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FULL PAPER

Absorbed organ and effective doses from digital intra-oral and panoramic radiography applying the ICRP 103 recommendations for effective dose estimations

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Objective: During dental radiography, the salivary and thyroid glands are at radiation risk. In 2007, the International Commission on Radiological Protection (ICRP) updated the methodology for determining the effective dose, and the salivary glands were assigned tissue-specific weighting factors for the first time. The aims of this study were to determine the absorbed dose to the organs and to calculate, applying the ICRP publication 103 tissue-weighting factors, the effective doses delivered during digital intraoral and panoramic radiography.

Methods: Thermoluminescent dosimeter measurements were performed on an anthropomorphic head and neck phantom. The organ-absorbed doses were measured at 30 locations, representing different radiosensitive organs in the head and neck, and the effective dose was calculated according to the ICRP recommendations.

Results: The salivary glands and the oral mucosa received the highest absorbed doses from both intraoral and panoramic radiography. The effective dose from a full-mouth intraoral examination was 15 µSv and for panoramic radiography, the effective dose was in the range of 19–75 µSv, depending on the panoramic equipment used.

Conclusion: The effective dose from a full-mouth intraoral examination is lower and that from panoramic radiography is higher than previously reported. Clinicians should be aware of the higher effective dose delivered during panoramic radiography and the risk-benefit profile of this technique must be assessed for the individual patient.

Advances in knowledge: The effective dose of radiation from panoramic radiography is higher than previously reported and there is large variability in the delivered radiation dosage among the different types of equipment used.

INTRODUCTION

Dental radiography has been, and still is, one of the most frequently used radiological procedures according to the United Nations Scientific Committee on the Effect of Atomic Radiation 2008 report.¹ In the European Union member states, many millions of dental radiographs are taken annually and the numbers of dental radiographs (intraoral, panoramic and cephalometric) vary considerably across countries, ranging from 0.4 to 1.6 exposed radiographs per person per year.² A recent report from the UK also shows a large variation in radiation dose within a country.³ The variation in the patient entrance dose for intraoral radiography was found to be 1.15–2.8 mGy depending on the detector used.

Radiographs are essential in dentistry for the diagnosis, treatment planning, treatment monitoring and follow-up of patients. Intraoral radiography is the most commonly used technique. It is easily accessible and the cost, in terms of both radiation dose and monetary, value, is low compared with other radiographic techniques. The quality of the radiographs depends mainly on the correct positioning of the detector with optimal projection geometry, but also on the greyscale and contrast performance of the images. The use of intraoral radiographs is limited by their inability to portray the entire region of interest and the intolerance of patients to intraoral positioning of the detector. An alternative is to use an extraoral technique, e.g. panoramic radiography, which has become widely implemented but

has some inherent drawbacks, such as inadequate projection geometry and poor ability to display fine anatomical details, which may necessitate other projections.⁴ Even though radiographic screening should not be performed for oral diseases, panoramic radiography has been used as a screening method⁵ and is often recommended as an integral part of orthodontic planning and treatment. Both intraoral radiography and panoramic radiography are low-dose techniques, as compared with three-dimensional imaging systems used more recently in oral radiography, e.g. cone-beam CT, and for diagnostic medical radiology.

The salivary and thyroid glands are among the organs at risk in dental radiology. In particular, the salivary glands often lie within the primary beam in both intraoral and panoramic radiography. The notion of “effective dose” was introduced by the International Commission on Radiological Protection (ICRP) to sum the effect of the radiation doses delivered to the tissue and organs for radiological protection purposes. In 2007, the ICRP updated the effective dose estimation. The new recommendation (ICRP publication 103) replaced that issued in 1991 and for the first time, salivary glands and brain tissues had their own weighting factors included in the weighting scheme.⁶ In the ICRP 103, the end point for the assessments was changed from death from cancer to cancer incidence. The revised effective dose estimation has resulted in reassessments of earlier estimations of risk from dental radiographic examinations.

