Evaluation of radiation-induced cancer risk to patients undergoing intra-oral and panoramic dental radiographies using experimental measurements and Monte Carlo calculations

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ABSTRACT

Background: Radiation doses associated with the conventional dental radiographies are relatively low, but their number is high. Therefore, justification is necessary to ensure that radiation doses to patients, particularly children, are kept as low as reasonably achievable. ***Materials and Methods***: The exposure factors applied for real patients in four age groups (5, 10, 15-year-old and adult) were obtained for conventional dental radiographies, periapical, bitewing, and panoramic. The dose-area product (DAP) values were measured for every dental radiographies. The risk of exposure-induced cancer death (REID) was estimated for every dental radiographies in different age groups and in both genders. ***Results:*** The range of the REID values in periapical radiography were 1.3 to 20.9 per ten million for male patients, and 1.6 to 28.3 per ten million for female patients in different age groups. The range of REID values in bitewing radiography were 1.5 to 11.2 per ten million for male, and 1.9 to 13.2, per ten million for female in different age groups. The mean of REID values in panoramic radiography were 7.32, 4.70, 3.55, and 2.1 per ten million for male patients in 5-, 10-, and 15-year-old and adult age groups, respectively, and were 9.43, 5.86, 4.25 and 2.41 per ten million for female patients in 5, 10, 15-year-old and adult age groups, respectively. ***Conclusion:*** In accordance with the results of the present study, the overall risk of cancer from radiation in children was more than adult and in female patients is more than male patients in dental X-ray examinations.

Keywords: *Dental radiography, organ doses, effective dose, radiation risk.*

INTRODUCTION

Radiology examinations are used in dentistry for diagnosis and treatment planning of dental diseases. Conventional dental radiographies include periapical, bitewing, and panoramic. Periapical radiography is a lateral projection displaying both the crown and root of the tooth and the surrounding bone. Bitewing radiography is an intra-oral radiographic view that demonstrates the crowns of the teeth and the alveolar crestal bone of the premolar and molar regions of both the maxilla and mandible. Panoramic radiography is a tomographic imaging that displays both jaws and their respective dentitions on a single extraoral film [(1)]. Despite the benefits of these radiographies for patients, the risks of carcinogenesis of X-rays used in these tests should not be ignored [(2)]. Radiation doses to patients undergoing the conventional dental radiographies are relatively low, but the number of examinations is high [(3)]. Therefore, dentists' awareness about the risk of carcinogenesis from these tests is important for making decisions for requesting them.

A number of studies have reported radiation dose measurements from dental radiographies; however, their results were only limited to the presentation of dose-width-product, entrance surface dose, some organ doses, and effective dose (E) for some age groups. Aps assessed the thyroid gland's radiation dose from radiographies taken in dento-alveolar trauma cases in pediatric patients. He performed it by means of personal computer X-ray Monte Carlo calculations (PCXMC) software, taking into account voltage, milli-Amperes, exposure time, vertical projection angle, beam collimation and age of the patient [4]. The study by Walker and van der Putten involved retrospective analyses of dose-width-product and entrance surface dose measurements obtained in Irish Dental Practices for both panoramic and intra-oral units respectively, followed by comparisons with Monte-Carlo generated computer models of these procedures [5]. While radiation-induced cancer risks have been reported in some studies, they estimated radiation-induced cancer values only for adults by multiplying the effective dose by a constant factor [1, 6, 7]. Souza *et al.* obtained absorbed doses to the thyroid gland in intra-oral dental examinations by using a Monte Carlo code and the FAX (Female Adult voXel) and MAX (Male Adult voXel) phantoms. They also estimated the lifetime cancer incidence attributable to dental examinations for adults [8] .

The use of the effective dose for explaining the stochastic harm to patients from ionizing radiation is sometimes criticized [9-11], because the effective dose is not expressed in terms of gender and age, while the risk of exposure-induced cancer death (REID) values vary with age and gender [12]. Hall *et al.* have shown that for patients in the first decade of life, the risk is about 15%/Sv, while for adults in late middle age, the risk drops to 1% or 2%/Sv and female patients are more radiosensitive than male patients [13]. Therefore, it was suggested that the risk coefficients from the Biological Effects of Ionizing Radiations (BEIR) VII Committee Report [14] be used to perform the risk estimation. These risk coefficients take into account organ specific dose, the cancer site, gender, and age at the exposure. The REID values are comprehensible for physicians to justify a dental radiography and compare them with other potential health risks including smoking, alcohol, car accidents, fire, pesticides, earthquakes, air traveling, and swimming [15]. For example, a REID value of 10 per million is approximately equivalent to 1 return transatlantic flight [16].

