ray units had a 3 mm Aluminum filter, and all the studies were performed with grids. Data were collected on patient doses for 11 months. The tube outputs (OP) of the two X-ray units were measured at 80 kV at 1 m normalized to 10 mAs using an Unfors Xi dosemeter with an accuracy better than 5% (Unfors Inc., Billdal, Sweden). The OP data were entered in the DoseCal software version 2.31 using a computer equipped with a Windows-XP.

Once the patient's age, sex, weight, and exposure parameters such as kVp, the mAs, the FSD, and filtration are known and entered into the DoseCal software, the ESD can be calculated from Equation 1 as reported by Davies et al. (1997).

$$ESD = OP \left(\frac{kVp}{80}\right)^2 \times mAs \times \left(\frac{100}{FSD}\right)^2 \times BSF \qquad (1)$$

where BSF is the backscatter factor calculated automatically by the DoseCal software.

Kyriou et al. (2000) reported that the ED was calculated using Equation 2.

$$ED = ESD \times Cf(D) \qquad (2)$$

Where Cf (D) is the conversion factor used to change ESD to ED based on the National Radiological Protection Board (NRPB) tables (Hart et al., 1991).

Simulation with PCXMC

The PCXMC carried out the dose calculation after defining the examination data and performing a Monte Carlo simulation using a PC equipped with a 2.53 GHz processor.

Once the recorded geometrical parameters of the abdomen and chest examinations such as X-ray field limits on the patients and FSD, age, weight, height, maximum keV, and several photons are known and entered into the PCXMC software, the simulation step can be started. The number of photons and the maximum energy used was 20,000 and 150 keV, respectively. The physical processes in the simulation begin with photons being emitted from an isotropic point source and are followed by random interactions with phantom, including Raleigh scattering, Compton scattering, or photoelectric absorption. Finally, the photons' histories generated and calculated the energies deposited in various organs and used for dose calculations.

In the dose calculation step, the X-ray spectrum was defined according to the X-ray tube potential, anode angle, and total filtration used in this study. The ESD calculated by DoseCal, according to the output measurement mentioned previously, was divided by the BSF provided by DoseCal before being entered into the PCXMC. Once the simulation process is complete, the ED, organ doses, and their estimated statistical precision are displayed in PCXMC.

The PCXMC calculated the ED using Equation 3.

$$ED = \frac{1}{2}\sum W_T[H_T(Female) + H_T(Male)] \quad (3)$$

where H_T is the average equivalent dose in a tissue or organ.

For patients undergoing both abdomen and chest X-ray examinations, the model developed by the Committee on the Biological Effects of the Ionizing Radiations (BEIR) was used to assess the risk of exposure-induced cancer death (REIC) (Tapiovaara & Siiskonen, 2008). Once a patient's age, gender, and mortality are known and entered into the PCXMC software, the radiogenic risk can be estimated using Equation 4.

$$\text{REIC} = \int_T^{\infty} \left[\mu_C(t|e,D) - \mu_C(t)\right] S(t|e,D)dt \quad (4)$$

where μ_C is the mortality rate; t is the age; c is the death cause; e is the exposure; D is the dose; S is the conditional probability, and $\mu_C(t)$ is the background mortality rate. T is equal e + L, where L is the latency period in years.

Statistical parameters such as the mean, error percentage, and variation factor, including abdomen AP and chest AP/PA X-ray examinations, have been calculated using SPSS version 14 (SPSS Inc, Chicago, IL).

RESULTS

A total of 510 patients who were referred for abdomen and chest X-ray examinations at NUH were included in this study. Gender distribution shows that 279 (54.7%) were males

while 231 (45.3%) were females. The mean of the anthropometric data and exposure parameters are shown in Table 1. The data outside the brackets in Table 1 represent the mean, and the data inside the brackets represent the minimum and maximum of subjects.

Table 1
Patient anthropometric data and exposure parameters of abdomen and chest radiographic examinations

	Patient age (year)	Gender		Patient weight (kg)	Radiographic data		
		Male	Female		Tube voltage (kVp)	mAs	FSD (cm)
Abdomen AP	42(18-63)	115	95	82(44-105)	64(60-85)	16(11-43)	100 (70-110)
Chest AP	44(19-88)	85	63	67(45-97)	64(50-80)	28(6-160)	100 (70-105)
Chest PA	39(25-76)	79	73	64(42-90)	64(50-85)	18(6-46)	100 (70-105)

The distribution of the mean ED calculated by PCXMC for abdomen AP and chest AP/PA X-ray examinations using W_T of ICRP publication 60 (ICRP, 1991) and ICRP publication 103 (ICRP, 2007) are summarized in Table 2. It was observed that the mean of ED values for chest AP and PA X-ray examinations calculated with ICRP publication 103 (ICRP, 2007) are higher than the values calculated with ICRP publication 60 (ICRP, 1991), with a factor range between 1.2 and 1.3 and lower in abdomen AP with a factor of 7.0.