The salivary glands comprise 3 sets of paired major glands and >750 minor salivary glands in the oral mucosa.⁷ Ludlow et al⁸ found that the salivary glands and oral mucosa absorbed the highest doses of radiation of all the tissues during common dental radiographic examinations. In dental radiography, digital radiographic systems are becoming more commonly used and they have several advantages over analogue radiography (film-based direct radiography): digital detectors may be more sensitive to radiation, allowing for a lower radiation dose³ and necessitating fewer retakes owing to improvements in the greyscale and image contrast.

Berkhout et al⁹ and Poppe et al¹⁰ showed that digital systems generally require less exposure than conventional films for diagnostically acceptable intraoral radiographs. All the digital X-ray systems tested resulted in a reduced dosage of radiation, as compared with using E-speed films, although the magnitude of the reduction was dependent upon the system used and ranged from 30 to 70%. In digital panoramic radiography, dose reductions of 40–70%, without significantly affecting the subjective image quality, have been reported in studies conducted by Farman et al,¹¹ Dula et al¹² and Dannewitz et al.¹³ In panoramic radiography, the radiation field size is system dependent, with different preset collimator height and/or width settings sometimes available. These can be used to reduce the dose, particularly for paediatric patients.¹⁴ Even though the new ICRP recommendations appeared in 2007, few studies have actually measured the absorbed dose and used them as the basis for effective dose estimations in intraoral and panoramic radiography. Thus, the aim of this study was to report the absorbed organ doses and to determine the effective dose for digital intraoral radiography and panoramic radiography.

METHODS AND MATERIALS

Dose measurements

The absorbed dose measurements were made with thermoluminescent dosimeters (TLDs) with dimensions of $3.2 \times 3.2 \times 0.9$ mm (TLD-100™; Harshaw, Solon, OH) in an anthropomorphic head and neck phantom that represented an average male (ART phantom; Radiology Support Devices Inc., Long Beach, CA). The phantom was sliced horizontally into 2-cm-thick sections (Figure 1a) and each slab contained, in fixed positions, drilled holes for placement of the TLD. Suitable positions of the TLD for representation of organs of interest were chosen and verified radiographically with CT scanning using lead foils in the dose-meter positions (Figure 1b).

The TLDs were positioned in the slab at a depth of 0.5–1.0 cm from the top surface and covered with the same tissue-equivalent material as the phantom, thus avoiding direct X-ray exposure during irradiation due to a gap between the slabs.

Figure 1. (a) Reformatted three-dimensional image of the phantom head. The numbers on the phantom head surface indicate each slab. (b) Midline sagittal slice from CT showing the different levels in the phantom head.

For each radiographic examination, 30 TLDs were placed in the locations representing the different radiosensitive organs. The locations and numbers of TLDs are given in Table 1 and Figure 2. A total of 270 TLDs were used and each TLD was assigned an identification number. The TLDs were divided into groups permitting several examinations during each measuring session. To minimize the variation in the determination of organ-absorbed dose, the individual TLD in each group was retained in its designated location for all the examinations.

30 TLDs were used in the phantom for each examination. The level of background radiation was determined using three or four TLDs in each measuring session. These dosimeters were handled in the same way as those used for organ dose determination, although they were kept in the control room during the exposure. Reference dosimeters (5–7 TLDs) were also used to correct for the sensitivity of the TLDs between the calibration session and the measurement session.

One examination consisted of a number of repeated exposures, 10 or 20 times for intraoral and 5 times for panoramic imaging, to increase the signal level. To obtain the dose for 1 examination, the TLD signal was thereafter divided by 10 or 20 for intraoral radiography and by 5 for panoramic radiography.

