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Estimation of x-ray radiation related cancers in US dental offices: Is it worth the risk?

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Objectives. The objective of this study was to estimate the possible number of cancer cases produced during 2019 in US dental offices from radiography, estimate the possible reduction in those rates resulting from use of intraoral rectangular collimation and selection criteria, and determine the frequency and quality of website radiation risk information and informed consent forms.
Study Design. An analysis of dental radiation examinations in 2014 to 2015 US national survey data, Nationwide Evaluation of X-ray Trends, and National Council on Radiation Protection and Measurements surveys was performed, in addition to an analysis of 2008 to 2020 *Journal of Clinical* Orthodontics national orthodontic surveys for radiographic examination frequencies. Lifetime attributable cancer risk estimates from US and European studies were used to generate the total dental and orthodontic office cancer totals. In total, 150 offices were examined online for the quality and frequency of risk information in websites and consent forms.
Results. The 2019 estimate for all office cancers is 967. Collimation and selection criteria could reduce this to 237 cancer cases. Most cancers arise from intraoral and cone beam computed tomography examinations, with 135 orthodontic cancers over 21 months (average treatment time). Collimation and selection criteria could reduce this to 68. Only 1% of offices use collimators or informed consent for radiography. The website and consent information were of poor quality.
Conclusions. Dentists are not following selection criteria or using collimators according to guidelines. Up to 75% of cancer cases could be avoided. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;132:597−608)

It is just over 125 years since Wilhelm Conrad Röntgen discovered x-rays, with clinical applications commencing within months.[1] Although the diagnostic benefits were easily appreciated, the carcinogenic potential of low dose x-ray examinations was not known for a long time.[2] X-ray exposures can be divided into high-dose, such as radiotherapy and fluoroscopy, and low-dose diagnostic radiology. Once a patient receives more than approximately 2 Gy of absorbed dose to the skin, erythema can be seen.[3] At these x-ray dose levels and above, the dose is classified as deterministic, meaning that it is high enough to guarantee observable side effects. Dental x-ray diagnostic examinations are nondeterministic because the effective doses (EDs) are in the range of 3 to 1000 μSv.[4] At these levels there are almost always no clinically observable signs of radiation damage and the risk is from stochastic, random effects of ionizing radiation exposure, causing sufficient damage to cells to lead to cancer, DNA damage, or death of single cells. The risk of cancer development from very low x-ray doses, using the linear no-threshold hypothesis,[5,6] has been estimated from higher doses caused by atomic bombs and nuclear accidents. Because low-dose stochastic cancers have no unique cellular characteristics to differentiate them from cancers caused by chemicals, viruses, and natural background radiation, predictions of cancer generation are statistical.[5] Any individual cancer in the head and neck region may be associated with diagnostic radiation exposure, but cause and effect cannot be proven. Nevertheless, the linear no-threshold hypothesis for cancer is widely accepted and forms the basis for teaching ALARA, exposing patients to doses as low as reasonably achievable.

"Dental x-rays are the most frequently used radiologic procedure in the US for healthy individuals." (page 108)[6] For many years, researchers have been measuring and estimating the doses and risks from dental radiography; intraoral (IO), panoramic (Pan), cephalometric (Ceph), and, more recently, cone beam

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Statement of Clinical Relevance

US dentists may cause 967 cases of cancer per year from dental radiography. Use of rectangular collimation and selection criteria could reduce this to 237. The trend in orthodontic treatment is to replace lower dose panoramic and cephalometric radiography with higher dose cone beam computed tomography.

computed tomography (CBCT).[6] However, simple recommendations, such as using selection criteria[7] to reduce the number of unnecessary radiographs and the implementation of rectangular collimation for intraoral equipment[8] to reduce the dose of IO, have not been widely adopted.[8] Dose reductions of 80% have been reported when using rectangular collimators (RCs) and RCs with thyroid shields in children.[4] The Nationwide Evaluation of X-ray Trends (NEXT) dental survey found that only 0.6% of offices used rectangular collimation in 2014 and 2015.[8] A recent survey of pediatric dentists reported that only 22% used rectangular collimation.[9]

Previous work on dental radiography risk estimates has described risk in terms of fatal cancer cases per 1 million radiographic examinations,[10] per 100,000 examinations,[11] and even 3 per 18,200 examinations.[12] However, no recent paper has presented a projection for the total number of possible cancer cases resulting from all dental offices or by specialty in the United States. Children are especially sensitive to x-rays, with girls more than twice as sensitive as boys.[11,12] Children aged 11 to 15 years have more than twice the risk of 22-year-olds.[11,12] Ludlow et al. estimated the risks for IO, Pan, and Ceph examinations in 2008, but there was no assessment of the effects of age and sex.[10] Recently, Johnson and Ludlow published estimates of ED using phantoms to represent adults and 10-year-old children.[13] In 2008, CBCT was a relatively new radiographic technology and was not included in the estimations.[10] Since then, CBCT has seen large market growth in US dental offices, especially in orthodontic practice, with an increase from 2% of all children in 2008 to 16% in 2020 routinely undergoing CBCT examinations.[14] In addition, a 2010 survey reported that 18% of orthodontic residency programs routinely used CBCT examinations on every patient.[15] Therefore, it is important to study the radiation risks for child orthodontic patients, because they have been reported as receiving multiple radiographic examinations from IO, Pan, Ceph, and CBCT in one course of treatment.[14]

Dental patients are required to read and sign informed consent forms before any dental treatment can be performed.[16] For a consent to be valid, the following conditions apply: "(1) patient competence (legal ability and capacity to understand and decide), (2) disclosure of material information (in this case by the dentist), (3) understanding (by the patient), (4) voluntariness (with respect to the patient), and (5) consent (patient authorization to proceed)." (page 78)[16] A number of studies have reported that dental informed consent forms fail to comply with those aims.[17,18] Geist reported that some dental x-ray informed consent forms incorrectly stated that the American Dental Association (ADA) recommended "full-mouth series every 3 to 5 years and bitewings every 1 to 2 years." (Page A9)[19] In a limited hospital study, parents have reported not receiving sufficient or understandable information regarding radiation dose and available imaging alternatives to x-ray−based examinations.[20] It is important to know what information patients are provided with, relevant to dental radiography, for informed consent. A review of the literature did not provide this for general dentistry, pediatric dentistry, or orthodontics offices.

