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Original Article

Evaluation of Organ and Effective Doses to Patients Arising From Some Common X-Ray Examinations by PCXMC Program in Sabzevar, Iran

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Abstract

Introduction
The purpose of this study was to estimate organ and effective doses in patients undergoing some common X-ray examinations in Sabzevar, Iran. The effective dose is one of the best parameters for describing the amount of radiation dose received by a patient undergoing any diagnostic X-ray examination. The public dose from X-ray examinations depends on various factors, and its contribution to the overall public dose from medical applications widely varies in different societies; however, in Iran, limited data is available on this subject.
Materials and Methods
In the present study, we aimed to estimate organ and effective doses arising from some common X-ray examinations on patients. Organ and effective doses were calculated by employing PCXMC program, based on Monte Carlo method.
Results
The mean effective doses in this study were compared with similar findings reported in previous research. The applied methods in different studies are the main factors, which influence the effective dose values.
Conclusion
Radiation doses to radiosensitive organs such as the ovaries, testicles, and thyroid may induce harmful effects, e.g., cancer and genetic effects. Therefore, we should try to maintain the organ doses as low as possible.

Keywords: Effective dose, Organ dose, PCXMC program, Radiography, Radiation Effects

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1. Introduction

Ionizing radiations are widely used in all hospitals and clinics for diagnostic imaging procedures [1, 2]. X-ray is the most frequently used form of ionizing radiation in everyday life. In many cases, prompt and accurate diagnosis of diseases or injuries calls for immediate use of X-ray examinations [2].

X-ray examinations provide the physician with important information about an individual's health and help ensure the suitability of patient treatment. Recent advances in clinical X-ray technologies by simplifying X-ray-based diagnostic procedures have resulted in a rapid increase in the use of X-ray facilities and equipments in medical practice[3].

Diagnostic radiology accounts for an enormous share of public dose from man-made sources. In fact, diagnostic radiology is recognized as the largest source of man-made radiation. More importantly, its application has risen sharply from 15% in 1980 to 48% in 2006 in the United States [3, 4].

Unlike occupational exposure, no dose limits have been defined for radiation doses to the general public arising from medical exposure, although local and national dose references have been established. All medical exposures involve a balance between benefit and risk to the patient. X-ray examinations can promote disease detection and suitable treatment (based on the stage of the disease) by monitoring its progression. The patient can benefit from successful treatment, which may both prolong his/her life and improve its quality. Overall, the advantages should overweigh the risks associated with radiation exposure.

Failure to carry out a prescribed examination can place a patient at a significantly greater risk, compared to radiation exposure. On the other hand, a procedure is of no value if it does not influence patient management in any way and only imposes unnecessary risks on the patient [5].

In order to determine the stochastic risk of an X-ray examination, it is necessary to determine the absorbed dose in each susceptible organ and identify the risk of the absorbed dose arising from organ irradiation . The organ or tissue dose in a patient, resulting from a radiological procedure, depends on the amount of incident radiation, i.e., the entrance surface dose, as well as the location and direction of the incident beam[6-8]

In radiation protection, effective dose is used to compare the stochastic risk in situations where there is no uniformity in the received doses, and the absorbed doses are low enough to avoid deterministic radiation effects , effective dose can be used t compare the risks caused by a non-uniform exposure and a uniform exposure of the whole body. The stochastic risks are in fact carcinogenetic and induce genetic effects[9-12].

The patient effective dose (E) was introduced by the International Commission of Radiological Protection (ICRP) as an indicator of stochastic radiation risk, associated with medical exposures; it is also regarded as a basis for estimating the risk of occupational exposure. Determination of patient effective dose contributes to the understanding of the link between radiation dose and dose damages. Also, it can be an appropriate index for comparing the relative risk of different diagnostic procedures [13-15].

The effective dose is given as a weighted average of equivalent doses in various organs and tissues [16, 17]. The effective dose (E) is calculated by summing the equivalent doses to individual organs (H_T), multiplied by (W_T):

$$E=\sum W_T \times H_T$$

where W_T is the tissue weighting factor, which corresponds to the relative sensitivity of various tissues.

2. Materials and Methods

This study was carried out in eight radiology centers in Sabzevar, Iran. Eleven X-ray units and 485 patients were evaluated in this study. For each patient and X-ray unit, the following parameters were individually recorded: sex, age, weight, height, tube potential (kVp), mAs, focus-film distance, film size, and grid usage. The study sample included patients with a weight range of 40-107 kg.