Table 2
The mean of ED (mSv) calculated in this study using PCXMC

Examinations	Using WT of ICRP 60	Using WT of ICRP 103
Abdomen AP	0.062	0.088
Chest AP	0.132	0.168
Chest PA	0.047	0.056

Table 3
The ED (mSv) calculated in this study using DoseCal and PCXMC

	DoseCal			PCXMC*		
	Abdomen AP	Chest AP	Chest PA	Abdomen AP	Chest AP	Chest PA
Min	0.021	0.073	0.017	0.094	0.078	0.023
Max	0.340	0.852	0.103	0.860	0.950	0.111
Mean	0.051	0.115	0.045	0.062	0.132	0.047
Error (%)	0.40	0.20	0.30	0.30	0.20	0.30
Sample size	210	148	152	210	148	152

*Using WT of ICRP 60 (ICRP, 1991)

Table 4
Comparison between the mean of ED calculated in this study and previously published data

	Abdomen AP	Chest AP	Chest PA
This study using PCXMC*	0.062	0.132	0.047
This study using PCXMC**	0.088	0.168	0.056
This study using DoseCal	0.051	0.115	0.045
B. F. Wall et al. (2011)	0.430	-	0.014
Nahangi and Chaparian (2015)	0.113	-	0.043

*Using WT of ICRP 60 (ICRP, 1991)
**Using WT of ICRP 103 (ICRP, 2007)

Table 5
The D to organs and tissues using DoseCal and PCXMC software for abdomen AP examinations

Variation factor	D error (%)**	D (mGy)**	D (mGy)*	Organ/Tissue
1.000	1.6	0.0124	0.0124	Adrenals
1.100	0.8	0.0011	0.0010	Breast
1.005	2.1	0.1248	0.1254	Gall bladder
1.002	1.2	0.1332	0.1334	Stomach
1.008	1.5	0.1001	0.1009	Small intestine
1.001	1.6	0.1262	0.1263	Upper Large intestine
1.000	4.3	0.0806	0.0806	Lower Large intestine
1.068	0.5	0.0029	0.0031	Heart
1.006	0.6	0.0182	0.0183	Kidneys
13.000	1.7	0.0013	0.0001	Thyroid
1.000	0.4	0.0714	0.0714	Liver
1.294	0.2	0.0017	0.0022	Lung
1.005	22.2	0.0755	0.0751	Ovaries
1.006	1.2	0.0499	0.0502	Pancreas
1.360	3.2	0.0423	0.0311	Skin
1.007	2.1	0.0276	0.0278	Spleen
1.000	2.1	0.0138	0.0138	Testicles
1.000	0.6	0.0003	0.0003	Thymus
1.011	1.1	0.1810	0.1791	Urinary bladder
1.000	1.6	0.1018	0.1018	Uterus
3.233	1.0	0.0097	0.0031	Oesophagus
****	****	***	0.0573	Trunk region
****	****	***	0.0019	Leg region
1.323	0.1	0.0221	0.0167	Skeleton
1.063	0.1	0.0119	0.0112	Active (red) marrow

* using DoseCal software
** using PCXMC software
*** Organ/Tissue not available in phantom
**** indicates data not available.

For clarification, Table 3 presents a statistical distribution of the ED values of abdomen AP and chest AP/PA using DoseCal and PCXMC software. The mean values of EDs calculated by DoseCal for abdomen AP and chest AP/PA X-ray examinations were lower than those calculated by PCXMC, with a factor range between 1.2 and 1.0.

Table 6
The D to organs and tissues using DoseCal and PCXMC software for chest PA examinations