The aim of this article was to estimate (1) the possible total rates for cancer incidence in the United States associated with dental and maxillofacial radiology, (2) the potential decrease in radiation dose if IO rectangular collimation is used and if selection criteria are used for prescribing radiographs, and (3) the quality and number of informed consent forms.

METHODS

Estimates for the number of examinations for the US population from dental radiography (IO, Pan, CBCT) were derived from 2 reports: the 2014 to 2015 NEXT[8] and *Medical Radiation Exposure of Patients in the United States*.[21]

Estimates for the number of examinations for people undergoing a course of orthodontic treatment in 2020 to 2021 were derived from the 2020 *Journal of Clinical* Orthodontics (JCO) study of orthodontic diagnosis and treatment procedures.[14]

Estimates for the rate of cancer incidence per 1 million IO, Pan, and Ceph radiographic examinations were derived using data from Ludlow et al.[10] and Johnson and Ludlow.[13] Corresponding estimates for CBCT examinations were derived from Hedesiu et al.[11]

US population

Intraoral risk estimation. The NEXT survey was performed from 2014 to 2015 and surveyed 199 dental offices.[8] Since the survey, the number of dentists in the United States has increased by 1.04% to 201,515 as of 2019.[22] The NEXT estimates for the number of radiographic examinations were projected to 2019 using that figure. The National Council on Radiation Protection and Measurements (NCRP) report[21] stated that 72% of patients receiving IOs were adults and 28% were children. These numbers were used to divide the total number of examinations into those for adults and those for children. The NEXT IO estimates were for the number of complete radiographic examinations, not individual intraoral radiographs. To use the Ludlow risk estimates,[10,13] it was first necessary to convert the NEXT IO examinations into full mouth x-ray (FMX) for adults or 4 bitewing (BW) equivalents for children. NEXT provided the average number of IOs per examination for young children, children/

Table I. Estimation of US LAR for cancers generated in 2019 by dental radiography from NEXT[8] and NCRP[21] 2014 to 2015 surveys

Type of radiographic exam	*No. of exams*	*Equivalent FMX*	*Equivalent 4 BWs*	*LAR for cancer per 10^6 exams**	*Total no. of cancer cases for all radiographs from each type of exam*		
							Selection criteria −43% exams
Intraoral							
Adult	216,103,680	95,085,619		7.5	713[¶]	193[‡]	110
Child	84,040,320		18,675,627	6.1	114[¶]	83[‡]	47
Total IO exams[§]	300,144,000				**827**[¶]	**276**[‡]	**157**
Pan							
Adult	16,370,554			2.2	36		21
Child	6,366,326			3.0	19		11
Total Pan exams[§]	22,736,880				**55**		**32**
Ceph							
Adult	688,919			0.5	0.3		0
Child	1,771,507			1.1	1.9		0
Total Ceph exams[‖]	2,460,427				**1**		0
CBCT							
Adult	3,708,000			6.3	23		13
Child	1,468,000			41.5	61		35
Total CBCT[§]	5,176,000				**84**		**48**
Total x-ray exams	330,517,307						
Total cancer cases					**967**	**416**	**237**

LAR, lifetime attributable risk; *NEXT*, Nationwide Evaluation of X-ray Trends; *NCRP*, National Council on Radiation Protection and Measurements; *FMX*, full mouth x-ray; *BW*, bitewing; *IO*, intraoral; *Pan*, panoramic; *Ceph*, cephalometric; *CBCT*, cone beam computed tomography.

*LAR of cancer is calculated for children aged 10 to 12 years and adults aged 30 years.[†]Selection criteria estimate a 43% reduction in examinations except Ceph, because risk equates to only 1 cancer case.

¶Round collimation.

‡Rectangular collimator reduces ED by 73% (from 80% - 7% re-exposures).

§All radiographic totals increased by 1.04% to match 2019 increase in dentists.

‖Total Cephs = 0.75% of all IO, Pan, and CBCT examinations.

adolescents, and adults. NEXT also provided the number of re-exposures per examination. By combining these numbers, it was found that the average young child or child/adolescent had 4.5 intraoral exposures per examination. Because most of these were likely BWs, it was assumed that each child examination was equivalent to 4 BWs. The BW dose was estimated by taking the ED of 89 μSv for the 10-year-old FMX of 12 IOs[13] and dividing this by 3, producing a 4 BW ED of 30 μSv. The 4 BW lifetime attributable risk (LAR) for 10-year-olds was calculated from the BEIR VII (Biological Effects of Ionizing Radiation; table 12D1),[5] which contains the number of predicted lifetime cancer cases per 100,000 persons exposed to a single dose of 0.1 Gy. The 30 μSv ED was converted into 0.030 mSv to match the 100 mGy units used in the LAR table. Because the BEIR VII table is for 100,000 exposures, the LAR number was multiplied by 10 to adjust for 1,000,000 exposures.