The aim of this study was to obtain dose-area product (DAP), organ doses, effective dose, and to estimate REID values from conventional dental radiographies (periapical, bitewing and panoramic) in different age groups and male patients and female patients, separately.

MATERIALS AND METHODS

Age groups considered in this study

The four standard groups including five-, ten-, and fifteen-year-olds, and adults were assessed in this study.

Determination of exposure factors and measurement of DAP for different dental radiographies

The exposure factors applied for real patients in four age groups (5, 10, 15-year-old and adult) were determined for conventional dental radiographies, periapical, bitewing, and panoramic. Three analog intra-oral dental machines (Intra, Planmeca, Finland) and one digital panoramic machine (Planmeca Proline XC, Finland) were assessed. Exposure factors for intra-oral radiographies, periapical and bitewing, including tube-current exposure-time product (mAs), tube voltage (kVp), focus-skin distance (FSD), and projection angle for each type of teeth (incisors, canines, premolar, and molar in upper and lower jaws) were determined for different age groups. Also, for panoramic radiography, exposure factors including tube current (mA), exposure time (second), and tube voltage (kVp) were determined for different age groups. Totally, 520 patient's exposure data were collected for different dental radiographies in four age groups.

The DAP is the product of the mean radiation dose in the X-ray beam and the area of the x-ray field. A DAP-meter consisting of a large area ionization chamber (placed directly in front of the exit portion of the X-ray tube) and a mobile electrometer (Diamentor M4; PTW-Freiburg, Germany) were used to measure the DAP values. The measurements of DAP were performed in the absence of the patient, while the exposure factors related to the real patients were applied for every dental radiographies in the different X-ray machines.

Monte Carlo simulations for various dental radiographies

The Monte Carlo code named PCXMC [17] created by STUK (Radiation and Nuclear Safety Authority in Finland) was used to simulate and calculate the dose of different dental radiographies. The anatomical data in the PCXMC were based on the mathematical phantom models created by Cristy and Eckerman [18]. For intra-oral radiography, bitewing, and periapical, the geometry of projections were defined and modeled for all teeth in all age groups using PCXMC. The size of the radiation field, the coordinates of the location and angle of beam on the patient, focus-skin distance, the number of simulated photons, and maximum energy were defined in the program. While, statistical errors in Monte Carlo simulation methods are not a problem because modeling can work with arbitrarily high photon numbers, in the PCXMC simulations, the number of histories was set to two million for all examinations to achieve less than 0.1% statistical uncertainty in the simulation results.

The geometry of projections in panoramic radiography could not completely simulate all at once in PCXMC; therefore, this radiography was simulated by splitting the scan into eighteen sections of the left ear to right ear. The size of the radiation field, the coordinates of the location and angle of beam on the patient, focus-reference point distance, the number of simulated photons, and maximum energy were defined in the program for each section. So, for obtaining information about a panoramic radiography, at least eighteen simulations and calculations were performed.

Calculation of organ doses and effective doses for different dental radiographies

Effective dose (E) is derived from the weighted sum of doses to organs by the equation: $E=\sum W_T. H_T$, where E is the product of the tissue weighting factor (W_T), which represents the relative contribution of that organ or tissue to the overall risk, and the equivalent dose H_T. Both the earlier W_T (ICRP 60) [12] and the new ones (ICRP 103) [9] can be used to calculate the effective dose. Therefore, for achieving the effective dose and the risk of carcinogenesis from radiology tests, it was necessary to obtain dose of organs. The organ doses and effective doses were calculated by the PCXMC program for different dental radiographies. The Monte Carlo simulation method was used in PCXMC for dose calculation. For every dental radiography, the measured DAP, kVp, and total filtration were entered into the program to calculate the organ doses. The PCXMC was able to obtain the effective dose both with the present tissue weighting factors of ICRP Publication 103 [9] and ICRP Publication 60 [12] .

Estimation of the REID values for different dental radiographies

The REID was also computed by PCXMC program based on the risk models of BEIR VII Committee for different dental radiographies. The BEIR VII models were developed to provide an estimate of lifetime risks of cancer incidence and mortality. These models also take gender, age at exposure, dose rate and other factors into account. A more thorough explanation of the details of these estimation can be found in a technical program document [17] and in previous studies [19, 20].