Variation factor	D error (%)**	D (mGy)**	D(mGy)*	Organ/Tissue
1.019	1.5	0.0463	0.0472	Adrenals
1.333	3.4	0.0003	0.0004	Brain
1.002	0.8	0.4801	0.4792	Breast
****	****	***	0.0021	Eye lenses
1.013	1.2	0.0843	0.0854	Gall bladder
1.001	2.8	0.2181	0.2183	Stomach
1.000	5.7	0.0043	0.0043	Small intestine
1.015	1.9	0.0067	0.0068	Upper Large intestine
1.000	4.9	0.0008	0.0008	Lower Large intestine
1.002	0.8	0.2978	0.2985	Heart
1.025	0.6	0.0241	0.0247	Kidneys
13.254	3.2	0.3075	0.0232	Thyroid
1.004	2.4	0.1852	0.1859	Liver
1.008	0.6	0.2202	0.2219	Lung
1.167	21.5	0.0006	0.0007	Ovaries
1.014	1.1	0.1211	0.1228	Pancreas
1.092	1.4	0.0694	0.0758	Skin
1.044	1.1	0.0710	0.0741	Spleen
0.000	0.9	0.0007	0.0000	Testicles
1.001	3.5	0.4886	0.4892	Thymus
1.500	1.5	0.0003	0.0002	Urinary bladder
2.000	0.3	0.0002	0.0004	Uterus
1.134	1.1	0.0852	0.0966	Oesophagus
****	****	***	0.0581	Trunk region
****	****	***	0.0000	Leg region
2.026	0.1	0.2233	0.1102	Skeleton
1.081	0.3	0.0493	0.0456	Active (red) marrow

* using DoseCal software
** using PCXMC software
*** Organ/Tissue not available in phantom
**** indicates data not available.

Table 7
The D to organs and tissues using DoseCal and PCXMC software for chest AP examinations

Variation factor	D error (%)**	D (mGy)**	D (mGy)*	Organ/Tissue
1.003	1.4	0.1829	0.1835	Adrenals
1.000	2.9	0.0007	0.0007	Brain
1.042	0.7	0.0273	0.0262	Breast
****	****	***	0.0003	Eye lenses
1.085	1.2	0.0201	0.0218	Gall bladder
1.037	2.7	0.0298	0.0309	Stomach
1.048	5.8	0.0022	0.0021	Small intestine
1.381	1.2	0.0021	0.0029	Upper Large intestine
1.000	3.2	0.0004	0.0004	Lower Large intestine
1.031	0.5	0.0453	0.0467	Heart
1.007	0.3	0.1282	0.1291	Kidneys
16.316	3.1	0.7032	0.0431	Thyroid
1.019	2.3	0.0683	0.0696	Liver
1.007	0.2	0.1672	0.1683	Lung
1.000	21.1	0.0003	0.0003	Ovaries
1.015	1.3	0.0619	0.0628	Pancreas
1.192	1.1	0.0521	0.0437	Skin
1.004	1.2	0.1563	0.1570	Spleen
1.000	1.3	0.0000	0.0000	Testicles
1.329	3.2	0.0143	0.0190	Thymus
1.000	1.2	0.0000	0.0000	Urinary bladder
1.000	0.1	0.0003	0.0003	Uterus
1.212	1.2	0.0523	0.0626	Oesophagus
****	****	***	0.0792	Trunk region
****	****	***	0.0000	Leg region
1.861	0.2	0.2051	0.1119	Skeleton
1.195	0.4	0.0563	0.0471	Active (red) marrow

* using DoseCal software
** using PCXMC software
*** Organ/Tissue not available in phantom

In Table 4, a comparison is given between the mean EDs obtained in this study and the data reported by Wall et al. (2011) and Nahangi and Chaparian (2015). It was observed that the mean ED values of chest PA in this study are comparable to data reported by Nahangi and Chaparian (2015). In contrast, mean EDs of abdomen PA calculated by PCXMC and Dosecal are lower than data reported by Wall et al. (2011), with a factor range between 4.9 to 8.4.

Tables 5-7 compare the average D values for organs and tissues between DoseCal and PCXMC software for the abdomen AP, chest PA, and AP examinations. PCXMC

can calculate doses for 45 organs and tissue; however, only 27 organs and tissues available in DoseCal or at X-ray exposure risk are presented in Tables 5-7. The gall bladder, stomach, upper large intestine, and urinary bladder in the abdomen examinations and the breast and thymus in chest examinations receive the highest dose. The mean values of the REIC (per million) calculated by PCXMC for abdomen and chest examinations are shown in Figure 1 for male and female patients.

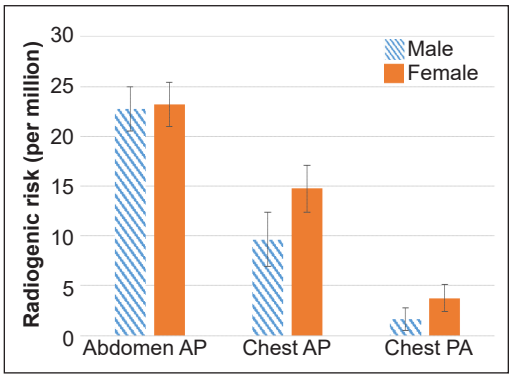

Figure 1. The mean REIC (per million) from abdomen and chest examinations of male and female patients

DISCUSSION

This article evaluated the ED, organ doses, and radiogenic risks for patients undergoing chest and abdominal diagnostic X-ray examinations using DoseCal and PCXMC software. The estimated EDs ranged from 0.045–0.168 mSv, and the median weight and age for all patients were 76 kg and 42 years, respectively. The variation in the mean of ED (mSv) presented in Table 2 could be attributed to the different tissue-weighting factors used in the ICRP publication 60 (ICRP, 1991) and ICRP publication 103 (ICRP, 2007).