Prior to each measuring session, the TLDs were annealed for 1 h at 400 °C. After each irradiation but before the read-out, they were washed for a few seconds in a solution of methanol that contained 12-mmol HCl per litre, to reduce the non-radiation-induced background signal. The TLDs were then read in

a Universal Toledo TLD reader (654 E; Vinten Instruments, UK). Each dosimeter was individually calibrated in a ^{60}Co beam to a known absorbed dose in water. Depending on the tube voltage (60–73 kV) used, a correction factor of 0.77 or 0.775 was used to compensate for the increased sensitivity of the TLDs in relation to the radiation quality used for the calibration. The sensitivity of the TLDs was found to be constant with beam quality (tube voltages between 60 and 77 kV), as the variance of the correction factor was below 0.0004.

Determination of effective dose

The effective dose was determined as the sum of the equivalent dose delivered to the organs specified in ICRP 103 multiplied by their given tissue-weighting factors (w_T).⁶

To determine the mean organ dose (D_T), for example, to the salivary glands, the average dose for the 18 TLDs (located in the parotid and submandibular glands on both the left side and the right side) was calculated. The different TLD positions are indicated in Figure 2, and the symbols indicate which TLD is included in the specified organ. For example, the symbol $\odot$ indicates that these TLDs were used to calculate the average organ dose of the parotid glands. Similarly, the symbol $\triangle$ was used for the submandibular gland dose estimation. For the oral mucosa, the average organ dose was estimated from six TLDs, two parotid TLDs and four submandibular TLDs, as indicated in Figure 2, by superimposition of the symbol $\star$.

As stated by Ellis,¹⁵ the fractions of the red bone marrow in a 40-year-old male are 11.9% for the cranium and 1.2% for the mandible. The radiation dose delivered to the red bone marrow organ was estimated using 11.9% of the dose to the TLDs in the brain ($\square$) together with the 1.2% of the dose to the mandible (here estimated based on the submandibular salivary gland dose $\triangle$). The average organ dose to the bone surface was calculated by multiplying the red bone marrow organ dose by the bone-to-muscle mass energy absorption coefficient ratio (MEACR) using the equation: $\text{MEACR} = 6.9406 - 0.0618 \times 2/3 \text{ kV}_p$ ¹⁶ and the data from the National Bureau of Standards handbook no. 85.¹⁷ For 60 kV_p, the MEACR was estimated as 4.47.

The radiation dose delivered to the thyroid organ was calculated as the average for the three TLDs marked ($\diamond$) in Slab 11.

The oesophagus organ dose was estimated as 5% (intraoral) or 10% (panoramic) of the average for the two TLDs in Slab 9 and the three TLDs used for the calculation of the thyroid organ dosage. The radiation dose to the extrathoracic region was taken as 10% of the thyroid organ dose. The radiation dose to both the muscle and the lymphatic nodes was taken as 5% of the average radiation dose to the parotid gland.

The radiation dose to the skin for the intraoral projections was calculated as the fraction of the irradiated skin area to the total skin area of an adult male (estimated as 0.08%) and multiplied by the entrance surface dose at the centre of the irradiation field. Similar estimations of the irradiated skin area were performed for the different panoramic units.

Table 1. Location and number of thermoluminescent dosimeters (TLDs) in the phantom head

Anatomic region/organ	Phantom location Slab number	Number of TLDs
Brain anterior part	2	1
Brain posterior part	3	1
Pituitary gland	4	1
Right eyelid	4	1
Left eyelid	4	1
Right eye	4	1
Left eye	4	1
Right parotid gland	6,7,8	6
Left parotid gland	6,7,8	6
Right submandibular gland	8,9	3
Left submandibular gland	8,9	3
Thyroid gland	11	3
Thyroid surface	11	1
Skin entrance surface		1

Figure 2. The placement of thermoluminescent dosimeters (TLDs) representing the organ of interest at different sections in the phantom head: □ = brain, ⊠ = pituitary gland, ☆ = eye, ⊗ = eyelid, ○ = parotid gland, △ = submandibular gland, ◇ = thyroid gland and ● = skin entrance surface. The TLDs used for the estimation of the organ dose to the oral mucosa are the ones with the symbol ☆ overimposed on the glandular symbols.