The BEIR VII LAR is 2611 for 10-year-old girls and 1445 for boys. The average for both sexes is 2028. By multiplying 2028 by 0.030 mSv and dividing by 10, the LAR for a 10-year-old child is 6.1 cancer cases per 1,000,000 exposures (Table I).

For adults, the average number of IOs, including re-exposures, was 8.[8] Assuming that a FMX had 18 radiographs, 8 radiographs were equivalent to 0.44 FMX. The FMX equivalents were generated by multiplying this number times the number of adult examinations. The adult FMX ED was 86 μSv (0.086 mSv).[13] This assumed photostimulable phosphor plates or F-speed film and a round collimator.[13] The average LAR for a 30-year-old male or female is 875 (BEIR VII, table 12D1).[5] Using the same calculation described above to estimate the child BW LAR, the 30-year-old adult LAR was 7.5 cancer cases per 1,000,000 examinations.

The total number of cancer cases from IO examinations was multiplied by 0.2 to estimate an 80% reduction in cancer cases due to using RCs in adults and RCs with thyroid shields in children.[4] However, due to cone cuts that may make the image nondiagnostic, about 7% of these exposures will need to be repeated, reducing the dose saved from 80% to 73%.[23-26] Therefore, the IO total risk was reduced by 73%. A further reduction of 43% was applied by assuming that selection criteria would be used by all dentists.[27-29]

Panoramic risk estimation. The NEXT survey did not contain an estimate of the annual examination workload because of the lack of reliable estimates for the number of panoramic systems in the United States at the time of the survey. However, the later NCRP report[21] did, so their numbers were used. The NCRP report had a proportion of adult and child examinations similar to that in the NEXT survey. Because a Pan examination is usually one radiograph, the Pan radiographs were set to equal the examination number. The adult ED of 19 μSv[10] was used to calculate the LAR of 2.2 cancer cases per million examinations for a 30-year-old adult and LAR of 3.0 cancer cases for a 10-year-old child using BEIR VII risk estimates,[5] similar to the child BW and adult FMX calculations above.

Ceph risk estimation. The NEXT and NCRP surveys could not generate an accurate number of Ceph examinations but it was estimated that they were less than 1% of all dental x-ray imaging examinations. All IO, Pan, and CBCT examinations were added and multiplied by 0.0075 (or 0.75%) to give an estimate of less than 1% (2,460,427 Cephs; Table I). The ratio of adult to child patients for orthodontic treatment was calculated from the 2020 JCO survey as 28% adults to 72% children. The ED of 5.6 μSv per lateral cephalometric examination[10] was used to calculate the LAR[5] for 10-year-olds of 1.1 cancer cases per million examinations and 0.5 cancer cases for 30-year-olds, using the method discussed above.

CBCT risk estimation. The NEXT and NCRP surveys provided estimates of CBCT examinations, separated by child and adult examinations. The child and adult examination proportions compared very closely with the IO and Pan surveys. The NEXT and NCRP child EDs were similar to those from a European pediatric study,[11] although the European study provided EDs for 8 age groups from 0 to 20 years. Therefore, the ED of 204.8 μSv for 11- to 12-year-olds from the European study was used, because this age group had the highest ED and could match the age for initial orthodontic examinations. The BEIR VII LAR cancer risk was estimated to be 41.5 per million examinations (children aged 11 to 12 years).[5] The LAR of 41.5 is an average of 53.4 cancer cases for females and 29.6 cancer cases for males, which hides the large risk difference between girls and boys. The 21- to 22-year-old European group ED of 72.5 μSv was used to estimate LAR at age 30. The rationale was that head size does not change after age 21 to 22 and that one can estimate the LAR at 30 years using BEIR VII data. This is a better estimate for adults, because LAR decreases with age. Similarly, a 30-year-old's LAR of 6.3 cancer cases per million exposures was an average of 7.7 for females and 4.9 for males.

Orthodontic population

The 2020 JCO study was completed by 153 respondents with an active caseload of at least 50 patients per year, which is approximately 1.4% of the 10,814 orthodontists listed in the ADA 2019 estimate of practicing orthodontists.[22]

Orthodontists reported the percentage of cases in which they "routinely" or "occasionally" used FMX, Pan, Ceph, and CBCT for "pretreatment," "progress," and "posttreatment" records. For the dose and risk calculations, because "occasionally" had no definite interpretation, these reports were excluded; only "routinely" was interpreted as radiographic examinations performed on all patients. Although BW and periapical (PA) radiographs were recorded separately from FMX because their numbers and doses were low (≤3% routinely examined) and the number of radiographs was unknown (1-4 BWs, 1-13 periapicals), BWs and PAs were excluded from the dose risk calculations. However, they were included in a comparison to see how the percentage of radiographic examinations changed between 2016 and 2020 to help validate the data (Table II).

The LAR of cancer cases per million examinations for FMX was calculated using the ED for adults of 86 μSv[13] and the ED for children of 89 μSv.[13] Adult and child FMX examinations comprised 18 and 12 IO radiographs, respectively.[13] The LARs for 12-year-

Table II. Change in number of orthodontic radiographic examinations 2008 to 2014, 2014 to 2020,* JCO 2008 to 2020 survey data[14,32]

	Change in no. of x-ray exams 2014 to 2020			*Change in no. of x-ray exams 2008 to 2014*		
Type of x-ray exam	*Pre-treatment %*	*Progress %*	*Post-treatment %*	*Pre-treatment %*	*Progress %*	*Post-treatment %*
Full mouth series	+7	+2	+6	+1	0	−1
BW series	−2	0	−2	−1	0	−1
Periapicals	−5	−1	−1	−1	+1	−1
Panoramic	−6	−8	+2	−5	+1	−4
Cephalometric	+6	+4	+8	−10	+3	−9
CBCT	+6	+1	+8	+8	+5	+5

JCO, Journal of Clinical Orthodontics; BW, bitewing; *CBCT*, cone beam computed tomography.
*Orthodontists who said they routinely use pre-treatment, progress and post-treatment radiographic examinations during a course of treatment.

olds and 30-year-olds were 16.24 and 7.5 cancer cases per million examinations, respectively.[5] The proportion of adults and children in the orthodontic population (28% and 72%, respectively) was used to ensure that the LARs for different age groups were applied to the correct proportions of the population.

