Dose and risk in dental diagnostic imaging: with emphasis on dosimetry of CBCT

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In a review paper published at the end of 2007 in the New England Journal of Medicine (NEJM), two highly regarded health physicists, David Brenner and Eric Hall, estimated that from 1.5% to 2% of all cancers in the United States (US) may be attributable to the radiation from computed tomography (CT) studies.[1] While this statement is not without controversy, the fact that it was published in the NEJM suggests that there is substantial evidence supporting this statistic. Indeed when we look at the total number of CT examinations during the period from 1993 to 2006, we see an exponential rise in the number of examinations each year (Fig. 1). The annual growth of more than 10% far exceeds the growth in the US population over the same period. Similar patterns may be observed in other developed countries of the world.

In 1994 a popular textbook, Oral Radiology, Principles and Interpretation by Goaz and White, described a total annual effective dose of ionizing radiations to a person in the US as 3.60 mSv.[3] Of this approximately 0.49 mSv was contributed by exposures to ionizing radiation procedures in diagnostic procedures. Current estimates of per capita annual US dose are 6.20 mSv with almost 3 mSv coming from diagnostic procedures (Fig. 2).[2]

Technological advances and innovations in medicine have produced significant benefits for society evidenced by healthier, longer lives. Early disease detection in many instances involves diagnostic imaging that exposes patients to radiation. While timely detection and treatment of disease is critical to improving outcomes, radiographic procedures carry with them an inherent risk that must be overbalanced by the potential benefits of improved health and longevity. The ALARA principle (As Low As Reasonably Achievable) is a concept for reducing the dose from diagnostic imaging to insure as high a benefit/risk ratio as possible. The increased use of evidence based patient management may be expected to further enhance the benefit/risk ratio. In dentistry we have many examples of evidence-based care incorporating the use of diagnostic imaging procedures with good benefit risk ratios. Use of radiographic imaging criteria for caries detection is a good example of the use of conventional imaging techniques in the detection, monitoring, and treatment of one of the most common oral diseases.[4]

Cone beam computed tomography (CBCT) is a promising but relatively young technology which does not as yet have the weight of evidence needed to judge how this will be most useful in patient management and where alternate modalities may be more efficacious. Recent reviews of the literature suggest that evidence supporting diagnostic efficacy of CBCT for most tasks is lacking. Data presented by Kim and coauthors at the 2009 IADR meeting surveyed publications through June of 2008.[5] Papers were assessed using an epidemiological study design hierarchy and a diagnostic efficacy hierarchy. Of the 195 articles in 51 journals, 68 were clinical research studies: 42% were case reports/series, 56% were cross-sectional, and 2% were case-control studies. Of the 34 diagnostic efficacy studies, 9% were technical efficacy and 91% were diagnostic accuracy efficacy. The authors concluded that study designs used in the majority of CBCT clinical studies do not provide strong evidence for informed clinical decision-making. None of the efficacy studies addressed the impact of CBCT on actual patient outcomes. This suggests the need for additional research at the higher ends of the study design and efficacy hierarchies.

The European Union SEDENTEXCT project which seeks to develop evidence-based guidelines on use of CBCT in dentistry, including referral criteria, quality assurance guidelines and optimization strategies, recently published a draft document on safety and efficacy of CBCT. Thirty-four diagnostic tasks were scored for the quality of scientific support using an A-D grading scale. When evidence was lacking in support of a task, a grade of GP was given indicating that the use of CBCT was deemed "good practice" based on the opinion of a group of experts involved with construction of the guidelines. Only 12 of the tasks were scored with a grade other than GP. Two of these were negative recommendations on the routine use of CBCT for caries evaluation and periodontal evaluation. Of the remaining 10, a B level of evidence was found for 3rd

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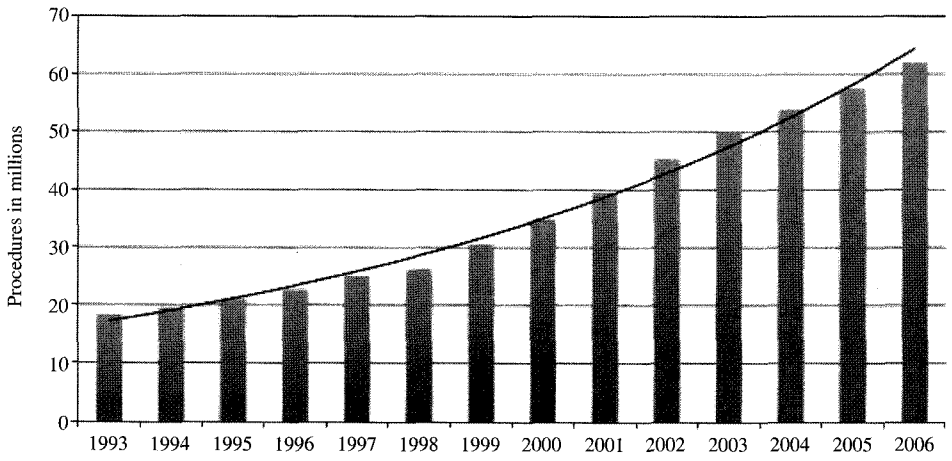


