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Patient Risk Related to Common Dental Radiographic Examinations: The Impact of 2007 International Commission on Radiological Protection Recommendations Regarding Dose Calculation

John B. Ludlow, Laura E. Davies-Ludlow and Stuart C. White

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Patient risk related to common dental radiographic examinations

The impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation

John B. Ludlow, DDS, MS; Laura E. Davies-Ludlow, BS; Stuart C. White, DDS, PhD

ABSTRACT

Background. In 2007, the International Commission on Radiological Protection (ICRP) revised estimates of the radiosensitivity of tissues including those in the maxillofacial region. The authors conducted a study to reassess patients' risk related to common dental radiographic exposures using the 2007 ICRP recommendations.

Methods. The authors used a tissue-equivalent head phantom to measure dose. They calculated effective doses by using both 1990 and revised 2007 ICRP recommendations. Effective dose is a calculation that takes into consideration the different sensitivities of organs to long-term effects from ionizing radiation. It is the preferred method for comparing doses between different types of exposures.

Results. Effective doses (per the 2007 ICRP) in microsieverts were as follows: full-mouth radiographs (FMX) with photo-stimulable phosphor (PSP) storage or F-speed film with rectangular collimation, 34.9 µSv; four-image posterior bitewings with PSP or F-speed film with rectangular collimation, 5.0 µSv; FMX using PSP or F-speed film with round collimation, 170.7 µSv; FMX with D-speed film and round collimation, 388 µSv; panoramic Orthophos XG (Sirona Group, Bensheim, Germany) with charge-coupled device (CCD), 14.2 µSv; panoramic ProMax (Planmeca, Helsinki, Finland) with CCD, 24.3 µSv; posteroanterior cephalogram with PSP, 5.1 µSv; and lateral cephalogram with PSP, 5.6 µSv. These values are 32 to 422 percent higher than those determined according to the 1990 ICRP guidelines.

Conclusions. Although radiographs are an indispensable diagnostic tool, the increased effective doses of common intraoral and extraoral imaging techniques are high enough to warrant reconsideration of means to reduce patients' exposure.

Clinical Implications. Clinicians can reduce patients' dose substantively by using digital receptors or F-speed film instead of D-speed film, rectangular collimation instead of round collimation and radiographic selection criteria.

Key Words. Dental radiography; radiation dosage; risk assessment.
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In 1990 the International Commission on Radiological Protection (ICRP) determined that effective dose was the preferred unit of measure for comparing risk from different radiographic examinations.[1] Effective dose was created to provide a dose quantity related to the probability of health detriment due to stochastic effects of exposure to low doses of ionizing radiation. Effective dose is derived from the weighted sum of doses to tissues that are known to be sensitive to radiation and so can be derived only by calculation. The tissue-weighting factors are derived from the extrapolation of epidemiologic evidence. Effective dose was intended for use in radiation protection, but it has found wide application in comparing risks of exposures involving only certain parts of the body.[2]

In 2007, the ICRP updated the method for calculating effective dose on the basis of the latest available scientific information on the biology and physics of radiation exposure.[3] The 2007 method involves revised estimates of the radiosensitivity of tissues and their corresponding tissue-weighting factors. Brain tissue

Dr. Ludlow is a professor, Department of Diagnostic Sciences, University of North Carolina School of Dentistry, 1008 Tarson Hall, Chapel Hill, N.C. 27599-7450, e-mail "jbl@email.unc.edu". Address reprint requests to Dr. Ludlow.
Ms. Davies-Ludlow is a senior dental student, University of North Carolina School of Dentistry, Chapel Hill.
Dr. White is a professor and the chair, Oral and Maxillofacial Radiology, University of California Los Angeles School of Dentistry.