The effect of radiation on the eye is deterministic; so, this organ was not included in the effective dose determinations.

The value of the D_T was then multiplied by the radiation-weighting factor to give the equivalent dose.⁶ Here, radiation-weighting factor = 1 was used as the irradiation comprised of photons.

Radiographic equipment and techniques

In both intraoral and panoramic imaging, the exposure parameters were those used for an average male patient.

Intraoral radiography

The intraoral radiographic unit used was the Gendex Oralix DC® (Gendex, Milan, Italy) operating at 60 kV and 7 mA, with a focus-to-skin distance of 20 cm. A rectangular collimator with a 35 × 45-mm opening was used.

In total, 10 different intraoral image positions were studied, representing the regions of interest for a full-mouth radiographic examination, comprising in total 18 intraoral radiographs. The design of the phantom does not allow the image receptor to be positioned in the mouth. However, exposures were made to correspond to the acquisition of the periapical radiographs in the region of the maxillary and mandibular incisor, canine, premolar and molar and in addition, two posterior bitewing projections, premolar and molar. To ensure the correct

projection angles in the vertical and horizontal directions, a skull phantom was used for practising the projections before the dose measurement. The angles were noted for each region, and these were used on the anthropomorphic phantom. Figure 3 shows an example of a full-mouth radiograph for one patient.

The exposure times for the intended use of a photostimulable phosphor (PSP) plate (Digora® Optime; Soredex, Helsinki, Finland) at the different projections are given in Table 2.

Panoramic radiography

The anthropomorphic phantom head was examined in three different digital panoramic units: Veraviewepocs® (Morita, Osaka, Japan); Cranex Tome Ceph® (Soredex, Helsinki, Finland); and Scanora® (Soredex, Helsinki, Finland). Each panoramic unit has one pre-designated beam movement and one fixed form of the image layer. The fixed layer, or the focal trough, is a three-dimensional curved zone in which anatomical structures are clearly visible. The patient must be positioned precisely within such a fixed layer so that the jaw coincides with the image layer during exposure.

The Veraviewepocs unit was equipped with a charge-coupled device-based detector. In the Cranex Tome Ceph, a PSP plate was exposed and visualized in a Digora PCT® (Soredex, Helsinki, Finland) phosphor plate scanner. In the Scanora unit, the PSP image plate and scanner were incorporated into the X-ray

Figure 3. An example of a full-mouth radiographic examination.

unit. The panoramic programs and exposure parameters used are given in Table 3. The jaw panorama exposes a larger volume of the patient, the entire jaws, than the dental imaging systems that focus exclusively on the tooth-bearing regions. Figure 4 is an example of a jaw and dental panoramic radiograph of a patient.

RESULTS

For all the measurement sessions, the average background radiation dose was $5.3 \mu\text{Gy}$, with a standard deviation of $\pm 1.2 \mu\text{Gy}$. The minimum detectable absorbed dose (expressed as three times the standard deviation of the background) was therefore $3.6 \mu\text{Gy}$.

For each measuring session, the background radiation dose was subtracted before the D_T was estimated.

Table 2. Intraoral radiographic region and exposure time

Image type	Region	Exposure time (s)
Periapical maxillary	Incisor	0.32
	Canine	0.32
	Premolar	0.32
	Molar	0.50
Periapical mandibular	Incisor	0.25
	Canine	0.25
	Premolar	0.32
	Molar	0.40
Bitewing	Premolar	0.32
	Molar	0.40

All the mean absorbed doses to the relevant organs during intraoral and panoramic radiography are listed in Tables 4 and 5. The salivary glands and the oral mucosa received the highest absorbed organ doses during bitewing imaging (4 intraoral images), *i.e.* 108 and $164 \mu\text{Gy}$, respectively, and during full-mouth examinations (18 intraoral images), *i.e.* 452 and $584 \mu\text{Gy}$, respectively.