Fig. 1. CT procedures in the US from 1993-2006. Data from NCRP Report No. 160.[2]

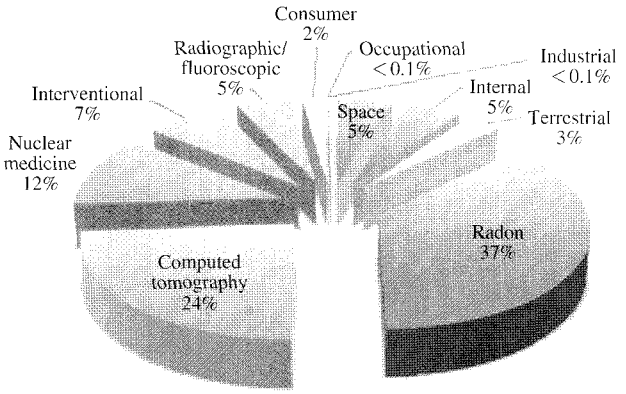


Fig. 2. 6.2 mSv annual per-capita radiation dose to the US population of which 3.1 mSv is ubiquitous background and 2.98 mSv is from diagnostic procedures.

molar root proximity to inferior alveolar canal and TMJ assessment as an alternative to CT to reduce dose. A C level of support was seen for impacted tooth localization, assessment of infrabony and furcal defects, investigation of equivocal root canal anatomy, evaluation of endodontic treatment complicated by resorption, and unspecified craniofacial diagnostics. D level support was found for surgical endodontics use, as a substitute for CT in implant cross sectional images-due to dose, and substitution for CT in maxillofacial fracture assessment due to dose. It is clear that the published evidence supporting the use of CBCT for many if not most of the diagnostic tasks for which we might use this technology is weak or absent. This is in large part because CBCT is a new technology and it will take time for research validation to catch up with the market place. In the interim period clinicians must rely on good practice so that CBCT examinations are prescribed judiciously for our patients.

An important aspect of our judgment to use diagnostic imaging is a consideration of the risk of harm that accompanies exposure to x-rays. Because different harms and risks are associated with different types of exposures, it is not surprising that our patients are often confused about the real risks associated with diagnostic imaging. We can categorize risks into stochastic and deterministic groups. A stochastic effect is one where the chance of occurrence of the effect increases with increasing exposure but does not affect the severity of the effect. Cancer is an example of a stochastic effect. Evidence for a cancer risk from exposure to x-rays has been documented down to 100 mGy for an adult exposure and 10-20 mG for fetal exposure. A linear-no-threshold hypothesis of x-ray risk fits most data for cancer development. But extrapolation of this data must be used to estimate risks from the lower doses that are utilized for diagnostic imaging. Heritable (germ cell) mutations are another stochastic effect. To date, no expressions of germ cell mutations have been observed in human populations.

Deterministic effects of x-ray exposure are those where the severity of the effect increases with increasing exposure. Implicit in this concept is that there is a threshold below which effects do not occur. Examples of deterministic effects include birth defects which have a threshold of 100-250 mSv, cataract of the lens of the eye which has a threshold of 2 Gy of exposure, and radiation burn which has a 3 Gy threshold of exposure. None of these effects will be found with the relatively low and localized exposures that are used for dental and maxillofacial imaging.

It is clear that the preeminent risk from maxillofacial imaging is late developing cancer. But how do we measure and quantify that risk? In its 1990 recommendations, the International Commission on Radiological Protection (ICRP) suggested that effective dose (E) be adopted as the best means of comparing

dose and risk from any exposure to ionizing radiation.[6] A table of organs and tissues known to be most susceptible to radiation damage was developed and weights were applied to each of the listed tissues representing the relative contribution of each tissue to overall risk. Effective dose, reported in Sieverts, was defined as the sum of the products of each tissue-weighting factor (w_T) and the equivalent dose to that tissue (H_T) in the following formula:

$$E=\sum w_T \times H_T$$

Effective dose is now a widely used calculation that permits comparison of the detriment of different exposures to ionizing radiation to an equivalent detriment produced by a full body dose of radiation. In 2007 the ICRP published a revision of the table of tissues and weights used in effective dose calculation.[7] The principal reason for revising tissue-weighting factors in the 2007 ICRP recommendations is the availability of cancer incidence data that was not available when the 1990 guidelines were published. ICRP 1990 cancer risks were computed based on mortality data. Incidence data provide a more complete description of cancer burden than do mortality data, particularly for cancers that have a high survival rate. Much of the cancer incidence data comes from the Life Span Study (LSS) of Japanese atomic bomb survivors which has been updated with follow-up through 1998, and has been corrected using DS86 bomb dosimetry. Weighted tissues and organs were selected in the 2007 revision because of sufficient epidemiological information on the tumorigenic effects of radiation to make judgments necessary for estimating cancer risks.