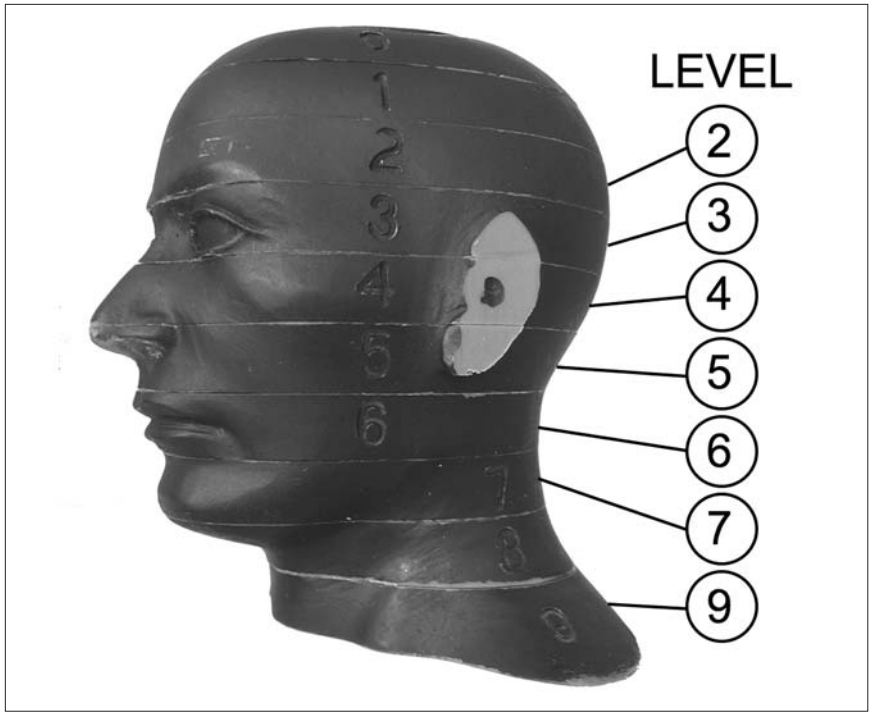

Figure. Adult skull and tissue-equivalent phantom (RANDO, The Phantom Laboratory, Salem, N.Y.) showing levels where dosimeters were located. Image reproduced with permission of the British Institute of Radiology from Ludlow and colleagues.[4]

was given more weight and, for the first time, salivary glands, oral mucosa and extrathoracic airway tissues were included in the weighting scheme. These changes regarding tissues in the maxillofacial region have the potential to affect estimations of risk from dental examinations significantly. We hypothesize that use of the 2007 ICRP data will result in an upward reassessment of effective dose from common dental radiographic examinations and their associated detriment.

MATERIALS AND METHODS

We used a phantom (RANDO, The Phantom Laboratory, Salem, N.Y.) consisting of a small adult skull and surrounded by soft-tissue–equivalent material (Figure[4]) to simulate a patient in the various radiographic examinations. We placed thermoluminescent dosimeter (TLD) chips (TLD 100, supplied and analyzed by Landauer, Glenwood, Ill.) at 24 selected locations in the head and neck of the phantom to record the distribution of the absorbed radiation dose. (For detailed information regarding placement of the chips, see Appendix 1, which is available as supplemental data to the online version of this article [found at "http://jada.ada.org"].) We performed 10 replicate examinations for each technique to provide a more reliable measure of radiation in the dosimeters. To determine the exposure per examination for each dosimeter, we divided TLD doses by 10.