Statistical analysis

Statistical analysis was performed with SPSS (version 17, SPSS Inc., Chicago, IL). Normality of data distribution was assessed by using the Kolmogorov-Smirnov test. Assessing the significant differences among the age groups was performed by use of one-way ANOVA analysis. Independent Samples T tests were used to compare REID values between two genders. The level of significance was defined as $p < 0.05$.

RESULTS

Results of measurement of DAP for different dental radiographies

The results of the measurement of DAP values for dental radiographies, periapical and bitewing, were shown in tables 1 and 2 in terms of $mGycm^2$ for all teeth and age groups. As shown in these tables, the entrance exposure increases from incisors to molar teeth and also increases with age. This is due to the increase in the thickness of the teeth, which causes radiation conditions and then the amount of the entrance radiation to increase.

The mean and standard deviation of DAP values for panoramic radiography were 53.77 ± 11.89, 62.59 ± 17.39, 92.05 ± 10.20, and 94.43 ± 13.46 $mGycm^2$ in 5-, 10-, and 15-year-old and adult age groups, respectively. As shown, due to the increase in the thickness of the teeth in higher ages, the entrance exposure increases with age ($p<0.001$).

The results of the calculation of effective dose for different dental radiographic examinations

Tables 3 and 4 show the mean and standard deviation values of effective dose for periapical and bitewing radiography, respectively, for different teeth in different age groups in terms of microSievert (μSv).

The mean and standard deviation of effective dose for panoramic radiography were 7.72 ± 1.66, 6.09 ± 1.64, 5.52 ± 0.59, and 5.04 ± 0.70 μSv in 5-, 10-, and 15-year-old and adult age groups, respectively. For almost all examinations, the effective dose decreases with increasing age ($p<0.05$).

Table 1. Mean and standard deviation of DAP for four age groups and different teeth in periapical radiography in terms of $mGycm^2$.

Type of teeth		Age groups: 5	10	15	Adult	P value
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Upper jaw	incisors	34.86 ± 5.13	38.62 ± 4.97	56.75 ± 5.95	62.76 ± 15.25	<0.001
	canines	36.19 ± 8.26	38.62 ± 5.56	56.75 ± 6.65	62.76 ± 17.05	<0.001
	premolar	NA	40.89 ± 9.38	61.25 ± 12.91	69.53 ± 21.67	<0.001
	molar	56.01 ± 12.79	60.89 ± 15.75	74.36 ± 19.78	84.69 ± 28.30	0.036
Lower jaw	incisors	29.21 ± 2.48	31.74 ± 5.45	47.37 ± 4.34	51.66 ± 10.29	<0.001
	canines	30.94 ± 0.83	31.74 ± 6.09	47.37 ± 4.86	51.66 ± 11.51	<0.001
	premolar	NA	35.24 ± 7.57	51.68 ± 8.63	57.36 ± 16.65	0.003
	molar	47.33 ± 6.66	53.47 ± 10.36	65.65 ± 25.64	74.36 ± 19.15	0.004

Table 2. Mean and standard deviation of DAP for four age groups and different teeth in bitewing radiography in terms of $mGycm^2$.

Type of teeth	Age groups: 5	10	15	Adult	P value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
incisors	32.04 ± 3.72	35.18 ± 4.99	52.06 ± 4.86	57.21 ± 12.66	<0.001
canines	34.61 ± 3.69	35.18 ± 5.57	52.06 ± 5.43	57.21 ± 14.16	<0.001
premolar	NA	38.07 ± 8.19	56.46 ± 10.27	63.45 ± 19.07	<0.001
molar	51.67 ± 10.65	57.18 ± 12.59	70.00 ± 25.31	79.53 ± 23.54	0.002

Table 3. The mean and standard deviation values of effective dose for periapical radiography for different teeth in different age groups in terms of µSv.