In panoramic imaging, the absorbed organ doses varied between the three different units, although the salivary glands and the oral mucosa received the highest absorbed doses, 348–2887 μGy . The absorbed doses to other head and neck organs were all $<230 \mu\text{Gy}$.

The entrance surface doses to the skin during intraoral radiography are shown in Table 6.

The estimated effective doses are presented in Table 7. The effective dose from a full-mouth examination was $15 \mu\text{Sv}$ (mean, $0.8 \mu\text{Sv/intraoral}$) and for a panoramic radiograph, the effective dose was in the range of 19–75 μSv for the three different panoramic units.

DISCUSSION

The aims of the present study were to establish the absorbed doses to radiosensitive organs during common dental radiographic examinations and to determine the effective doses by applying the ICRP 103 w_T . As expected, the salivary glands together with the oral mucosa had the highest absorbed doses following both intraoral and panoramic radiography.

The result obtained in this study shows that the effective dose received from a full-mouth examination, using PSP exposure factors and rectangular collimation, is $15 \mu\text{Sv}$. In a review conducted by White¹⁸ in 1992, the average effective dose from seven

Table 3. Programs and exposure parameters for the panoramic units

Equipment brand Panoramic program	Image magnification	Tube voltage (kV)	Tube current (mA)	Exposure time (s)
Cranex Tome Ceph® (Soredex, Helsinki, Finland)				
Jaw	×1.3	66	20	13
Dental	×1.7	66	20	15
Veraviewepocs® (Morita, Osaka, Japan)				
Jaw	×1.3	73	6	15
Dental	×1.7	73	6	15
Scanora® (Soredex, Helsinki, Finland)				
Jaw	×1.3	66	20	13
Dental	×1.7	66	20	15

different studies was found to be 84 μSv , using D-speed film and circular collimation, together with ICRP 60 w_T . In the study reported by Ludlow *et al*⁸ in 2008, the effective doses for a full-mouth examination using PSP or F-speed film and rectangular collimation were 12.2 or 34.9 μSv , depending on whether ICRP 60 or 103 factors, respectively, were used. While their results differed from those of White,¹⁸ both calculations were performed without the incorporation of tissue-specific weighting factors for the salivary glands (ICRP 60). However, Ludlow *et al*⁸ used both a faster film/detector and rectangular collimation, all of which influenced the effective dose, in this case reducing it from 84 to 12.2 μSv . Changing from circular to rectangular collimation can decrease the absorbed dose to the salivary glands by almost half, and changing from D-speed film to the more sensitive E-speed film further reduces the radiation dose by 40%.¹⁹

With respect to effective dose, the result from the present study (15 μSv) differs from that (34.9 μSv) obtained by Ludlow *et al*,⁸ even though both studies applied the ICRP 103 methodology. This discrepancy may be attributable to the different projection techniques used in the studies. A larger vertical angulation of the central beam for both the upper and lower periapical images would increase the dose listed by Ludlow *et al*⁸ in Appendix 2. We applied a standardized paralleling technique in which the central beam was directed perpendicular to the object and an intended detector, resulting in a smaller vertical angle of the X-ray beam than that used by Ludlow *et al*.⁸ As regards the bitewing images, the results did not differ, and this may be due to the fact that the same projection technique was applied in the

two studies. Thus, the effective dose is affected by not only the speed of the detector and the size and shape of the collimation, but also the beam direction in intraoral imaging. Therefore, differences in film/detector speed, collimation size, projection technique, w_T and TLD placement need to be considered and evaluated when comparing the effective doses reported from different studies.