Table 1 compares the tissue weights from the 1990 and 2007 ICRP recommendations. In the current recommendations, risk from gonadal exposure has been greatly downgraded while risk to breast tissue has been dramatically increased. Of significance for maxillofacial imaging is an increase in the risk estimation for brain tissues and addition of salivary glands as a weighted tissue. Also significant is the addition of 3 tissues to the remainder tissue group as well as a large increase in weight given to the remainder tissues. These tissues include oral mucosa, which is extensively irradiated in any dental examination, and the extrathoracic airway, which is irradiated in exams including the maxilla, as well as lymph nodes which are partially irradiated in maxillofacial examinations. Increased weights and additional weighted tissues in the head and neck area overshadow reductions of 20% in thyroid and esophagus tissue weights. Because of this we might expect an increase in calculated risk from maxillofacial examinations when 2007 weights are used.

Table 1. Tissue weighting factors for calculation of Effective Dose - Comparison of 1990[6] and 2007[7] ICRP Recommendations

Tissue	1990 w_T	2007 w_T
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
Bladder	0.05	0.04
Esophagus	0.05	0.04
Gonads	0.20	0.08
Liver	0.05	0.04
Thyroid	0.05	0.04
Bone surface	0.01	0.01
Brain	Remainder	0.01
Kidneys	Remainder	Remainder
Salivary glands	–	0.01
Skin	0.01	0.01
Remainder tissues	0.05*	0.12†

*Adrenals, **brain**, upper large intestine, small intestine, kidney, **muscle**, pancreas, spleen, thymus, uterus

†Adrenals, **Extrathoracic region**, Gall bladder, Heart, Kidneys, **Lymphatic nodes**, **Muscle**, **Oral Mucosa**, Pancreas, Prostate, Small Intestine, Spleen, Thymus, and Uterus/cervix

Tissues in **Bold** represent those that are directly exposed in whole or in part during maxillofacial imaging procedures.

Radiation detriment, the total harm to an exposed population and their descendants, can be calculated from effective dose. Detriment includes the weighted probabilities of fatal and non-fatal cancer, relative length of life lost, and hereditary effects. Because of great uncertainty of the dose response below 1 Sv, the 2007 ICRP commission concluded that no specific estimate of risk of non-cancer diseases is possible following exposure to low doses. Therefore, a risk coefficient of 0.055 events per Sv based on cancer risk alone was used for the 2007 risk estimates for dental radiography.

A number of approaches have been taken in measuring dose. Measurements of exposure, while simple to perform or calculate are of little value outside the context of risk for biological systems. Alternatives that lead to an estimation of effective dose include human phantom studies and Monte Carlo computer modeling. Phantom studies are time consuming. Monte Carlo modeling is promising, but is model and software dependent. In our continuing dosimetry studies at we have used a phantom simulation approach, utilizing a RANDO phantom (Nuclear Associates, Hicksville, NY) and commercially processed TLD 100 thermoluminescent dosimeter chips. Chips are placed at 24 sites representing the location of weighted tissues of the head and neck area that are potentially directly exposed during maxillofacial imaging (Fig. 3).

Phantom location (level of TLD location)	TLD ID	Phantom levels
Calvarium anterior (2)	1	
Calvarium left (2)	2	
Calvarium posterior (2)	3	
Mid brain (2)	4	
Pituitary (3)	5	
Right orbit (4)	6	
Left orbit (4)	7	
Right lens of eye (3)	8	
Left lens of eye (3)	9	
Right cheek (5)	10	
Right parotid (6)	11	
Left parotid (6)	12	
Right ramus (6)	13	
Left ramus (6)	14	
Center C spine (6)	15	
Left back of neck (7)	16	
Right mandible body (7)	17	
Left mandible body (7)	18	
Right submandibular gland (7)	19	
Left submandibular gland (7)	20	
Center sublingual gland (7)	21	
Midline thyroid (9)	22	
Thyroid surface-left (9)	23	
Esophagus (9)	24	

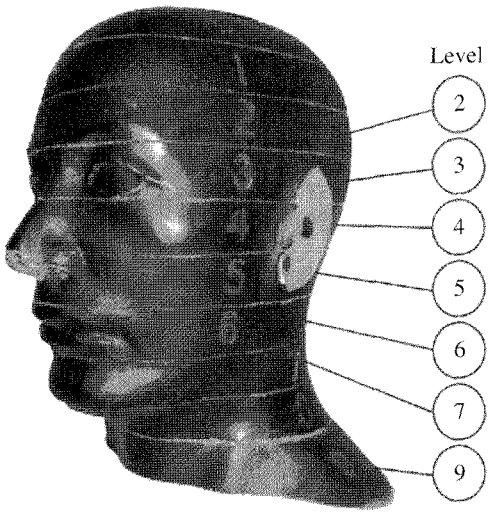


Fig. 3. Locations of TLD chips in RANDO phantom.