Eight typical X-ray examinations in this study were as follows: chest (PA), chest (AP),

lumbar spine (AP), lumbar spine (LAT), pelvis (AP), abdomen (AP), and cervix (AP and LAT). In order to estimate the effective dose, dose area product (DAP) value, kVp, total filtration, and field size needed to be determined. DAP values were measured by a DAP meter (Gammex-RMI, model 840A, USA). The DAP meter was used to measure the radiation dose to air and the area covered by the X-ray field; DAP is expressed in $Gy.cm^2$ or $mGy.cm^2$.

An ionization chamber larger than the area of the X-ray beam was placed exactly under the X-ray collimators. The ionization chamber should intercept the entire X-ray field for an accurate reading. The reading from the DAP meter was changed in case of any alterations in X-ray technique factors (kVp, mAs, or time), the field area, or both.

In order to calculate the organ and effective doses, we employed PCXMC Version 2, which is a Mont Carlo-based program. PCXMC is designed to calculate the mean absorbed dose, averaged over the organ volume. Also, this program calculates the effective dose for two tissue weighting factors (w_T), suggested by ICRP 2007 and ICRP 1991. In PCXMC, all absorbed doses (and air kerma) are presented in mGy.

For photons, the numerical values of equivalent organ doses in mSv are equal to the corresponding organ doses in mGy; also, the effective dose is expressed in mSv [15]. Since PCXMC(2008, STUK-A231, Helsinki) software is based on Mont Carlo simulations, the number of photons and photon maximum energy were the main factors in determining the achievable statistical precision. Therefore, in the software entries, we set the number of photons at 1,000,000 and maximum energy at 100 kVp.

3. Results

As presented in figures 1 & 2, the radiation doses received by a particular organ from different X-ray examinations were widely different. Also, considerable variations were observed among different organs in terms of the received dose from a specific examination.

In the PA chest radiography, the ribs received the highest organ dose, whereas in the AP examination, not only the ribs, but also breast and clavicles received the highest doses. Similar findings were reported in other examinations and organs in this study. It should be mentioned that in figures 1 & 2, the organ doses, which were less than 0.1 mGy, were excluded for all fields. Readers can refer to the detailed information presented in figures 1 & 2 for further clarification.

The mean effective doses from different X-ray examinations in the study population (averaged over eight centers) are presented in Figure 3. According to this figure, it is evident that the largest effective dose was produced by the AP abdominal examination, followed by AP pelvic X-ray examination; however, the minimum effective dose was induced by LAT cervical X-ray examinations.

Patient information (e.g., age, weight, and the average and range of exposure), as well as kVp and mAs settings, is presented in Table 1. The average effective doses of patients in this study were compared with the corresponding values reported in three previous studies (Table 2).

B. F. Wall et al. studied the effective dose, using PCXMC software;the obtained results are presented in Table 2. Based on the findings in this table, it can be concluded that effective doses reported by Z. Begum in Bangladesh were generally higher than the corresponding values reported in this study [6]. This conclusion can also be extended to the results reported by Bahreyni et al. for male and female patients [4]. The methods used for evaluating the effective dose and radiographic parameters in different studies are the main factors which influence the values of effective dose. In fact, without having access to the details of relevant factors, it is difficult to draw an analytical conclusion.

Table 1. The average and range of exposure values, age, and weight of patients in the present study

Examinations	Average (Range)			
	kVp	mAs	Age	Weight
Chest (PA)	67.82 (57-86)	18.40 (6.3-45)	49.78(15-82)	62.82 (42-87)
Chest (AP)	65.59 (51-79)	29.54 (6.3-160)	60.18(25-88)	64.64(45-90)
Abdominal (AP)	69.54(56-76)	29.72 (12.5-80)	40.39(20-76)	67.68 (50-82)
Pelvic (AP)	66.95 (60-81)	40.27(16-75)	44.04 (22-81)	61.63 (45-78)
Lumbar (AP)	71.45 (80-60)	43.90 (10-90)	38.30(15-88)	61.63 (45-78)
Lumbar (Lat)	78.32 (63-90)	68.08 (20-180)	38.08 (15-81)	63.04(45-78)
Cervical (AP)	60.67 (54-70)	17.33 (6.3-30)	51.32(16-80)	67.60 (45-97)
Cervical (LAT)	63.26 (58-73)	16.49 (6.3-30)	48.85 (16-76)	66.55(45-97)

Table 2. The effective doses (mSv) calculated in this study and previous research