For diagnostically acceptable radiographs, digital intraoral systems may require less radiation than film.^{9,10} This argument is often used by manufacturers as motivation for investment in a digital system. However, the difference in sensitivity varies between digital detectors, and it might be lower for charge-coupled device detectors than for PSP detectors. The PSP detector used in our study required higher exposure levels than the more radiation-sensitive PSP detector currently in the market. Therefore, our results may overestimate the effective dose from intraoral radiography. If, for example, the exposure time is halved, the effective dose is reduced by a factor of 2. Another important aspect of our study is that all the organ-absorbed doses were measured without an intraoral detector in place. An intraoral digital detector, as well as an intraoral film, would absorb some of the transmitted radiation, thereby reducing the organ doses to the opposite side.

The present study, together with other studies, shows that the absorbed dose to the salivary glands during panoramic radiography is 2–3-fold higher than the dose from a full-mouth intraoral examination. The high organ doses to the salivary glands reflect the fact that: (1) the salivary glands are located

Figure 4. An example of a jaw (a) and dental (b) panoramic radiograph.

Table 4. Mean absorbed organ dose (in μGy) from intraoral radiography

Organ	Bitewing (4 images)	Full-mouth examination (18 images)
Brain	0	0
Salivary glands	108	452
Thyroid gland	8	53
Red bone marrow	2	6
Oesophagus	2	8
Bone surface	8	35
Lymphatic nodes	4	20
Oral mucosa	164	584
Muscle	4	20
Extrathoracic region	8	53
Eye	4	96

within the X-ray beam during the period of exposure; and (2) the locations of the major glands (the parotid and sub-mandibular glands) coincide with the location of the rotational centre, in both the posterior and anterior parts of the image layer. Together with the revised estimates of organ-specific sensitivity, the salivary gland doses will have a major impact on the effective dose.

Ionizing radiation is associated with salivary gland cancer.^{20,21} The cancer induction time is relatively long for solid tumours; for exposures during childhood and adolescence, the induction

period is 10–35 years.²² There are a few epidemiological studies on a possible relationship between dental radiography and salivary gland cancer. Horn-Ross et al²³ reported that panoramic radiography was not associated with an increased risk but that full-mouth dental examinations were. The increased risk was mainly limited to patients who were exposed to full-mouth intraoral radiographs before 1955, when exposure settings were considerably higher.

The positioning of the TLDs in the phantom is a crucial parameter in effective dose estimations based on organ-absorbed doses. In the present study, the same individual TLD remained in its designated location for all the examinations, limiting the variability of organ dose determination. However, the holes in which the TLDs were placed were fixed in the phantom, so they may not always have represented the exact position or extent of the organs of interest. If the conversion factor between the effective dose and the air kerma–area product had been known for the specific examination, the effective dose determination could have been performed in a less time-consuming way.²⁴ In addition, the kerma–area product value itself could serve as a dose indicator.

Panoramic radiography is often used as an alternative to intraoral imaging, even though it has a lower spatial resolution and is more difficult to interpret. One reason may be that the radiation risk from panoramic imaging has traditionally been considered to be equivalent to a few single intraoral images. In 1992, the estimated effective dose for film screen-based panoramic radiography was $6.7 \mu\text{Sv}$, *i.e.* <10% the risk estimate for a full-mouth examination.¹⁸ In the present study, the effective doses were in the range of 19–75 μSv . Thus, one panoramic image would, from a radiation risk point of view, be equivalent to approximately 1–5 full-mouth examinations. In panoramic

Table 5. Mean absorbed organ doses (in μGy) from panoramic radiography

Organ	Cranex Tome Ceph® (Soredex, Helsinki, Finland) jaw	Cranex Tome Ceph dental	Veraviewepocs® (Morita, Osaka, Japan) jaw	Veraviewepocs dental	Scanora® (Soredex, Helsinki, Finland) jaw	Scanora dental
Brain	26	10	10	5	18	19
Salivary glands	1028	1182	869	939	2887	2428
Thyroid gland	40	48	53	52	126	111
Red bone marrow	11	10	13	18	54	38
Oesophagus	14	17	16	13	221	68
Bone surface	45	44	51	69	229	162
Lymphatic nodes ^a	63	71	43	38	116	113
Oral mucosa ^a	348	445	1042	1529	2151	982
Muscle ^a	63	71	43	38	116	113
Extrathoracic region ^a	4	5	5	5	126	11
Eye and eyelid	9	5	7	4	10	10

^aRemainder tissue.