In a similar manner, Pan and Ceph LARs were calculated using EDs of 19 μSv and 5.6 μSv, respectively.[10]

Because the number of routine pretreatment CBCT examinations increased by 8% from 2008 to 2014 and another 6% (10% to 16%) from 2014 to 2020 (Table II),[14] we calculated what the risk would be if the number of CBCT examinations increased from 16% to 50% for routine pretreatment. At the same time, the number of Pans and Cephs that could be generated from the CBCT machines was proportionately reduced; that is, 86% Pans was reduced by 50% to 36% and 70% Cephs was reduced to 20% (Table III). Routine pretreatment CBCT examinations were increased to 86% to replace all Pans and Cephs so their numbers became 0% (Table III).

Survey of informed consent

Using an Internet web browser, a randomly identified population was created for 1 general dental office (GDO), 1 pediatric office (PO), and 1 orthodontic office (OO) for each US state, for a total of 50 for each category (total of 150 offices). The search criteria for the population were as follows:

Because CBCT devices generate the highest doses, the search criteria were "family dentistry," "CBCT," and the name of a US state. For GDOs, potential candidate offices were searched for information on a CBCT machine, any descriptive text about ionizing radiation/risk, and the presence of an online-accessible patient consent form for treatment. If any text was present describing radiation risk, such as "More radiation than a conventional dental radiograph," "More risk for children than adults," or "100 to 200 times less radiation than a medical CT of the head," this was noted as a specific attempt to indicate risk, although of poor quality. Lastly, consent forms were examined for the presence of information relating to risks and benefits of radiographic examinations.

A similar search was made for POs and OOs but CBCT was excluded from the POs because its inclusion yielded very few search results. An additional inclusion criterion was that offices must have board-certified pediatric dentists and orthodontists. Some offices did have CBCT machines and this was recorded; otherwise, they were recorded as having IO and/or Pan and/or Ceph machines.

Sample dental x-ray informed consent

A sample informed consent form was constructed that included risk estimations for children, adults (5- or 10-year age bands), sex, and type of radiographic examination (Figure 1). The EDs for IO, Pan, and Ceph were taken from Ludlow et al.[10] and Johnson and Ludlow.[13] EDs for CBCT were taken from Hedesiu et al.[11] and used to estimate the LAR, as described above. However, the male and female risk estimates were not averaged in order to show the difference between the sexes.

RESULTS

NEXT survey

For 300,144,000 IO examinations the risk estimate was 827 possible cancer cases, of which 114 were in children (14%). From 22,736,880 Pan examinations, there were 55 possible cancer cases, with 35% in children. Of 2,460,427 Ceph examinations, there was 1 possible cancer. For 5,176,000 CBCT examinations there were 84 possible cancer cases, with 73% in children. If rectangular collimators were used for the IO examinations, reducing the dose by up to 73%, the number of cancer cases could be reduced from 827 to 276. By applying selection criteria to all radiographic examinations, a further 43% reduction[26-29] was estimated, reducing all cancer cases from 967 to 237 (Table I).

JCO survey

The estimates were for radiographic examinations of all US orthodontic patients (21,573,930) who commenced a course of treatment starting in 2020. The estimated total number of possible cancer cases was 135: FMX 18, Pan 40, Ceph 6, and CBCT 71 (Table III). Using rectangular collimation for FMX examinations, the numbers could decrease from 18 to 5 (see Methods). A further 43% reduction, using selection criteria applied to all radiographic examinations, could lower the total number of cancer cases from 135 to 68.

If the future number of routinely prescribed pretreatment CBCT examinations were to increase from 16% to 50%, there would be no change in the number of cancer cases attributable to FMX. However, the extra CBCT could be used to generate fewer Pan radiographs, reducing the number of cancer cases attributable to Pan from 40 to 12. Similarly, the number of cancer cases attributable to Ceph would reduce to only 1. The increase in CBCT would result in a net increase of 119 cancer cases to a total of 254. If the CBCT examinations were increased to 86%, replacing all current Pan examinations, there would still be 18 cancer cases attributable to FMX, 0 to Pan, 0 to Ceph, and 343 to CBCT, for a total of 361 (Table III).

Between 2008 and 2014 there was very little change in the frequency of routinely prescribing FMX, BW, or PA (Table II). From 2014 to 2020 there was an increase in FMX with a corresponding fall in BW and PA. From

Table III. Estimate of all US orthodontic cancers generated over a single 21-month course of treatment 2020 to 2021