Type of teeth / Age group	Upper jaw				Lower jaw			
	incisors	canines	premolar	molar	incisors	canines	premolar	molar
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
5	7.0 ± 0.9	6.9 ± 1.2	NA	12.7 ± 2.6	5.7 ± 0.5	6.3 ± 0.1	NA	20.7 ± 2.6
10	4.8 ± 0.8	4.7 ± 0.9	4.9 ± 1.1	10.8 ± 2.4	4.4 ± 0.9	4.4 ± 1.0	5.1 ± 1.1	12.4 ± 2.2
15	4.3 ± 0.4	4 ± 0.4	4.3 ± 0.9	9.1 ± 2.3	4.1 ± 0.4	4.1 ± 0.5	4.2 ± 0.6	6.7 ± 2.5
Adult	3.6 ± 0.7	3.3 ± 0.8	4.2 ± 1.2	9.0 ± 2.9	3.5 ± 0.6	3.6 ± 0.8	3.8 ± 1.1	6.6 ± 1.6
P value	<0.001	<0.001	0.903	0.023	<0.001	<0.001	<0.001	<0.001

Table 4. The mean and standard deviation values of effective dose for bitewing radiography for different teeth in different age groups in terms of µSv.

Type of teeth / Age group	incisors	canines	premolar	molar
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
5	6.48 ± 0.70	6.05 ± 0.46	NA	10.06 ± 1.89
10	4.98 ± 0.90	4.38 ± 0.89	4.82 ± 0.87	9.73 ± 1.88
15	4.70 ± 0.45	4.32 ± 0.46	4.71 ± 0.84	9.47 ± 2.95
Adult	4.15 ± 0.84	3.83 ± 0.86	4.46 ± 1.28	9.10 ± 2.77
P value	<0.001	<0.001	0.003	0.053

The results of the estimation of REID values for different dental radiographic examinations

Figures 1 to 4 show the mean and standard deviation of REID values due to periapical radiography for different teeth in the upper and lower jaws of male and female patients in different age groups in terms of number per ten million.

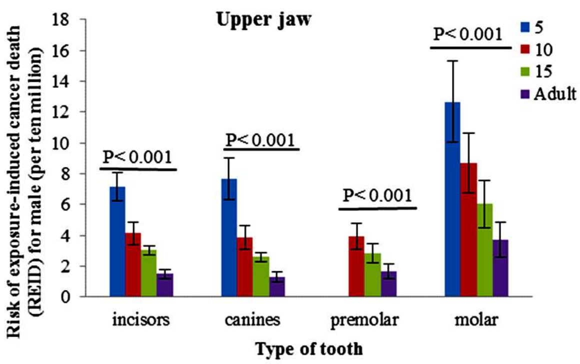

Figure 1. The mean and standard deviation of REID values due to **periapical** radiography for different teeth in the **upper jaw of male patients** in different age groups in terms of number per ten million.

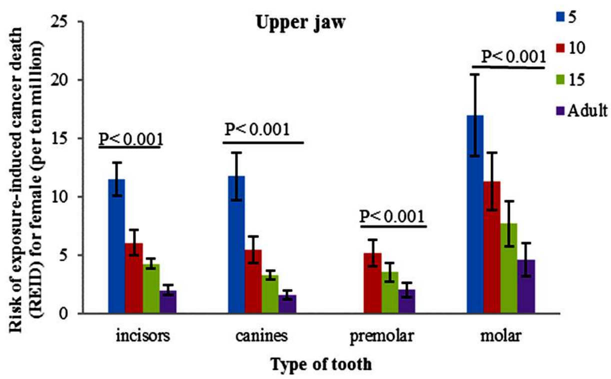

Figure 2. The mean and standard deviation of REID values due to **periapical** radiography for different teeth in the **upper jaw of female patients** in different age groups in terms of number per ten million.

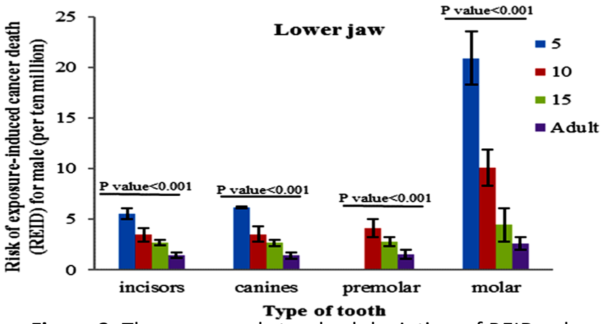

Figure 3. The mean and standard deviation of REID values due to **periapical** radiography for different teeth in the **lower jaw of male patients** in different age groups in terms of number per ten million.