We measured the radiation doses from a full-mouth intraoral radiographic series (FMX), a four-image posterior bitewing (BW) examination, a panoramic image, and lateral and posteroanterior (PA) cephalometric images. For intraoral photo-stimulable phosphor (PSP) and F-speed film images, we used a constant-potential direct-current intraoral radiographic unit (Intra, Planmeca, Helsinki, Finland) at 70 kilovolts and 8 milliamperes. We extrapolated doses for D-speed film by multiplying the F-speed film doses by 2.3, the exposure difference required to give both film types comparable densities in fresh processing solutions.[5] We used a 6-centimeter–diameter position-indicating device (cone) with a 30-cm source-to-end distance for round-cone techniques. For rectangularly collimated exposures, we placed over the cone's end a diaphragm collimator insert with a 3.6-cm × 4.6-cm opening (Rinn, Elgin, Ill.). Following are specific details regarding the four types of images we used:

- the 18-image FMX: detailed exposure parameters are available in Appendix 2, which is available as supplemental data to the online version of this article (found at "http://jada.ada.org").
- the four-image BW examination: this consisted of a premolar and molar image on each side of the phantom.
- cephalometric images: we made cephalometric images with a rotating anode source (Interay,

ABBREVIATION KEY. ADA: American Dental Association. **BW:** Bitewing. **CCD:** Charge-coupled device. ***E*:** Effective dose. **FMX:** Full-mouth radiographs. H_T: Equivalent dose. **IRCP:** International Commission on Radiological Protection. **MEACR:** Mass energy absorption coefficient ratio. **PA:** Posteroanterior. **PSP:** Photo-stimulable phosphor. **TLD:** Thermoluminescent dosimeter. w_T**:** Tissue-weighting factor.

Varian Medical Systems, North Charleston, S.C.); we acquired cephalograms by positioning the phantom in a cephalostat (Wehmer cephalostat, Addison, Ill.) with a source-midsagittal plane distance of 152.4 cm (60 inches), and we made PA projections by using 75 kilovolt-peak and 11.0 milliampere-second exposures and lateral projections by using 77 kVp and 6.5 mAs exposures.

- panoramic radiographs: we used two units, a ProMax (Planmeca) operated at 68 kV and 13 mA with a 16 second exposure time and an Orthophos XG (Sirona Group, Bensheim, Germany) operated at 64 kV and 8 mA for 14.1 seconds.

We averaged doses at different positions within a tissue or organ. The products of these values and the percentage of a tissue or organ irradiated in a radiographic examination were used to calculate the equivalent dose in microsieverts (Appendix 3, available as supplemental data to the online version of this article [found at "http://jada.ada.org"]). Appendix 4 (available as supplemental data to the online version of this article [found at "http://jada.ada.org"]) provides the details for the calculation of equivalent dose for bone marrow, bone, skin and extrathoracic airway.

RESULTS

We calculated effective dose, expressed in µSv, by using the equation $E = \sum w_T \times H_T$ and by using 2007 ICRP calculations,[3] where effective dose (E) is the sum of the products of the tissue-weighting factors (w_T), the relative contribution of each organ or tissue to the overall risk (Table 1) and the equivalent doses (H_T) (Table 2). Salivary glands and oral mucosa consistently received the highest equivalent doses of all tissues from common dental radiographic examinations. Of these, an FMX with D-speed film and round collimation resulted in the largest effective dose (Table 3, page 1242). The effective doses for examinations computed with the 2007 ICRP method are increased from 32 to 422 percent above the corresponding values computed with the 1990 ICRP method.

Radiation detriment, the total harm to an exposed population and its descendants, can be calculated from effective dose. Detriment includes the weighted probabilities of fatal and nonfatal cancer, relative length of life lost and hereditary effects. The coefficient assigned to these combined effects by the 1990 ICRP recommendations was 0.073 events per sievert. Because of great uncertainty regarding the dose response below 1 Sv, the 2007 ICRP commission concluded that no specific estimate of risk of noncancer diseases is possible after exposure to low doses. Therefore, we used a risk coefficient of 0.055 events per Sv on the basis of cancer risk alone for the 2007 risk estimates for dental radiography.[3] The estimate of detriment from dental radiography is substantively greater according to the 2007 ICRP method compared with the 1990 method, even with the reduced risk coefficient[6] (Table 4, page 1242).

TABLE 1

Tissue-weighting factors for calculation of effective radiation dose, according to the International Commission on Radiological Protection's 1990 and 2007 recommendations.