Two approaches may be taken when sampling dose in tissues of interest using TLDs. The first approach is to uniformly sample the tissue by placing TLDs at regular intervals throughout that tissue or organ. This is the approach taken with salivary glands where dosimeters are placed in the parotid, submandibular, and sublingual gland areas. Such an approach is inefficient for tissues that are more widely distributed such as bone marrow, muscle, and skin. In this instance dosimeters may be placed at representative locations and an estimation of the percentage of tissue in the directly irradiated area can be used to calculate an equivalent dose distributed over the entire organ. Table 2 delineates the estimates of percentages of tissues directly irradiated during maxillofacial imaging.

In the case of bone marrow, the calculation of 16.5% of total bone marrow in the calvarium, mandible, and cervical spine is based on the work of White and Rose.[9] Estimates for other tissues are approximations based on mass distribution of an average adult and are rounded to the nearest 5%. While this may result in under or over estimation of dose an estimate error of a few percent has little impact on the total effective dose.

Using the protocol described above, measurements of effective dose have been made on a variety of x-ray units.[10-13] When considering dose characteristics in CBCT examinations, the size of the field of view (FOV) is a significant factor. It is instructive to evaluate the effect of this factor as an ordinal variable by grouping FOVs into three sizes. A somewhat arbitrary division of those sizes might be:

small (less than 10 cm) detector-useful for dento-alveolar imaging,

medium (10-15 cm) detector-adequate for mandibulo-maxillary imaging, and

large (greater than 15 cm) detector-is desirable for maxillofacial diagnosis.

A comparison of effective doses calculated using 1990 and 2007 weights is seen in Table 3. When comparing the magnitude of change by size of FOV it can be seen that, on average, an increase of 71% was seen with large FOV examinations, 124% with medium FOV examinations, and 181% with small FOV examinations. Looking at the effect of changes in effective dose calculation it is clear that the estimation of risk has increased for all FOVs following the ICRP 2007 recommendations. The sources of this increase are evident in Fig. 4. Using 1990 estimates, approximately 85% of total effective dose arises from bone marrow & thyroid exposure while less than 10% of total E is from remainder tissues. With 2007 estimates, 40% of total effective dose arises from bone marrow &

Table 2. Estimated percentage of tissue irradiated and TLDs used to calculate mean absorbed dose to a tissue or organ

	Fraction irradiated	TLD ID (see Fig. 3)
Bone marrow	16.5%	
Mandible	1.3%	13, 14, 17, 18
Calvaria	11.8%	1, 2, 3
Cervical spine	3.4%	15
Thyroid	100%	22, 23
Esophagus	10%	24
Skin	5%	8, 9, 10, 16
Bone surface*	16.5%	
Mandible	1.3%	13, 14, 17, 18
Calvaria	11.8%	1, 2, 3
Cervical spine	3.4%	15
Salivary glands	100%	
Parotid	100%	11, 12
Submandibular	100%	19, 20
Sub-lingual	100%	21
Brain †	100%	4, 5
Remainder		
Brain †	100%	4, 5
Lymphatic nodes ‡	5%	11-15, 17-22, 24
Muscle † ‡	5%	11-15, 17-22, 24
Extrathoracic airway ‡	100%	6, 7, 11-15, 17-22, 24
Oral mucosa ‡	100%	11-14, 17-21

*Bone surface dose=bone marrow dose × bone/muscle mass energy absorption coefficient ratio= −0.0618 × 2/3 kV peak+6.9406 using data taken from NBS Handbook No. 85[8]

thyroid exposure while 55% of total effective dose is from salivary gland and remainder tissue exposures.

While FOV has no obvious influence on the distribution of dose using 1990 ICRP calculations (Fig. 5), several trends can be related to the effect of FOV using 2007 ICRP calculations (Fig. 6). Dose proportion decreases with decreasing FOV for bone marrow, thyroid, and brain tissues. In contrast to this an increase in dose proportion is associated with a decrease in FOV for salivary glands and remainder tissues. We can attribute the direct relationship of dose and FOV to the increasing proportion of widely distributed and peripheral tissues that are exposed with progressively larger fields of view. On the other hand, salivary glands and oral mucosa are concentrated near the dento-alveolar areas and are an increasingly important component of the total dose as FOV is reduced and tissues peripheral to the scan receive reduced dose.