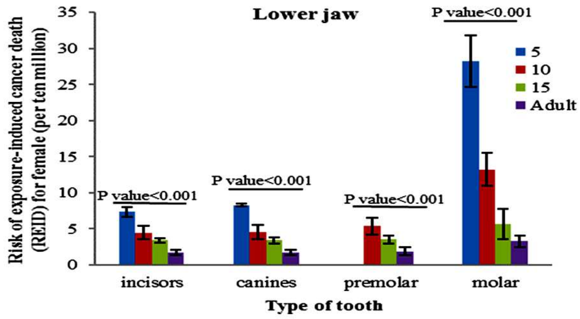

Figure 4. The mean and standard deviation of REID values due to **periapical** radiography for different teeth in the **lower jaw of female patients** in different age groups in terms of number per ten million.

Figures 5 and 6 show the mean and standard deviation of REID values due to bitewing radiography for different teeth for male and female patients in different age groups in terms of number per ten million.

Figure 7 shows the mean and standard deviation of REID values due to panoramic radiography for male and female patients in different age groups in terms of number per ten million. As in all diagrams overall cancer risk from radiation exposure is higher in children than in adults ($p<0.02$) and in female patients compared to male patients ($p<0.05$).

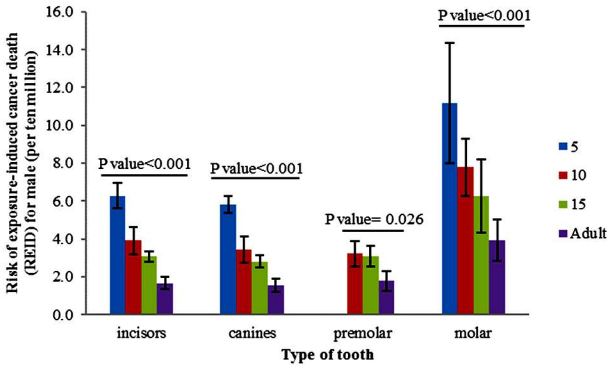

Figure 5. The mean and standard deviation of REID values due to **bitewing** radiography for different teeth for **male patients** in different age groups in terms of number per ten million.

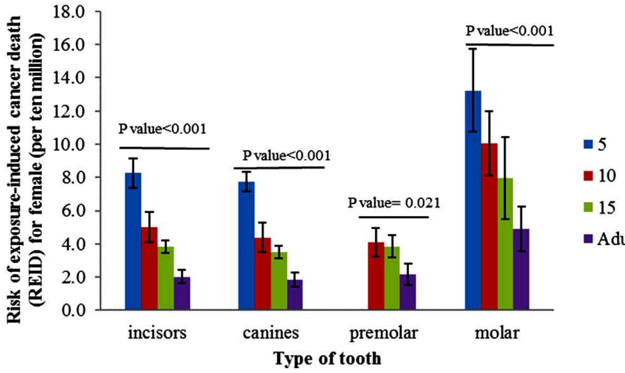

Figure 6. The mean and standard deviation of REID values due to **bitewing** radiography for different teeth for **female patients** in different age groups in terms of number per ten million.

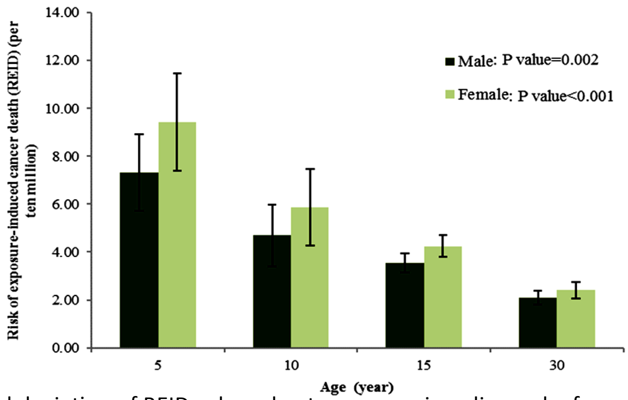

Figure 7. The mean and standard deviation of REID values due to panoramic radiography for male and female patients in different age groups in terms of number per ten million.

DISCUSSION

In this study, input dose, organ dose, effective dose, and REID values in dental radiographies of periapical, bitewing, and panoramic were obtained for some age groups in both genders. Also, this information was separately obtained in intra-oral radiographies, depending on the type of teeth (incisors, canines, premolars and molars in lower and upper jaws). In the previous studies, results were mostly obtained for an adult patient regardless of age, gender and type of teeth. In most of them, input dose or effective dose and or dose of some organs were only obtained. No study has comprehensively obtained input dose, organ doses, effective dose, cancer risk based on age, gender, type of teeth (for intra-oral radiographies), but in the current study, all of the above items have been completely obtained.