Examinations	The present study (2008)		B. F. Wall et al. [18]	Z. Begum (6)	Bahreyni Toosi et al. (4)	
	ICRP 60	ICRP 103			Male	Female
Chest (AP)	0.067	0.103	-	-	-	-
Chest (PA)	0.046	0.052	0.014	0.062	0.123	0.121
Cervical (AP)	0.068	0.061	0.018	-	0.082	0.079
Cervical (LAT)	0.017	0.011	0.012	-		
Abdominal (AP)	0.482	0.091	0.43	-	0.38	0.46
Lumbar (AP)	0.194	0.054	0.39	0.623	0.566	0.981
Lumbar (LAT)	0.071	0.126	0.21	0.168		
Pelvic (AP)	0.266	0.075	0.28	0.626	0.472	0.607

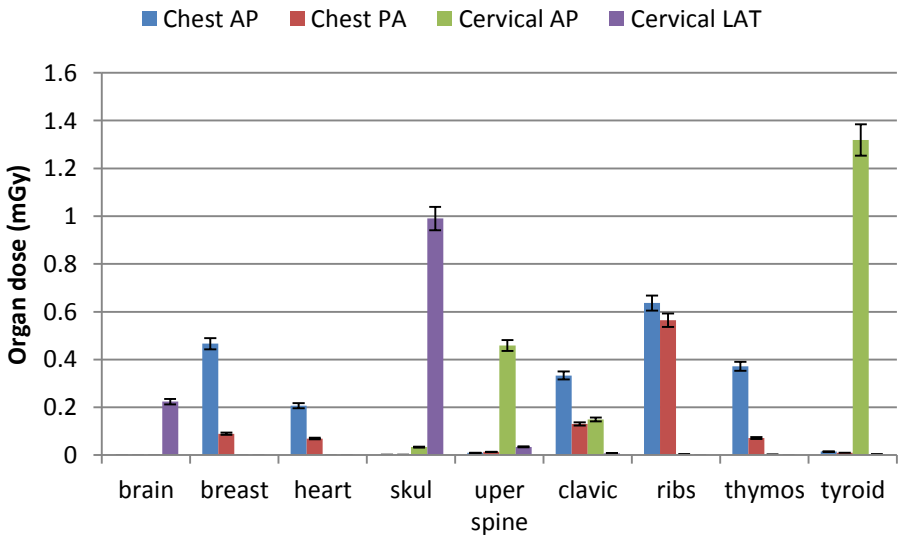

Figure 1. The mean values of organ doses (mGy)

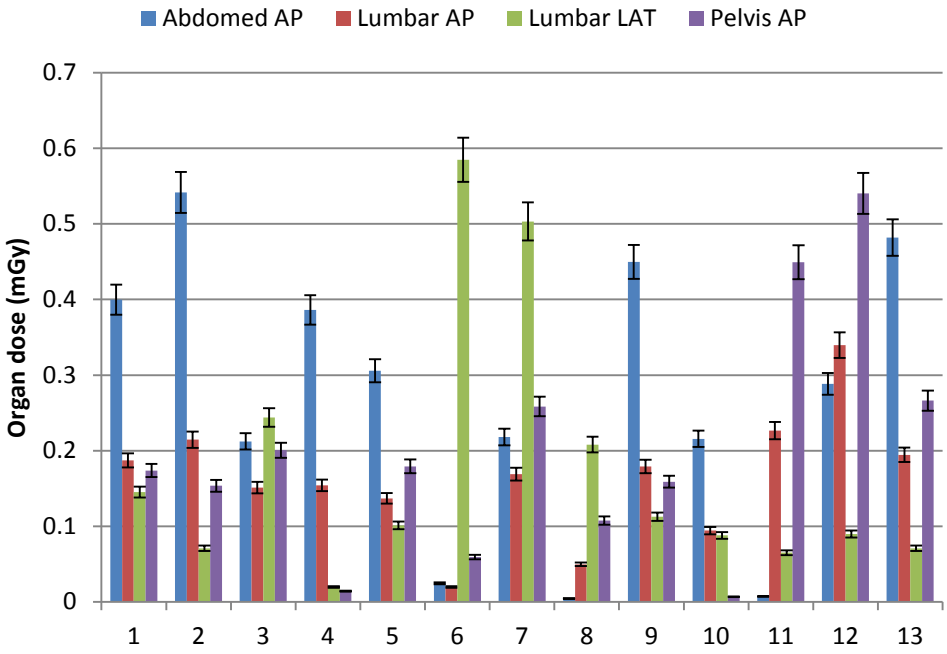

Figure 2. The mean organ doses (mGy), 1) colon (large intestine); 2) colon (upper large intestine); 3) lower large intestine; 4) gallbladder; 5) ovaries; 6) lower arm bones; 7) pelvis; 8) upper leg bones; 9) small intestine; 10) stomach; 11) testicles; 12) urinary bladder; and 13) uterus