When we compare doses of specific examinations within FOV groups we can see that there are significant variations among units. For instance, an 8-fold difference in dose is evident when the standard large field exposures of the Newtom 3G and CB Mercuray are compared. When a medium FOV Galileos exposure is compared with the standard dental protocol of the Somaton 64, a multidetector CT unit, a 12-fold difference in dose is seen. However, examining the dose of the

Table 3. Radiation dose of maxillofacial CT and CBCT examinations by field of view, comparing 1990 and 2007 ICRP calculations of effective dose

Technique	E in μSv ICRP 1990 W_T	E in μSv ICRP 2007 W_T	% change 1990-2007
Large FOV			
NewTom3G-Large FOV	42	68	62%
CB Mercuray-"Facial" FOV (standard quality)	464	569	23%
Next Generation i-CAT Portrait mode	37	74	100%
Iluma-(ultra)	252	498	97%
Average			71%
Medium FOV			
CB Mercuray-"Panoramic" FOV	264	560	112%
Classic i-CAT-Standard scan	29	69	137%
Next Generation i-CAT Landscape mode	36	87	139%
Galileos-(default exposure)	28	70	148%
Scanora 3D-7.5 cm × 14.5 cm FOV	31	76	145%
NewTom VG	47	109	130%
Somaton 64 MDCT	453	860	90%
Somaton 64 MDCT w/CARE Dose 4D	285	534	87%
Average			124%
Small FOV			
CB Mercuray-"I" FOV (maxillary)	156	407	161%
Scanora 3D-7.5 cm × 10.0 cm FOV	29	74	151%
Promax 3D (small adult)	151	488	224%
PreXion 3D-(standard exposure)	66	189	187%
Average			181%

Somaton 64 using "Care Dose 4D", an automatic exposure control protocol, we see a similar dose with a medium FOV CB Mercuray scan.

Large differences are also evident between units that produce small FOV examinations. Comparison of maxillary anterior and mandibular posterior scans of the Kodak 9000 3D unit in Table 4 reveals a 7-fold difference in dose. This is largely because salivary glands receive little exposure when the 5 cm × 4 cm FOV is centered on the maxillary anterior area.

While I have focused on doses to tissues and organs with the potential for direct exposure during maxillofacial examinations, this discussion is not complete without addressing the potential importance of dose to organs that are exposed only to scatter radiation. Table 5 depicts these tissues which account for 75% of the weighted tissues in a full body exposure. In spite of their significant proportion of risk these tissues account for less than 2% of the effective dose from maxillofacial radiographic scans. Of the included tissues, breast and lung exposures receive the largest proportion of this dose. Potential dose may be reduced by an order-of-magnitude or more when a lap apron is used during scanning. Under these conditions, dose to indirectly exposed tissues becomes negligible.

Because of the additional diagnostic information that is available in imaging volumes, a number of orthodontists have advocated the routine use of CBCT in Orthodontic diagnosis. As can be seen in Table 6, this might result in a 2.5 increase in patient dose using a low-dose unit and scanning protocol.

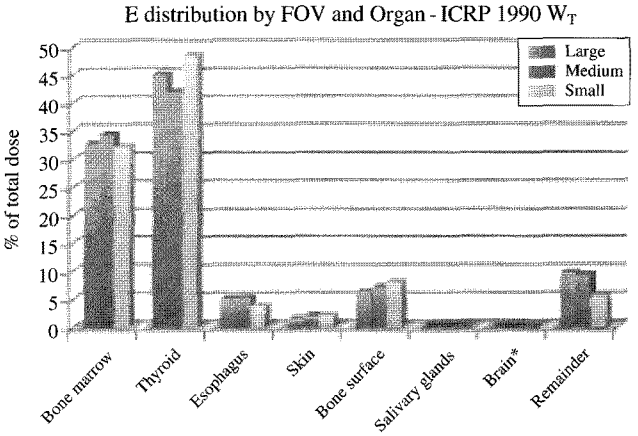


Fig. 5. 1990 ICRP W_T effective dose distribution by weighted tissue and FOV.

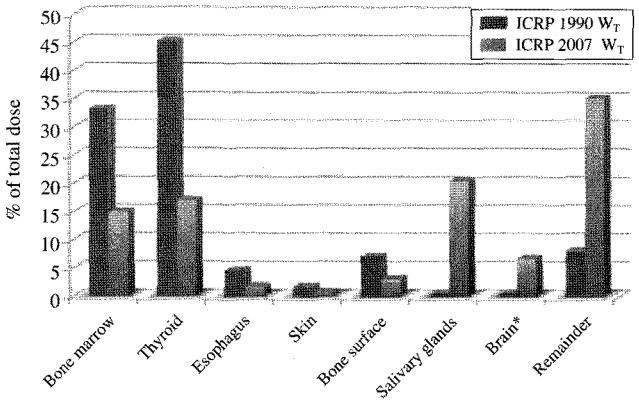


Fig. 4. Comparison of 1990 & 2007 W_T on E distribution for averaged CBCT examinations seen in Table 3.