The ED results shown in Table 4 for abdomen PA are lower than the data reported by Wall et al. (2011). Likewise, several researchers (Mettler et al., 2008; Osei & Darko, 2013; Taha et al., 2016), who have carried out radiation dose surveys, have also reported variations in patient dose arising from abdomen X-ray examinations. It could be attributed to several reasons: examination technique, the technologist's skill, clinical condition, equipment performance, film–screen combination speed, mAs, kVp, and FSD. For example, Nahangi and Chaparian (2015) pointed out that the mean kV and mAs used for abdomen examinations are 67 kV and 55 mAs, which could explain the lower value of the ED obtained in this study.

In Tables 5-7, the average D values for most organs and tissues between DoseCal and PCXMC software vary up to a factor range between 1.0 and 3.2. In contrast, some organs, such as the thyroid, showed a significant variation. For example, the D in thyroid for chest AP examinations varies by a factor up to 16.3, and this could be attributed to the difference in the positioning of the filed size or variation in the location of thyroid in the MIRD5 phantom and phantom models of Cristy and Eckerman (1987). In addition, some modifications carried out in the phantom models, such as the correction of depths of some organs, have been made in the PCXMC. These modifications have been described elsewhere (Wall et al., 2011) and could affect the results of the D of the organs calculated by each software.

In this study, the radiogenic risks in male and female patients were expressed as values of REIC per million. It can help the physician justify the X-ray examinations and compare them with other risks. The calculated REIC for abdomen AP and chest PA radiography showed a relatively good agreement with the findings of the Nahangi and Chaparian (2015). It can be observed that the mean of REIC values for the abdomen is higher than chest AP/PA, and this could be attributed to the higher radiosensitivity of the organs in the abdomen. As shown in Figure 1, the difference in the REIC between males and females was statistically correlated for chest examinations, similar to Nahangi and Chaparian's (2015) findings. This correlation in the chest examinations could be explained due to the difference in radiosensitivity of some organs, such as breasts which are different in patients according to gender.

The major limitation of this study was the modicum number of the X-ray examinations included in this study. Essentially, a variety of the x-ay examinations used could affect the findings of the variation between DoseCal and PCXMC software. However, the comparison performed in this work showed that the computed doses for most of the organs relatively correlate well in both software.

CONCLUSION

This study investigated the patient doses using DoseCal and PCXMC software for patients undergoing abdomen and chest diagnostic radiology examinations only. It is necessary to reproduce bigger reliability in DoseCal and PCXMC by involving many X-ray investigations. The conclusion was that both software produced, to some extent, similar results, except one generated ED based on ICRP 60 and the other on ICRP 103. As the DoseCal used old data of ICRP 60, it may result in inaccurate risk factor calculations unless it was corrected by the new W_T recommended by ICRP 103. Calculating ED with old factors may give a difference of up to 30% and 21% for abdomen and chest examination receptively. We highly recommend that the dose surveyors utilize PCXMC because it uses the most recent WTs and provides a risk calculation.

The REIC values obtained in this study from abdomen and chest X-ray examinations for male and female patients can be an indicator helping physicians to judge radiation risks and encourage them to be concerned about knowing the REIC values.

ACKNOWLEDGMENT

The authors want to thank the co-operation of the NUH Directorate, the radiologists, Prof. M K Saeed for his valuable comments, and Mrs. Rose-Ann Telebangco Quilaton from the Radiology Department for participating in this study.

REFERENCES

Abdelhalim, M. A. K. (2010). Patient dose levels for seven different radiographic examination types. *Saudi Journal of Biological Sciences*, *17*(2), 115-118. https://doi.org/10.1016/J.SJBS.2009.12.013

Alsayyari, A. A. S., Omer, M. A. A., Alkhidir, N. A. M., & Auod, A. S. A. (2017). Study of common requested radiographs and relative exposure dose in Qassim State. *International Journal of Medical Imaging*, *5*(2), 14-18. https://doi.org/10.11648/J.IJMI.20170502.12