TISSUE	TISSUE-WEIGHTING FACTOR	
	1990*	2007†
Bone Marrow	0.12	0.12
Breast	0.05	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Gonads	0.20	0.08
Bladder	0.05	0.04
Esophagus	0.05	0.04
Liver	0.05	0.04
Thyroid	0.05	0.04
Bone Surface	0.01	0.01
Brain	NA‡	0.01
Salivary Glands	Not included	0.01
Skin	0.01	0.01
Remainder Tissues	0.05§	0.12¶

* Source: International Commission on Radiological Protection.[1]
† Source: Valentin.[3]
‡ NA: Not applicable; classified as a remainder tissue.
§ Adrenals, **brain,** upper large intestine, small intestine, kidney, **muscle**, pancreas, spleen, thymus, uterus (text in **boldface** represents remainder tissues used for calculation of maxillofacial dose).
¶ Adrenals, **extrathoracic region,** gallbladder, heart, kidneys, **lymphatic nodes, muscle, oral mucosa,** pancreas, prostate, small intestine, spleen, thymus and uterus/cervix (text in **boldface** represents remainder tissues used for calculation of maxillofacial dose).

DISCUSSION

The purpose of this study was to assess the effect of using the 2007 ICRP recommendations for calculating effective dose, in combination with

dosimetry and use of contemporary dental imaging modalities, on the estimated risk for dental patients. We hypothesized that inclusion of brain and salivary glands in the tissue list—as well as extrathoracic airway tissues, lymphatic nodes, muscle and oral mucosa—would contribute to an elevated risk compared with the 1990 effective dose. We measured the dose received by these tissues and applied the latest ICRP tissue and tissue-weighting factors to estimate the risk arising from common dental examinations. The results of this study show that after application of the 2007 ICRP guidelines, the risk associated with dental radiography is 32 to 422 percent higher than that estimated according to the 1990 ICRP guidelines.

TABLE 2

Equivalent dose* to tissues and organs in the head and neck resulting from common dental radiographic examinations.

VALUES FROM RANDO PHANTOM,† BY TYPE OF EXAMINATION	TISSUE OR ORGAN						
	Bone Marrow	Thyroid	Esophagus	Skin	Bone Surface	Salivary Glands	Brain‡
FMX¶ with PSP# or F-Speed Film and Rectangular Collimation	29	117	10	90	117	783	33
BW** with PSP or F-Speed Film and Rectangular Collimation	4	0	0	26	17	156	0
FMX with PSP or F-Speed Film and Round Cone	134	550	134	122	542	4,110	100
Panoramic Orthophos XG†† (CCD‡‡)	14	25	12	4	60	313	10
Panoramic ProMax§§ (CCD)	20	67	7	6	82	761	17
Posteroanterior Cephalometric (PSP)	11	30	8	4	42	55	35
Lateral Cephalometric (PSP)	5	45	7	4	20	80	40

* In microsieverts.
† RANDO Phantom is manufactured by The Phantom Laboratory, Salem, N.Y.
‡ Source: International Commission on Radiological Protection.[1]
§ Source: Valentin.[3]
¶ FMX: Full-mouth radiographs.
# PSP: Photo-stimulable phosphor.
** BW: Bitewing.
†† Orthophos XG is manufactured by Sirona Group, Bensheim, Germany.
‡‡ CCD: Charge-coupled device.
§§ ProMax is manufactured by Planmeca, Helsinki, Finland.