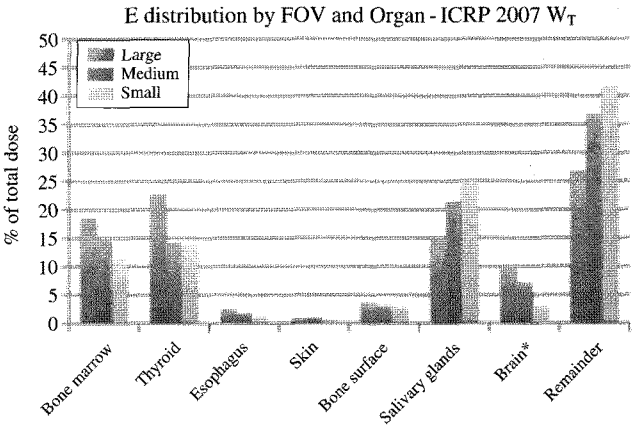


Fig. 6. 2007 ICRP W_T effective dose distribution by weighted tissue and FOV.

Table 4. Dosimetry of the Kodak 9000 3D x-ray unit: Effective dose and risk as multiple of panoramic images, days of background dose, and chance of cancer. Calculations based on 2007 ICRP Recommendations

Technique	Effective dose in μSv	Dose as multiple of average panoramic dose†	Days of per capita background	Probability of X in a million fatal cancer
Max right posterior	9.8	0.6	1	0.5
Max anterior	5.3	0.3	1	0.3
Mand left posterior	38.3	2.4	5	2.1
Mand anterior	21.7	1.3	3	1.2
PBW (average)	22.8	1.4	3	1.3

†Average of 5 units: Sirona-Orthophos XG, Planmeca-ProMax, Kodak-9000, SCANORA 3D, Instrumentarium-OP 200 VT

Table 5. Effective dose contribution of indirectly irradiated tissues

Organ or tissue	Tissue W_T	% of total E (2007 W_T)	% of total E using lap apron
Breast	0.12	1.32%	0.03%
Lungs	0.12	0.31%	0.01%
Thymus	0.0092	0.17%	0.00%
Stomach	0.12	0.07%	0.00%
Colon	0.12	0.02%	0.00%
Esophagus	0.04	0.01%	0.00%
Liver	0.04	0.01%	0.00%
Ovaries	0.04	0.01%	0.00%
Testis	0.04	0.01%	0.00%
Bladder	0.04	0.01%	0.00%
Spleen	0.0092	0.00%	0.00%
Pancreas	0.0092	0.00%	0.00%
Gall bladder	0.0092	0.00%	0.00%
Adrenal	0.0092	0.00%	0.00%
Kidney	0.0092	0.00%	0.00%
Small intestine	0.0092	0.00%	0.00%
Uterus	0.0092	0.00%	0.00%
Total	0.754	1.95%	0.04%

Table 6. Dose implications of substituting a CBCT exam for standard orthodontic exam

Technique	Effective dose in μSv*	Dose compared to pan+PA+Lat
Panoramic-CCD†	16.1	
PA Cephalometric-PSP	5.1	
Lateral Cephalometric-PSP	5.6	
Total	26.8	1X
NewTom3G-Large FOV	68	2.5X
CB Mercuray-"Facial" FOV (standard quality)	569	21X

*ICRP 2007 Recommendations calculations

However, it is apparent that other units and protocols may result in much higher doses to the patient. In the higher dose example in Table 6, a 21-fold increase in patient dose is a substantial increase over conventional alternatives for an increase in diagnostic efficacy or patient treatment efficacy that has yet to be demonstrated.

Similar observations may be made of conventional imaging of the maxillofacial area. The bulk of patient radiographic examinations in dentistry have been intraoral and panoramic views and will remain so because these modalities are relatively low cost and low dose. Table 7 provides current estimates of dose from a variety of conventional dental radiographic examinations. While full mouth intraoral radiographs (FMX) taken with high speed receptors and using rectangular collimation produce doses several times less than comparable FOV CBCT examinations, it is evident that a FMX made with round cone and D Speed film techniques exceeds many of the medium and large FOV CBCT exams.

It is interesting that in spite of recommendations by the American Dental Association[14] and the National Commission on Radiologic Protection[15] that image receptors slower than E Speed should not be used and that rectangular collimation should be used, D Speed film and round collimation remains the most widely used technique for FMX imaging. There is no good reason for this. It is ironic that practitioners who switch from FMX examinations to digital panoramic and bitewing examinations for the sake of increasing office efficiency may also be reducing dose to their patients by as much as 11X (Table 8).