Exam type	*Pretreatment exams, % all orthodontists**	*No. of x-ray exams*	*LAR of cancer, all patients†*	*Progress exams, % all orthodontists**	*No. of x-ray exams*	*LAR of cancer, all patients†*	*Posttreatment exams % all orthodontists**	*No. of x-ray exams*	*LAR of cancer, all patients†*	*Total x-ray exams*	*Total LAR of cancer*		
											All exams	*Rectangular collimator −73%‡*	*Selection criteria −43% dose*
FMX	12	648,840	10	3	162,210	2	7	378,490	6	1,189,540	18	5	3
Pan	86	4,650,020	15	6	3,244,200	11	78	4,217,460	14	12,111,680	40	40	23
Ceph	70	3,784,900	4	18	973,260	1	28	1,513,960	1	6,272,120	6	6	2
CBCT	16	865,120	30	7	378,490	14	14	756,980	27	2,000,590	71	71	40
Total		**9,948,880**			**4,758,160**			**6,866,890**		**21,573,930**	**135**	**122**	**68**
Increase CBCTs to 50% to partially replace Pan and Ceph													
FMX	12	648,840	10	3	162,210	2	7	378,490	6	1,189,540	18	5	3
Pan	36	2,270,940	7	0	0	0	28	1,513,960	5	3,784,900	12	12	7
Ceph	20	1,081,400	1	0	0	0	0	0	0	1,081,400	1	1	1
CBCT	50	2,703,500	94	18	973,260	34	50	2,703,500	94	6,380,260	223	223	127
Total										**12,436,100**	**254**	**241**	**138**
Increase CBCTs to 86% to replace all Pan and Ceph													
FMX	12	648,840	10	3	162,210	2	7	374,080	6	1,175,680	18	5	3
Pan	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceph	0	0	0	0	0	0	0	0	0	0	0	0	0
CBCT	86	4,650,020	162	18	973,260	34	78	4,217,460	147	9,840,740	343	343	196
Total										**11,016,420**	**361**	**348**	**199**

LAR, lifetime attributable risk; *FMX*, full mouth x-ray; *Pan*, panoramic; *CBCT*, cone beam computed tomography; *Ceph*, cephalometric.
*Percentage of all orthodontists who reported routinely making examinations on all patients.
†LAR cancer estimates are for all US orthodontic examinations. LAR estimates are for 10- to 11-year-old children and 30-year-old adults during one 21-month treatment period 2020 to 2021.
‡Rectangular collimation is only applicable to intraoral radiographs.

Dental X-ray Informed Consent

Your dentist has recommended you undergo the **X-ray examinations** listed below to determine if you have the following **Conditions**: (*Dentist writes here*)

X-ray exam ……………………………………………………………………………………….

Conditions ……………………………………………………………………………………….

The presence of these conditions is likely to result in the following **Treatment** or **Referral**: (*Dentist write here*)

Treatment……………………………………………………………………………………………

Referral………………………………………………………………………………………………

X-rays are important for diagnosis of oral and facial disease. It is important that the benefits from an X-ray examination are more than the risks.

X-rays are ionizing radiation and the diagnostic doses you will be exposed to will not cause any immediate effects you can detect. However, there is a chance that you could in the future develop a cancer. The risk depends on the type of X-ray machine, dose settings, size of the X-ray beam and whether film or digital detectors are used. In addition, your age and sex are important, since **children** are more at risk than adults and **girls** more than boys. All X-ray exposures have risks which add together with more examinations. To help you understand the risks, the table below describes the examination/s and the risk of developing cancer i.e. 1: 500,000 means one cancer in every 500,000 examinations. **For comparison, a 4-5-hour flight from the US East to West coasts would present a future cancer risk from Cosmic Rays of 1 in 500,000.**[1]

Pregnancy: If you are suffering from a serious condition, such as an acute infection with swelling of the face, an X-ray may be needed for diagnosis and treatment. X-rays for women at *low risk* for tooth decay and gum disease, are not needed during pregnancy.

If you wish for more information about the risk of cancer from dental X-rays, please ask your dentist.

☐ I have read this form and understand the risks from dental X- rays. I consent to a radiographic examination.

☐ I do not consent to a dental X-ray examination.

Patient name: ……………………… Date: ………………………

Signature of Patient (or Parent/Guardian) ………..………………………………………………..

Please circle examinations **X-RAY RISK 1 Cancer : X-ray exams** Data derived from [2-4]

Age group	4BWs round collimators		**FMX round collimators**		Panoramic		Lat Skull
years	Female	Male	**Female**	**Male**	Female	Male	Female
0-4	**1: 72,000**	1: 132,000	**1: 24,000**	**1: 44,000**	1: 110,000	1: 205,000	1: 374,000
5-9	1: 100,000	1: 186,000	**1: 33,000**	**1: 62,000**	1: 156,000	1: 289,000	1: 529,000
10-14	1: 129,000	1: 233,000	**1: 43,000**	**1: 78,000**	1: 202,000	1: 364,000	1: 684,000
15-19	1: 163,000	1: 285,000	**1: 54,000**	**1: 95,000**	1: 255,000	1: 445,000	1: 865,000
20-29	1: 212,000	1: 357,000	**1: 71,000**	1: 119,000	1: 320,000	1: 539,000	1: 1,500,000
30-39	1:327,000	1:509,000	1:109,000	1:170,000	1:494,000	1:767,000	1:1,677,000
40-49	1:394,000	1:538,000	1:131,000	1:179,000	1:594,000	1:812,000	1:2,016,000
50-59	1:471,000	1:590,000	1:157,000	1:197,000	1:711,000	1:891,000	1:2,413,000
60-69	1:595,000	1:713,000	1:198,000	1:238,000	1:898,000	1:1,076,000	1:3,047,000
Age group	**One Cone Beam CT**		**Two Cone Beam CTs**		**Three Cone Beam CTs**		Lat Skull
years	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	Male
0-4	**1: 41,000**	**1: 76,000**	**1: 21,000**	**1: 38,000**	**1: 13,000**	**1: 25,000**	1: 697,000
5-9	**1: 22,000**	**1: 40,000**	**1: 11,000**	**1: 21,000**	**1: 7,000**	**1: 14,000**	1: 1,500,000
10-14	**1: 20,000**	**1: 37,000**	**1: 10,000**	**1: 18,000**	**1: 6,000**	**1: 12,000**	1: 1,236,000
15-19	**1: 35,000**	**1: 61,000**	**1: 17,000**	**1: 30,000**	**1: 11,000**	**1: 20,000**	1: 1,511,000
20-29	**1:81,000**	1:137,00	**1:40,000**	**1:68,000**	**1:27,000**	**1:46,000**	1:1,828,000
30-39	1:125,000	1:194,000	**1:62,000**	**1:97,000**	**1:42,000**	**1:65,000**	1:2,603,000
40-49	1:151,000	1:206,000	**1:75,000**	1:103,000	**1:50,000**	**1:69,000**	1:2,756,000
50-59	1:180,000	1:226,000	**1:90,000**	1:113,000	**1:60,000**	**1:75,000**	1:3,022,000
60-69	1: 228,000	1: 273,000	1: 114,000	1: 137,000	**1: 76,000**	**1: 91,000**	1: 3,652,000