Azevedo, A. C., Osibote, O. A., & Boechat, M. C. B. (2006). Paediatric X-ray examinations in Rio de Janeiro. *Physics in Medicine and Biology*, *51*(15), Article 3723. https://doi.org/10.1088/0031-9155/51/15/008

Cristy, M., & Eckerman, K. F. (1987). *Specific absorbed fractions of energy at various ages from internal photon sources: 7, Adult male*. Oak Ridge National Lab. https://inis.iaea.org/Search/search.aspx?orig_q=RN:19012902

Davies, M., McCallum, H., White, G., Brown, J., & Helm, M. (1997). Patient dose audit in diagnostic radiography using custom designed software. *Radiography*, *3*(1), 17-25. https://doi.org/10.1016/S1078-8174(97)80021-1

Hart, D., Jones, D. C., & Wall, B. F. (1991). *Normalized organ doses for medical X-ray examinations calculated using Monte Carlo techniques*. *NRPB-SR262*. National Radiological Protection Board.

Hart, D., Jones, D. G., & Wall, B. F. (1994). *Estimation of effective dose in diagnostic radiology from entrance surface dose and dose-area product measurement* (NRPB R-262). National Radiological Protection Board.

ICRP. (1991). 1990 Recommendations of the International Commission on Radiological Protection. *Annuals of the ICRP*. *21*(1-3), 1-201. https://pubmed.ncbi.nlm.nih.gov/2053748/

ICRP. (2007). *The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103*. *Annals of the ICRP, 37*(2-4), 9-34. https://doi.org/10.1016/J.ICRP.2007.10.003

Jones, D. G., & Wall, B. F. (1985). *Organ doses from medical X-ray examinations calculated using Monte Carlo techniques* (NRPB-R-186). National Radiological Protection Board.

Kyriou, J. C., Newey, V., & Fitzgerald, M. C. (2000). *Patient doses in diagnostic radiology at the touch of a button*. The Radiological Protection Center, St. George's Hospital.

Mettler, F. A., Huda, W. J., Yoshizumi, T. T., & Mahesh, M. (2008). Effective doses in radiology and diagnostic nuclear medicine: A catalog. *Radiology*, *248*(1), 254-263. https://doi.org/10.1148/RADIOL.2481071451

Nahangi, H., & Chaparian, A. (2015). Assessment of radiation risk to pediatric patients undergoing conventional X-ray examinations. *Radioprotection*, *50*(1), 19-25. https://doi.org/10.1051/RADIOPRO/2014023

Osei, E. K., & Darko, J. (2013). A survey of organ equivalent and effective doses from diagnostic radiology procedures. *ISRN Radiology, 2013*, Article 204346. https://doi.org/10.5402/2013/204346

Osman, H., Elzaki, A., Elsamani, M., Alzaeidi, J., Sharif, K., & Elmorsy, A. (2013). Peadiatric radiation dose from routine X-ray examination: A hospital based study, Taif pediatric hospital. *Scholars Journal of Applied Medical Sciences*, *5*, 511-515.

Rubai, S. S., Rahman, M. S., Purohit, S., Patwary, M. K. A., Meaze, A. M. H., & Mamun, A. A. (2018). Measurements of entrance surface dose and effective dose of patients in diagnostic radiography.

Biomedical Journal of Scientific & Technical Research, *12*(1), 8924-8928. https://doi.org/10.26717/BJSTR.2018.12.002186

Saeed, M. K. (2017). Dose measurement using Gafchromic film for patients undergoing interventional cardiology procedures. *Radiation Protection Dosimetry*, *174*(1), 109-112. https://doi.org/10.1093/RPD/NCW082

Servomaa, A., & Tapiovaara, M. (1998). Organ dose calculation in medical X ray examinations by the program PCXMC. *Radiation Protection Dosimetry*, *80*(1-3), 213-219. https://doi.org/10.1093/OXFORDJOURNALS.RPD.A032509

Taha, M. T., Kutbi, R. A., & Allehyani, S. H. (2016). Effective dose evaluation for chest and abdomen X-ray examinations. *International Journal of Science and Research (IJSR)*, *5*(3), 420-422. https://doi.org/10.21275/V5I3.NOV161884

Tapiovaara, M., & Siiskonen, T. (2008). *PCXMC : A Monte Carlo program for calculating patient doses in medical X-ray examinations* (STUK-A231). Finnish Centre for Radiation and Nuclear Safety.

Wall, B. F., Haylock, R., Jansen, J. T. M., Hillier, M. C., Hart, D., & Shrimpton, P. C. (2011). *Radiation Risks from Medical X-ray Examinations as a Function of the Age and Sex of the Patient* (HPA-CRCE-028). Health Protection Agency Centre for Radiation, Chemical and Environmental Hazards.