An issue in phantom based dosimetry studies involves the

Table 7. Conventional dental radiography dose calculations[12] following ICRP 2007 Recommendations

Technique	Effective dose in μSv	Dose as multiple of average† panoramic dose	Days of per capita background*	Probability of X in a million fatal cancer†
FMX with PSP or F Speed film and Rectangular Collimation	34.9	2.2	4.3	2
BWs with PSP or F Speed film and Rectangular Collimation	5.0	0.3	0.6	0.3
FMX with PSP or F Speed film and Round Cone	170.7	10.6	21	9
FMX with D Speed film and Round Cone¶	388	24.1	47	21
Panoramic-CCD†	16.1	1.0	2	0.9
PA Cephalometric-PSP	5.1	0.3	0.6	0.3
Lateral Cephalometric-PSP	5.6	0.3	0.7	0.3

*3,000 μSv[15]

† Average of 5 units: Sirona-Orthophos XG, Planmeca-ProMax, Kodak-9000, SCANORA 3D, Instrumentarium-OP 200 VT

† risk=dose in μSv × 5.5×10^{-2}

¶ Calculated as F-speed film value × 2.3

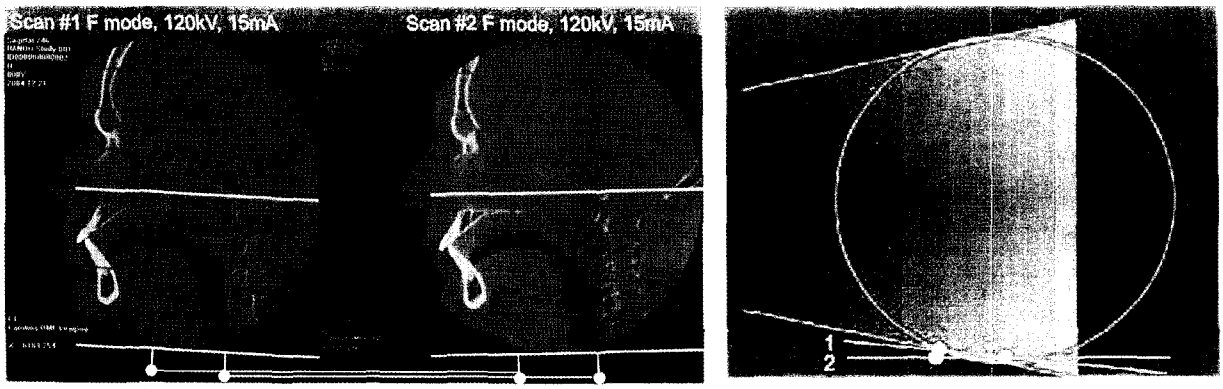
FMX=full mouth intraoral series of 18 images, PSP=photostimulable phosphor plate, CCD=charge couple device

choice of location of dosimeters and position of the phantom in the scan volume. In our studies we orient Frankfort horizontal parallel to the primary axial reconstruction plane unless the CBCT unit cannot accommodate the region of interest with this orientation. An example of this problem would be the Gendex CB 500, which in its extended field has a cylindrical scan diameter of 14 cm with an 8 cm scan height. To capture both the chin and roof of the glenoid fossa of the TMJ, it is necessary to tip Frankfort plane upward. As can be seen in Fig. 7, which depicts an experiment with a large FOV CB Mercuray scan, small rotations of the Frankfort plane can move superficial thyroid tissues into or out of the field of direct radiation. Because the thyroid tissue has a weight of 0.04, this change can have a significant impact on patient dose.

Although human phantom studies are time consuming and relatively expensive, alternative approaches to calculating

Table 8. Comparison of FXM and alternative Panoramic+Bitewing (PBW)

Technique	Effective dose in μSv	Dose compared to Pan+4 PBWs
Panoramic-CCD †	16.1	
4 BWs with PSP or F Speed film and Rectangular Collimation	5.0	
Total	21	1X
FMX with PSP or F Speed film and Rectangular Collimation	35	1.7X
FMX with D Speed film and Round Cone ¶	388	11X



Dosimeter tissue (location)	Scan #1 dose in mGy	Scan #2 dose in mGy	% difference (#1−#2)/(#1+#2)÷2
Midline thyroid (9)	11	11.4	−4%
Thyroid surface-left side (9)	12.9	4.8	92%
Esophagus (9)	6.3	6.1	3%

Fig. 7. Small changes in patient position-in this example a 10° rotation of the Frankfort plane-can have a significant influence on tissue exposure at the periphery of a scan.