1. Centers for Disease Control and Prevention. https://www.cdc.gov/nceh/radiation/air_travel.html 2.
2. Ludlow et. al. PMID 18762634. 3. Johnson. PMID 32979952. 4. Hedesiu et. al. PMID 29803375

Fig. 1. Sample dental x-ray informed consent. Reproduced with permission from Dental and Maxillofacial Radiology Omaha LLC.

2008 to 2014, CBCT increased 8% with a similar reduction in Pan and Ceph. From 2014 to 2020, CBCTs continued a similar rise, with a reduction in Pans but a rise in Cephs.

Informed consent

The informed consent survey revealed 50 GDOs with CBCT machines (100%), 1 of 50 POs with a CBCT unit (2%) and 49 with IO/Pan/Ceph units (98%), and 11 OOs

Table IV. Internet survey of dental offices for patient radiation risk information and informed consent forms

	X-ray machines			
Office	*IO, Pan, Ceph*	*CBCT*	*Risk example provided*	*Radiographic consent*
General dentists (n = 50)	0	50 (100%)	7 (14%)	2 (4%)
Pedodontists (n = 50)	49 (98%)	1 (2%)	2 (4%)	0
Orthodontists (n = 50)	39 (78%)	11 (22%)	7 (14%)	0

IO, intraoral; *Pan*, panoramic; *Ceph*, cephalometric; *CBCT*, cone beam computed tomography.

with CBCT units (22%) and 39 with IO/Pan/Ceph units (78%; Table IV).

GDO websites revealed that 43 provided no useful information about dose risk, such as "Digital x-rays have 80% less risk than conventional dental film" (86%). Seven provided a little more useful general information, such as "CBCT has more radiation than conventional dental x-rays and children have a higher risk than adults" (14%). Only 2 GDOs specifically provided a "CBCT Consent Form" (4%). One office stated that all patients must agree to have a CBCT at the initial examination.

Of POs, 48 provided no useful information about risk (96%). A total of 17 stated that they followed the American Academy of Pediatric Dentistry recommendations of BW at 6- to 12-month intervals, depending on caries risk, and Pan every 3 years (34%). Only 1 of the POs provided a detailed useful description of risk (2%). No offices provided a CBCT consent form.

Of OOs, risk examples were provided in 7 offices (14%) and only 1 office had a useful description of risk (2%). None had CBCT consent forms.

DISCUSSION

Cancers of the oral cavity and pharynx comprise 3% of cancers diagnosed in the United States each year.[30] From 2007 to 2016 these rates increased.[31] In 2017, a total of 46,157 new cancers in the oral cavity and pharynx were diagnosed and 10,126 people died.[30] In addition, 22,827 new cancers in the brain and nervous system were diagnosed and 16,804 people died.[30] Based on our risk estimates of 967 cancers generated from dental radiography in 2019, this could represent 2% of new cancers in the oral cavity/pharynx, 4% of brain tumors, or 1.5% of combined oral cavity/pharynx and brain cancers.

In this article, we derived estimates for the possible number of cancer cases associated with IO, Pan, and Ceph examinations based on published values for risk from the Ludlow et al.[10] and Johnson and Ludlow[13] estimates of fatal cancers per 1 million examinations. The CBCT risk was derived from the LAR for cancer (nonfatal cancer) per 1 million examinations.[11] The LAR estimates were used because they provided specific estimates of EDs for single and multiple CBCT examinations, such as those found in courses of orthodontic treatment.[11] The authors did not specify risk in terms of fatal cases for IO, Pan, and Ceph, as in the papers by Ludlow et al.[10] and Johnson and Ludlow,[13] but rather cancers for all examinations, because combining fatal cancers and nonfatal cancers might be confusing for readers. All cancer estimates in this article are expressed as the incidence per million x-ray examinations.

NEXT is a periodic national survey of clinical medical facilities performing selected diagnostic x-ray procedures, performed jointly by the Conference of Radiation Control Directors and the US Food and Drug Administration. It is also supported by the American College of Radiology. The unit for the survey in this study was the clinical site (office) rather than individual dentists. One hundred and ninety sites were randomly selected for survey in 25 states. The NEXT survey was unable to estimate the number of Pan machines in use because of a lack of data. However, a subsequent survey,[21] which included Pan, combined all data with the NEXT data to estimate the number of Pan examinations.