(Continued on next page)

The 2007 ICRP tissue and tissue-weighting factors reflect newly available cancer incidence and mortality data, whereas the 1990 ICRP guidelines were based only on mortality data. Incidence data provides a more complete description of cancer burden than does mortality data alone, particularly for cancers that have a high survival rate. Many of the cancer incidence data come from the Life Span Study of Japanese atomic bomb survivors, which has been updated through 1998, and have been corrected by means of DS86 bomb dosimetry.[3] Increasing evidence of cancer risk in salivary glands and brain caused these organs to be given increased weight in 2007. Indeed, an increased incidence of cancers in these regions has been linked to dental radiography.[7-9] The 2007 ICRP recommendations also reduced the weight for the thyroid gland and esophagus to 0.04 from 0.05.

The increases in effective dose for panoramic imaging measured in this study reflect primarily the addition of salivary glands as a target tissue. Inclusion of salivary glands is particularly important because in panoramic scanning, the location of the posterior rotational centers coincides with the parotid and submandibular glands, and the anterior rotational center coincides with the sublingual glands. Although much of the scanned anatomy is exposed to radiation only transiently, structures at the rotational centers are exposed continuously. Accordingly, effective doses arising from dental panoramic imaging are larger than those associated with common imaging procedures that produce a more uniform distribution of absorbed energy within the scanned volume.

TABLE 2 (CONTINUED)

Remainder Tissues/Organs				
Brain§	Lymphatic nodes‡	Extrathoracic airway‡	Muscle‡§	Oral mucosa‡
33	38	717	38	959
0	6	112	6	152
100	192	3,414	192	4,704
10	18	309	18	437
17	26	450	26	622
35	3	45	3	47
40	4	69	4	77

Dental radiography is indispensable, because it contributes enormous diagnostic benefits. However, study of the Japanese survivors of the World War II atomic bombings and numerous other cohorts exposed to ionizing radiation has shown that radiation can cause cancers.[3] The difficulty comes in estimating the risks from low-level exposures such as those used in dentistry. In this dose range, epidemiologic studies fail because of statistical limitations, thus necessitating the use of mathematical risk models. Most prominent among these is the linear nonthreshold dose-response model. This model extrapolates the risk associated with high doses where there are known effects to the low-dose range and where direct measurement of harm, if any, is not possible because of limitations in statistical analysis. In the absence of persuasive evidence of a threshold dose, below which there are no adverse effects, use of the linear nonthreshold dose-response model is widely considered to be a prudent and conservative basis for estimating risk and establishing policies for radiation protection. If there is a threshold dose, then the actual risk attributable to dental radiography may be much lower than that currently estimated, or even zero. Thus, given the increased possibility of the risk as measured in this study, we are compelled to reconsider means of reducing all unnecessary exposure.

The results of this study reinforce previous American Dental Association (ADA) recommendations[10] regarding simple and effective means to reduce patient exposure substantively. The most widely used FMX technique in the United States includes use of a round aiming cylinder and D-speed film. This technique carries more than a 20-per-million risk of death. A state-of-the-art FMX, made via rectangular collimation and a high-speed film or digital sensor, results in a two-per-million increased risk of fatal cancer. This 10-fold reduction in risk comes from making minor changes in radiographic technique and underscores the validity of these ADA recommendations:

- Clinicians should not use film slower than E-speed for dental radiographs. F-speed film, PSP and charge-coupled device (CCD) sensors all are faster than E-speed film and, thus, should be used.
- Radiographic equipment should provide rectangular collimation for exposure of periapical and BW radiographs.
- The clinician should obtain radiographs only after examining the patient and determining his or her individual needs. Radiographic selection criteria can inform this process.

CONCLUSIONS

Compared with previous guidelines, the 2007 ICRP recommendations for estimating risk associated with exposure to radiation place increased emphasis on structures in the oral region, particularly the salivary glands. If one uses the revised recommendations for calculating effective dose, the dental radiographic procedures we evaluated in this study are 32 percent to 422 percent riskier than previously thought. By using digital sensors or F-speed film instead of D-speed film, combined with rectangular collimation instead of round collimation, dentists can reduce patients' exposure by a factor of 10 for BW and FMX