Location	DAP in mGycm^2	Effective dose μSv
Pan	67	13
Mand post	92	50
Mand ant	92	55
Max post	92	29
Max ant	92	21
TMJ	92	42
Max post	260	38
Medium FOV	272	74
Large FOV	337	78
Dual scan	674	125

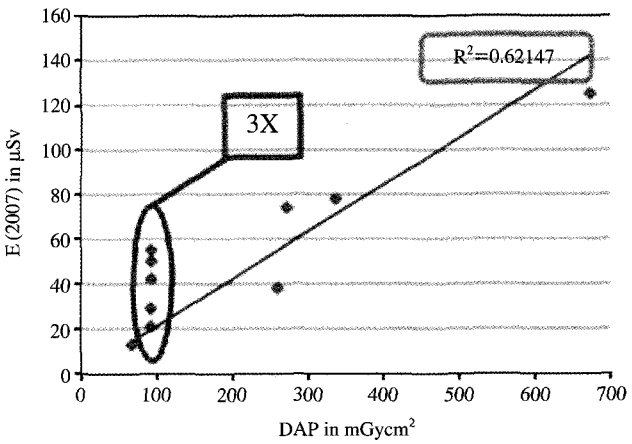


Fig. 8. SCANORA 3D: correlation of effective dose (E) and dose area product (DAP) for a variety of FOV size and position options. While correlation is moderate overall, there is essentially no correlation when the small FOV is used to examine different areas.

effective dose have clear shortcomings. A comparison of a RANDO phantom and an acrylic cylinder and ion chamber used to calculate CTDIvol demonstrated a 38-62% dose difference between the 2 techniques. CTDIvol underestimates effective dose in part by failing to account for scatter dose to tissues outside of the scan region.[12] Dose area product (DAP) has also been suggested as a simple approach for calculating dose. Experiments with the SCANORA 3D unit reveal a moderate correlation of DAP and effective dose (R-squared=0.62); however, when using the smallest FOV of the unit, this correlation disappears. An approximately 3-fold change in effective dose is seen between various locations of the small FOV with no change in DAP (Fig. 8).

When we look at the effect of radiographic parameters on dose, a number of relationships stand out. Size of the field of view is proportional to dose when other factors are held constant. This should prompt practitioners to choose the smallest FOV that is needed to achieve the diagnostic aims of a particular examination. But location of the FOV also has a significant impact on dose. The location effect is most apparent with smaller FOVs; however, even large FOVs may produce differing patient risks depending on how peripheral organs, such as the thyroid gland, are positioned with respect to direct exposure from the x-ray beam. This should prompt us to use thyroid shields and careful positioning strategies when possible. Shape of the FOV also influences dose to peripheral tissues. A sphere tends to increase brain and thyroid exposures in large FOVs while a carefully collimated cylinder can image the anatomy between the condyles and chin with a reduced vertical beam height.

The number of basis images that are acquired for an image volume and the amount of exposure per basis image have a direct effect on patient dose. For some units these factors are under the operator's control. When this is the case, choice of factors resulting in the lowest tube current and exposure time (mAs) consistent with the diagnostic task should be chosen.

Another factor that influences patient dose is the use of continuous or pulsed x-ray sources. Flat panels and the CCD and CMOS devices used in image intensifier receptors do not acquire information during short phases of the imaging cycle when the charge in the receptor is integrated and sent to the frame grabber for storage. Because of this some manufacturers pulse x-ray output, turning the beam off during the integration/data transmission phase of image acquisition. If the x-ray source is left on during this period when no new data can be acquired, the exposure is wasted and contributes unnecessarily to patient dose.

Pixel size has an indirect influence on patient dose in that more dose is required to achieve the same signal to noise ratio as pixel size is decreased. Given a choice, dentists prefer images with technical factors that provide high signal to noise ratios and high resolution. Dentists requesting images from an imaging center or providing examinations in their own offices may not understand the risk implications of using higher doses to obtain image volumes. If "pretty pictures" are being obtained when just a diagnostic image is needed, we are doing the patient a disservice. Further complicating this picture, general dentists referring patients to imaging centers may not clearly communicate the diagnostic reason for the scan, or the radiographic technician who lacks the training of a technologist may not be aware of the differences in image quality or resolution that are required for such varied tasks as investigating possible vertical root fracture vs. implant site treatment planning.

Ideally exposure factors are selected on the basis of image quality required to achieve the examination goals. Because image quality is proportional to dose, selection of image quality becomes a decision on dose and vice-as-versa. Ideally these decisions should be informed by the training and expertise of the radiologist who will be utilizing the examination for diagnosis. The reality is that the majority of scans will simply follow the manufacturer's suggested scanning protocol without further consideration of the potential for dose/image quality optimization. Therefore it will be important for future research to establish criteria for optimal levels of image quality taking into consideration both diagnostic yield and dose. It will be critical that professional radiology associations use these findings to guide manufacturers and end users to establish standard parameters for the operation of each CBCT unit. And finally it is important that we as radiologists continue to educate dentists and our patients about the risks and benefits of this evolving technology.

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