The 2020 JCO survey was part of a regular 6-year series that records types and frequency of radiographic investigations per orthodontist, not per clinical site as in the NEXT survey. The small sample size of 153 respondents has an error of ±11% at the 99th percentile. The surveys started in 1986, followed by 1996, 2008, 2014, and 2020. Because the 2 earliest surveys did not include digital IO or CBCT, only the 2008, 2014, and 2020 surveys were compared (Table II).[14,32]

The NEXT survey shows that the greatest number of radiographic examinations are IOs. The authors' estimate is 330,517,307 total radiographic examinations in 2019, with the equivalent of about 95 million FMX for adults and 19 million 4 BW exposures for children. The estimate for cancers generated from the 2019 IO examinations is 827, of which 14% were in children; for Pan, 55, with 35% on children; and for CBCT, 84, with 73% in children; the risk associated with Ceph is very low, with about 1 cancer, most likely in a child.

The vast majority of dental radiography occurs in GDOs, so what can be done to reduce the doses? Two things: Collimation of the x-ray beam to reduce the volume of tissue irradiated and use of selection criteria to reduce the number of exposures. If all BW and PA intraoral exposures used rectangular, rather than round, collimators, approximately 80% dose reduction could occur.[4] The authors would like to state that a cone cut that does not obscure a diagnostically important region does not need to be repeated. Allowing for cone cuts and 7% repeats,[23-25] the overall dose reduction would decrease from 80% to about 73%. From our estimates, the number of GDO-related cancers from IO examinations could decrease from 827 to 276. This is a significant reduction without reducing needed examinations. Currently fewer than 1% of GDOs use rectangular collimation,[8] but an NCRP report states that rectangular collimation *shall* be used.[33] Similarly, when making Pan, Ceph, or CBCT exposures, it is important to select the minimum exposure from the correct settings for age and the smallest field or volume possible. Adult size, full head CBCT volumes for all patients produce the highest doses. Similarly, high resolution usually increases the dose.

Another way to decrease dose is to reduce the number of unnecessary exposures by adhering to established selection criteria.[7,28,29] There should never be prescription of radiographs before a clinical examination, per the NCRP report.[33] The purpose of the clinical examination is to decide what question(s) a specific radiographic examination can answer. The answers should also affect treatment.[7] Clinical examinations can provide risk estimates for caries and periodontal diseases. These estimates should be incorporated into the decision-making process so that individuals with a low risk of dental disease have longer intervals between radiographic examinations than individuals with a higher risk.[7] Unfortunately, it is well documented that most dentists will image patients on a routine (annual or semi-annual) basis, including patients at low risk for dental caries.[26,27] In addition, in a nationwide survey, 82% of hygienists reported that there were times when dentists did not perform clinical examinations before prescribing radiographs.[27] One-third of hygienists reported that radiography intervals were based on the patient's insurance reimbursement.[27] The authors suggest that until office surveys report that variable radiographic intervals of 6 to 36 months are being used, linked to the risk of caries and periodontal disease, the dental profession is overprescribing radiographs. At this time it is difficult to know the precise amount of overprescription, but from our calculations we believe that at least a 43% reduction in IOs could be achieved with no impact on the quality of patient care/outcomes.[7,28,29] If this reduction is combined with the use of rectangular collimation, the total number of cancer cases could be reduced from 967 (Table I) to 237 for all types of dental radiography. Mupparapu et al. recently reported that size 1 and size 0 rectangular collimators are needed for pediatric radiography.[34]

The above estimates relate to all dental radiography provided in dental offices. It is of interest to examine the risks and trends in orthodontics, however. This is a large specialty in which the majority of patients are children, who are at elevated risk of developing cancer.

The JCO 2008 to 2020 surveys

The authors were surprised at the number of orthodontists who reported "routinely" making pretreatment, during-treatment ("progress"), and posttreatment radiographic examinations (Table III). Between 2008 and 2014[32] there was almost no change in the number of FMX, BW, or PA examinations (Table II). The number of orthodontists routinely prescribing CBCT increased 8% and Pan and Ceph declined by a similar amount. Presumably this represented the early introduction of CBCT technology, which can be used to generate replacement Pan and Ceph. Between 2014 and 2020,[14] routine FMX increased 7% with a smaller drop in BW and PA. It would appear that FMX partially replaced BW and selected PA. CBCT increased a further 6% and Pan declined by a similar amount. However, Ceph increased 6%. Once again, it could be that increased use of CBCT was matched by the decreased use of Pan, explaining their reduction. The trends overall are worrying because FMX and CBCT produce much higher doses than selected BW, PA, Pan, and Ceph. Unlike the NEXT/NCRP studies,[8,21] which related to a 12-month period during 2014 to 2015 and estimated radiographic examinations for all offices, the JCO studies are based on examinations related to a course of treatment. The average course of treatment was estimated to be over a 21-month period.[14] In the time period 2020 to 2021 the authors estimate that 135 LAR cancer cases could be generated, mostly in children. The highest risk is from CBCT (71 cancer cases), followed by Pan (40 cancer cases; Table III). In contrast to GDOs, the lower number of FMX could generate fewer cancer cases (about 18). However, whereas rectangular collimators could reduce the number of cancer cases from 827 to 276 attributed to GDOs, the number attributed to OOs would only decrease from 18 to 5. Using appropriate selection criteria would seem to be the only option in orthodontic practice to significantly reduce the risk of cancer. If the current trend of replacing Pans (effective dose 19 μSv) with CBCT (effective dose 132-205 μSv for individuals aged 9-16 years) continues, the cancer rate could increase significantly. If the number of CBCTs used routinely in pretreatment diagnosis increases to 50% so that Pans decrease from 86% to 36%, the cancer rate will almost double, from 135 to 254. If the 86% of orthodontists routinely exposing Pan images replace them with CBCT images, the increase in cases will be from the current 40 for Pan plus 71 for CBCT (a total of 111) to 343 for CBCT, for a net increase of 232 cancer cases with no diagnostic advantage, unless CBCT can be used to answer a specific question requiring 3D information. However, this needs to be justified by selection criteria.