TABLE 3

Effective dose for commonly used dental radiographic examinations: comparison of International Commission on Radiological Protection (ICRP) methods from 1990* and 2007.†

TYPE OF EXAMINATION	EFFECTIVE DOSE (MICROSIEVERTS)		CHANGE IN EFFECTIVE DOSE 1990-2007 (%)
	ICRP 1990 Tissue Weights	ICRP 2007 Tissue Weights	
FMX‡ with PSP§ or F-Speed Film and Rectangular Collimation	12.2	34.9	186
BW¶ with PSP or F-Speed Film and Rectangular Collimation	1.0	5.0	422
FMX with PSP or F-Speed Film and Round Cone	58.4	170.7	192
FMX with D-Speed Film and Round Cone#	133	388	192
Panoramic Orthophos XG** (CCD††)	4.3	14.2	231
Panoramic ProMax‡‡ (CCD)	7.1	24.3	241
Posteroanterior Cephalometric (PSP)	3.9	5.1	32
Lateral Cephalometric (PSP)	3.7	5.6	51

* Source: International Commission on Radiological Protection.[1]
† Source: Valentin.[3]
‡ FMX: Full-mouth radiographs.
§ PSP: Photo-stimulable phosphor.
¶ BW: Bitewing.
# Calculated as F-speed film value × 2.3 (see Ludlow and colleagues[5]).
** Orthophos XG is manufactured by Sirona Group, Bensheim, Germany.
†† CCD: Charge-coupled device.
‡‡ ProMax is manufactured by Planmeca, Helsinki, Finland.

TABLE 4

Detriment from common dental radiographic examinations: comparison of International Commission on Radiological Protection (ICRP) methods from 1990* and 2007.†

TYPE OF EXAMINATION	PER CAPITA BACKGROUND‡ (DAYS)		PROBABILITY OF X IN A MILLION STOCHASTIC EFFECT, ICRP 1990	PROBABILITY OF X IN A MILLION FATAL CANCER, ICRP 2007
	ICRP 1990	ICRP 2007		
FMX§ with PSP¶ or F-Speed Film and Rectangular Collimation	1.5	4.3	1	2
BW# with PSP or F-Speed Film and Rectangular Collimation	0.1	0.6	0.1	0.3
FMX with PSP or F-Speed Film and Round Cone	7	21	4	9
FMX with D-Speed Film and Round Cone**	16	47	10	21
Panoramic Orthophos XG†† (CCD‡‡)	0.5	1.7	0.3	0.8
Panoramic ProMax§§ (CCD)	0.9	3.0	0.5	1.3
Posteroanterior Cephalometric (PSP)	0.5	0.6	0.3	0.3
Lateral Cephalometric (PSP)	0.4	0.7	0.3	0.3

* Source: International Commission on Radiological Protection.[1]
† Source: Valentin.[3]
‡ Based on a naturally occurring U.S. background radiation of 3.0 microsieverts per year. Source: National Council on Radiation Protection and Measurements.[6]
§ FMX: Full-mouth radiographs.
¶ PSP: Photo-stimulable phosphor.
# BW: Bitewing.
** Calculated as F-speed film value × 2.3 (see Ludlow and colleagues[5]).
†† Orthophos XG is manufactured by Sirona Group, Bensheim, Germany.
‡‡ CCD: Charge-coupled device.
§§ ProMax is manufactured by Planmeca, Helsinki, Finland.

examinations. When considering the use of radiographs, the dentist first should examine the patient and determine his or her individual radiographic needs.

Until we have clear evidence for a threshold dose below which our patients are not at risk, we must assume that radiography involves a small, but real, risk to our patients. When examining a patient and considering his or her radiographic needs, each clinician should ask the simple question, "How is this exposure likely to benefit my patient?" When the clinician can identify a reasonable indication for the exposure, then it is most likely that for this patient the benefit will far exceed any risk, and the clinician will satisfy the exhortation of Hippocrates to "do no harm." ■

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