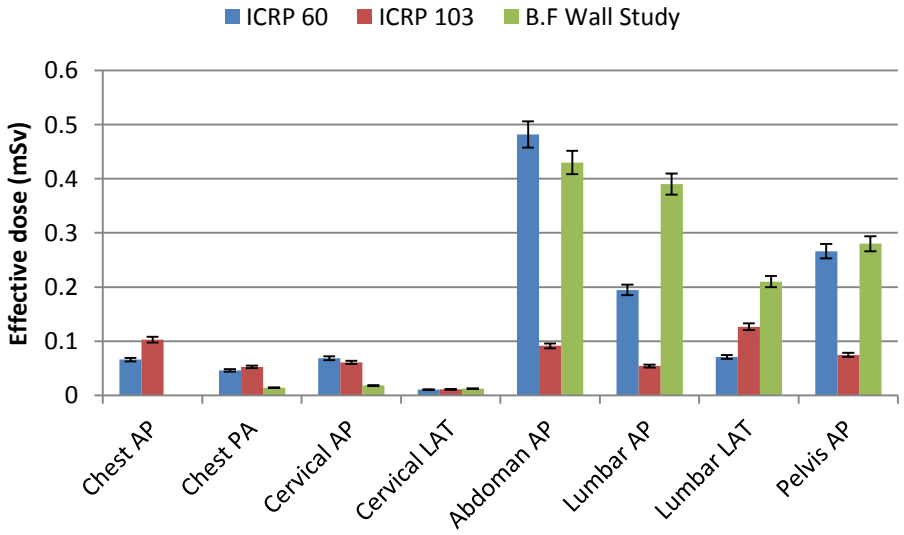

Figure 3. The effective doses (mSv) estimated by the use of DAP meter and PCXMC software, based on ICRP 60 and ICRP 103 tissue weighting factors

4. Discussion

Radiation has the potential to both induce harmful effects on patients and facilitate disease diagnosis. Therefore, it is essential to limit the potential risk in all procedures, knowing that there is no radiation with zero risk to the patient [19, 20].

The equivalent dose could be obtained, based on the adjustments in organ doses, proposed by ICRP [21, 22]. Effective dose is used to estimate the detrimental and hereditary characteristics of cancer; this is a calculated quantity, which cannot be measured directly.

Effective dose is age and sex averaged, although it can be used to enable comparisons between procedures which utilize ionizing radiation in terms of the relative detrimental effects. The effective dose is able to account for non-uniform irradiation of different tissues and organs in the body [22].

In addition to effective dose, absorbed organ doses are important for some procedures, which either involve high doses or include sensitive tissues in the primary radiation beam [23, 24]. We obtained doses for different organs, while evaluating the doses received by radiosensitive organs including the ovaries (female gonads), testicles (male gonads), and thyroid.

For procedures outside the abdomen/pelvis, i.e., head, neck, and chest, the only radiation to which the gonads are exposed is scattered radiation, which characteristically results in a very low received dose. Overall, for any significant radiation exposure to occur, some very unusual circumstances are required.

We also calculated the effective doses in different radiographic procedures for the ICRP 60 and ICRP 103 weighting factors. There are differences between the calculated effective doses by ICRP 60 and ICRP 103, since ICRP approved new tissue-weighting factors in 2007, which altered effective doses for most examinations.

There has been a decline in weighting factors for hereditary effects, while an increase has been reported in these factors for other tissues in ICRP 103 report rather than ICRP 60. Therefore, effective doses for abdominal, lumbar, and pelvic examinations would be lower than those reported by ICRP 60 [25, 26]. However, any such changes would be insignificant, compared to uncertainties involved in the estimation of effective dose.

The calculated effective doses based on ICRP 103 in the present study were compared with the values reported in the study by B. F. Wall and colleagues. In fact, the setting of the radiography equipment, field size, and other parameters, which are adjustable by the PCXMC user, can cause differences in the calculated effective dose by different users.

Also, imaging technologies and facilities such as screen-film radiography, computed radiography, and direct digital radiography have some impacts on both the absorbed and effective doses [27]. In previous studies, despite performing similar examinations by different digital systems, the calculated effective doses varied by nearly a factor of three, depending on the detector model [28, 29].

5. Conclusion

In conclusion, it can be stated that radiologists, physicians, and radiology technicians should balance the risks and advantages of various medical procedures and inform the patients. By exposing radiosensitive organs such as the ovaries, testicles, and thyroid, harmful radiation effects, such as cancer and genetic effects, may be induced; therefore, we should attempt to decrease the organ doses as much as possible. Effective dose provides a general idea of the disadvantages of ionizing radiation and allows comparisons between different procedures; moreover, it can help justify or optimize the procedures.

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