It should be stressed that our calculations of cancer risk were only made based on the group of orthodontists who reported routinely making specific radiographic examinations. The ED and LAR cancer risk were not estimated for orthodontists making occasional exposures. This means that our cancer risk estimates are an underestimate. It is also important to state that probably 3% of patients are routinely undergoing pretreatment, progress, and posttreatment CBCT imaging, for a total of 3 CBCT examinations in a 21-month period (Figure 1).[14] For 10- to 14-year-old girls (the highest risk group), this would create an LAR of 1 in 6000 (Figure 1).[5]

What is the justification for routinely exposing FMX for 12% of pretreatment, 3% of progress, and 7% of posttreatment patients?[14] FMX are usually indicated "... when the patient has clinical evidence of generalized oral disease or a history of extensive dental treatment." (Table 1, Page 5)[7] Because 76% of patients are children and 71% of these are at least 251% above the federal poverty level,[35] it would not be expected that these children have high levels of disease. In fact, if they are at high risk for dental disease, should they be having orthodontic treatment? Why did orthodontists adopt a change of practice from 2014 to 2020 when they moved away from BW and selected PA to FMX from 2008 to 2014? Perhaps part of the answer may be that more general dentists are performing aligner therapy and using FMX. However, it still does not explain why so many children in the age group 11 to 16 years are receiving FMX for orthodontic treatment.

Another question is why do so many orthodontists acquire Ceph images? Traditionally, orthodontists included Cephs as part of full records. Originally these radiographs were considered necessary to make comparisons over time in the size and shape of the jaws and bones of the face and the orofacial soft tissues. Superimposition of successive serial Cephs over time was used to assess changes attributed to treatment, growth, and development. Today it is no longer believed that facial growth can be reliably predicted in either amount or direction. A number of studies dispute the clinical utility of cephalometric analysis. There is no justification for retaining cephalometric radiographs as part of orthodontic diagnosis or treatment planning.[36-39] By avoiding unnecessary Cephs, which are low dose, the transition to high-dose CBCTs can be prevented. Similarly, the use of high-dose CBCTs to replace low-dose Pans should be avoided.

Why are dentists taking so many radiographs? Is it that they fear missing an unknown cancer? Osteosarcomas are rare in the jaws, occurring in about 1 in 2,000,000 people aged 0 to 19 years.[40] Two million Pans on asymptomatic patients with no signs of cancer are likely to cause 2 to 8 cancers depending on the age and sex of the patient. More than 40 years ago, Zeichner et al. reported that dental radiographic screening was not an effective way to detect unknown cancers of bone.[41] The more common early squamous cell carcinomas are found in the mucosa by clinical examination, not by radiographs.

What may be the response of an orthodontist, who is currently exposing a girl of 10 to 14 years to 3 CBCTs over a 2-year period, to reading that the risk of this child developing cancer is about 1 in 6000? We expect it is a shock, because we do not believe that they are intentionally producing this high risk of developing cancer, nor are they likely aware of the risks associated with this radiologic imaging procedure. Our Internet sample of 150 dental offices in 50 states shows that dentists believe that the risks of cancer from dental radiography are trivial. The examples of risk that the vast majority of dentists provided to their prospective patients were devoid of good examples conveying accurate risk estimates. In addition, the fact that only 1% of dentists provided an informed radiography consent form demonstrates their belief in a lack of legal risk to themselves. Perhaps it is that, unlike general anesthesia in a dental office, where a death from treatment is a known tragedy for the patient, their family, and possibly professionally for the dentist, a diagnosis of cancer in a dental patient cannot be attributed to a particular x-ray imaging event—it is an unknown anonymous event. However, the risk of death from a general anesthetic in a dental office is 1 in 300,000.[42] The risk of cancer for a girl of 5 to 15 years from 4 BW is about 1 in 130,000 and that from a Pan is about 1 in 200,000 (Figure 1).

A possible solution to the lack of awareness of dental radiology risks is to require an informed consent form that includes the following specific information: (1) a statement by the dentist listing the type of radiographic examinations proposed, (2) the clinical need for the examination, (3) the likely treatment that will result if the condition is detected, or (4) appropriate referral to a specialist, in addition to a list of cancer risk by examination type, age, and sex, as well as a statement for comparison of the 1:500,000 risk of cancer from cosmic rays in a 4- to 5-hour flight.[43] A sample form is shown in Figure 1.

Finally, we would like to state that there are definite benefits to having appropriate radiographic examinations. However, the literature does not provide quantitative measures of benefit, making it difficult to perform a careful comparison of risk vs benefit. It would be beneficial for others to model benefit to make a risk vs benefit comparison possible. Until then, our responsibility is *First Do No Harm*.

CONCLUSIONS

Dentists are possibly causing about 967 new cancer cases per year in the head and neck regions. Most of the cancer risk is from intraoral and CBCT radiographs. The use of intraoral rectangular collimation with selection criteria, as stipulated in ADA guidelines[7] and the NCRP report,[33] may reduce the number of cancer cases from 967 to 237.

Orthodontists are adopting CBCT technology with a reduction in the number of Pan examinations. In 2020 to 2021 all orthodontic courses of treatment may generate 135 cancer cases. This is probably an underestimate. Future replacement of low-dose Ceph and Pan radiographs by higher dose CBCT images could generate 361 cancer cases, mostly in children.

Use of an informed consent form containing sufficient information to help the patient and dentist understand the risk of cancer formation may help to reduce the overprescription of dental radiographs.

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