In this study, the DAP values increased for almost all examinations, with increasing age, because the radiation conditions which have a direct relation with the DAP values, increase with patient age. The DAP value for an adult patient undergoing a panoramic radiography was 94.43 mGycm^2 which was consistent with results of Horner *et al.* [1] and Lee *et al.* [21], but was less than the results of Zenone *et al.* [22]. On the other hand, for almost all examinations, the effective dose decreases with increasing age, which is similar to results of Zenone *et al.* [22]. This can be due to the fact that, unlike conventional radiography in which the size of the radiation field can be adjusted according to patient size, in all the dental radiographies, the radiation field size is identical for different ages. Therefore, in younger age groups, further organs and tissues were exposed. The mean of effective doses in our study for an adult for periapical, bitewing, and panoramic radiographies were 3 to 9 µSv, 4 to 9 µSv and 5 µSv, respectively, while the effective doses in the studies by Hart *et al.* [23], Tung *et al.* [24], and the Department of Health Services Europe [25] were 5, 7, 5 µSv, respectively, for periapical radiography. For bitewing radiography, it was 5, 4 and 5 µSv in the studies by Lam *et al.* [7], Kodak Dental Systems [26], and Ludlow *et al.* [6], respectively. For panoramic radiography, the effective doses were 2 to 9 and 3.85 µSv in the studies by Lecomber *et al.* [27] and Danforth *et al.* [28], respectively, which were relatively consistent with our findings. The differences between the results of the current study and some other studies could be due to the use of the new tissue weighting factors (ICRP 103) [9] for calculation of effective doses in this study, instead of the old weighting factors tissues (ICRP 60) [12] used in some previous studies.

In accordance with the results of the present study (figures 1 to 7), the overall risk of cancer from radiation in children was more than adult and in female patients was more than male patients in the all three types of dental X-ray test. In a few studies, radiation-induced carcinogenesis risk was only calculated for adults, regardless of gender. In the study by Souza *et al.* [8], the risk of radiation-induced carcinogenesis for an adult, was 1 to 14 per ten million in the periapical radiography, in the study by Ludlow *et al.* [6] in the bitewing radiography was 3 per ten million, and in the study by Horner *et al.* [1] in panoramic radiography was 2 to 9 per ten million which was relatively consistent with our results. The differences between the results of the current study and some other studies could be due to the variations in devices, radiation conditions, and methods of calculation. Another difference between the REID values in our study and the other studies can be due to the fact that in the other studies, for obtaining cancer risk, the effective dose was simply multiplied by constant coefficients, while in our study, risk assessment was done based on the models published by the BEIR VII [14]. In general, the REID values for dental radiographies are about 10 times smaller than ones of conventional radiographies [29, 30].

One limitation of this study was the large range of age and size of patients. To solve this problem, four standard age groups have been chosen, representing 5-, 10-, and 15-year-old, and adult patients. These selections of age groups have the advantage of matching the phantoms which are often used in other studies [4, 24-26] and also in Monte Carlo simulation programs [18]. The complete comparison of the results of this study with other studies was another limitation, because most of their results were only for an adult, and some of them didn't exactly mention the type of examinations i.e. they used general terms such as dental radiography or intra-oral radiography that was not clear which kinds of radiographies were surveyed. To solve this problem, the studies, which had characterized the type of examination, were compared in this study.

CONCLUSION

In accordance with the results of the present study, the overall risk of cancer from radiation in children was more than adult and in female patients is more than male patients in dental X-ray examinations. The REID values will help dentists to justify the requesting of the dental examinations by considering their benefits for the diagnosis and dental treatment planning, on one side, and awareness of the risk of the radiation-induced cancer, on the other hand. It is recommended that the average risk of cancer caused by exposure due to each examination be considered as a guide to assess the risks and the benefits for each age group. This is very important for children, because their organs and tissues are developing and dividing, which certainly are more sensitive to the ionizing radiation. On the other hand, repeating the examinations due to the lack of cooperation of children can proportionally increase the risk of examinations. So, the awareness of the REID values from exposures in different dental X-ray examinations is necessary for the justifications of these examinations and avoiding the superfluity and shortage in this field.

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