Table 6. Entrance surface doses (ESDs) (in μGy) to the skin from different intraoral projections

Radiographic region	ESD
Periapical maxillary	
Incisors	1618
Canine	1742
Premolar	1832
Molar	2723
Periapical mandibular	
Incisors	1592
Canine	1386
Premolar	2030
Molar	2488
Bitewing	
Premolar	1930
Molar	2383

imaging, film screen-based systems are much more sensitive to radiation than intraoral films and they are as sensitive as digital detectors. Changing from an analogue to a digital panoramic system will not reduce the radiation dose to the level associated with intraoral imaging.

The present study also shows large variations between the different panoramic units. The panoramic unit with the lowest effective dose was Cranex Tome Ceph (jaw) and the one with the highest effective dose was Scanora (jaw). The Cranex Tome Ceph was operated with a PSP-based detector, which is probably more sensitive to radiation than the built-in PSP of the Scanora.

The Veraviewepocs gave effective doses that were slightly higher than those provided by the Cranex Tome Ceph, even though it was operating at a higher tube voltage (in kilovoltage) and a lower tube current (in milliamperes). Furthermore, projection geometry, *i.e.* image layer depth and path of the rotation centre, may differ across the panoramic units, with parts of the salivary glands being left outside of the X-ray beam in some cases. This is probably one of the reasons why the salivary gland-absorbed doses varied between the different panoramic units.

A recent study has emphasized the variability of the effective dose within the same panoramic units and between panoramic units of different brands.²⁵ Whether a difference in radiation dose is reflected in the image quality and the diagnostic outcome was not investigated, nor was this issue within the scope of the present study. A previous study by Molander et al⁴ concluded that Scanora (dental) provided the best subjective image quality.

The present study shows that digital intraoral imaging is a low-dose radiographic technique. Panoramic radiographs generate higher risk of radiation than previously assumed, attributable to the effect of the radiation dose absorbed by the salivary glands. This study also shows that there is variability between different panoramic units. Other than differences in detector sensitivity, it is possible that the variation in inherent machine-specific factors, such as beam filtration, focus–detector distance, the path of the effective rotation centre and the central plane of the image layer, contributes to this variability between units. All the radiographic information must be obtained with the lowest level of radiation. For cases with equivalent diagnostic outcomes, this study shows that intraoral imaging is preferable over panoramic radiography, from a radiation risk perspective.

In conclusion, the results of this study show that the salivary glands and the oral mucosa received the highest organ doses

Table 7. Effective doses for dental radiographic examinations

Type of examination	Effective dose(μSv)
Full-mouth examination ^{a,b}	15
1 intraoral periapical	average 0.8 (range 0.1–2.6)
4 Bitewing ^b	3.4
Bitewing premolar	0.3
Bitewing molar	1.4
Panoramic radiography	average 36 (range 19–75)
Cranex Tome Ceph® (Soredex, Helsinki, Finland) jaw ^b	19
Cranex Tome Ceph dental ^b	22
Veraviewepocs® (Morita, Osaka, Japan) jaw ^c	23
Veraviewepocs dental ^c	30
Scanora® (Soredex, Helsinki, Finland) jaw ^b	75
Scanora dental ^b	49

^a18 images.

^bPhotostimulable phosphor.

^cCharge-coupled device.

from both intraoral and panoramic radiography. The effective dose from a digital full-mouth intraoral examination is lower than previously reported, while the effective dose from digital panoramic radiography is higher than anticipated. Clinicians should be aware of the higher effective dose when using a panoramic technique and should decide whether this type of

radiography is warranted. In this way, the benefits of this technique will be realized while the risks will be minimized.

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