RESEARCH ARTICLE

Ambient dose during intraoral radiography with current techniques: Part 1 conversion factor for scattered radiation using a rectangular collimator

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Objectives: The aim of this study was to establish a conversion factor for assessing the scattered radiation produced during intraoral radiography with a rectangular collimator in areas where the remnant beam is not present. The dose level in the remnant beam will be addressed in another study.

Methods: A radiological phantom (Rando) in the upright position was exposed to radiation delivered by a Planmeca Intra X-ray unit over 9 exposure geometries (right side of a full mouth series). For each geometry, the scattered radiation dose was measured at 5 locations in the horizontal plane and 4 locations in the vertical plane in front of the patient. The measurements were corrected for background and leakage radiation. An inventory of the distributions of the different geometries with respect to their share of the total workload was created in order to assign the correct weightings of the total ambient scattered radiation for the different geometries. The weightings were used to construct a scattered radiation pattern for a representative mix of exposures. The maximum value found in this pattern was used to arrive at a safe conversion factor.

Results: The scattered ambient radiation dose was evenly distributed over the horizontal plane. The scattered ambient radiation dose ranged from 20 to 65% lower in the vertical plane.

Conclusions: The conversion factor established for scattered ambient radiation was 0.05 μ Sv per mAs at 1 meter. This factor is 3-fold lower than the conversion factors reported previously. *Dentomaxillofacial Radiology* (2018) 47, 20180108. doi: [10.1259/dmfr.20180108](https://doi.org/10.1259/dmfr.20180108)

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Introduction

During intraoral radiography a beam of X-ray photons is directed towards an image detector placed in the mouth of a patient. A fraction of these photons is absorbed by the tissues of the patient and by the image detector. Another fraction does not interact and exits the patient in the original direction; this fraction is called the remnant beam. Finally a portion of the photons interacts with the encountered matter, which leads to

Compton and Rayleigh scattering. The scattered radiation can be detected in all directions. The remnant beam and the scattered radiation together with the leakage radiation from the X-ray device comprise the ambient radiation near the patient during the exposure.

The International Commission on Radiological Protection (ICRP) created a framework for radiation protection that has been implemented in most developed countries around the world.¹ One of the principles of this framework is the concept of dose limits. The ambient radiation exposure dose must be shown not to

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exceed the dose limit, which is expressed in millisieverts (mSv) per year. The limit for radiological workers is 20 mSv/year; for other persons in the facility the limit is 1 mSv year⁻¹; and at the perimeter of the facility, the dose limit can be more stringent, and varies based on local rules and regulations. The methods for demonstrating compliance with the dose limits vary from country to country. In general, a radiation protection expert must evaluate the ambient X-ray burden produced at dental facilities using dental X-ray devices.

The radiation expert takes a number of factors into account, including the annual workload of the X-ray device, which is expressed by the product of exposure time [seconds (s)] and the tube current [milli amperage (mA)], yielding an output value in mAs. The floor plan and construction of the dental office are also taken into consideration, because they provide information on the distance from the X-ray source to the position where the limit is valid and on shielding by the construction materials. A major parameter taken into account for the dose limit is the amount of ambient radiation produced per mAs. This paper focuses on the scattered radiation component of the ambient dose produced during intra-oral radiography. The dose level in the remnant beam resulting from intraoral radiography is the focus of another investigation in our department.

Two published reports from 1959 and 1968 have provided data on ambient radiation doses at different operator positions around the dental chair during intra-oral radiography.^{2,3} Although the materials and the methods described in those papers do not correspond to current radiological practice (type of cone, focus-to-skin distance, and units are out of date; and the ‘permissible dose’ is now obsolete), these papers clearly show that the scattered radiation dose is highest anterior to the patient’s head.

A more recent study by De Haan and Van Aken (1990) described the use of a phantom constructed of material equivalent to tissue that was exposed in 3 geometries (bitewing, upper molars, upper incisors).⁴ Measurements were performed at different heights around the phantom in a circle with a 1-m radius. The exposures were performed without a cone or a tube on the X-ray generator. The recorded dose levels were transposed to “effective dose equivalents” for a bystander. The systematics as well as the calculations, which were based on tissue-weighting factors, are no longer valid; since they were replaced by the 2007 Recommendations of the ICRP.⁵

Kuroyanagi and coworkers published a 1998 paper on the scattered radiation levels around the dental chair during intraoral radiography with the patient in the supine position.⁶ They evaluated 4 different exposure geometries (anterior and posterior periapical views of the maxilla and mandible). The X-ray machine was equipped with a round 6-cm-diameter cone and a 30 cm focus-to-end-of-tube distance. The distance from the end of the tube to the surface of the phantom during

exposures was not specified. The dose levels at 1 m varied from approximately 0.005 to 0.05 µGy, depending on the geometry and position. The area anterior to the patient’s head showed the highest scattered radiation doses, which is consistent with the previous studies.^{2,3}

The data from these studies can be used to deduce a conversion factor to estimate scattered radiation doses from the workload, although there are 3 limitations, as follows: (1) the projection geometries do not represent all intraoral exposures. A preferable reference value would be derived from a realistic combination of the different exposure geometries. The purpose of the reference value is, after all, to provide a realistic estimation of the scattered radiation dose to the environment of the dental facility from the total yearly exposure, which can then be compared with the dose limit. (2) Rectangular collimation is used by modern intraoral radiography. Reduction in the area of the patient being irradiated should lead to the reduced production of scattered radiation. (3) And finally, the X-ray generators used in the older studies ran on alternating current (AC). The steady output of the modern X-ray machines that run on direct current (DC) might produce different levels of scattered radiation in the tissues of the patient.

The radiation expert who wants to calculate the ambient scattered radiation dose currently does not have a valid conversion factor. Therefore, this study was designed to determine the conversion factor for scattered radiation dose levels produced by a realistic mix of exposure geometries normalised at 1 m per workload of the X-ray tube fitted with a rectangular collimator.

Methods and materials

The head and shoulders of a Rando radiological phantom (The Phantom Laboratory, Salem, NY) placed in a seated position were exposed to X-rays. The X-ray device was a wall-mounted Planmeca Intra X-ray unit (Planmeca, Helsinki, Finland). It was operated at a tube voltage of 70 kV, a tube current of 8 mA, and an exposure time of 3.2 s per exposure. It was equipped with a rectangular collimator of 37 × 30 mm at the end of the tube, with a focus-to-end-of-tube distance of 35 cm. The output of the Planmeca X-ray generator was tested by a semiconductor dosimeter (Unfors Raysafe ThinX; Unfors, Billdal, Sweden), which had been recently calibrated. Measurements of scattered radiation, background radiation, and leakage radiation doses were performed by a semiconductor survey detector (Unfors Xi Survey Detector) that had been recently calibrated by a source with parameters traced back to NIST and PTB standards. Scattered radiation measurements were performed at 9 positions: 5 in the horizontal and 4 in the vertical planes (Figure 1). All measurements were performed at a distance of 60 cm, except position I, where the distance was 29 cm. The difference in distance was compensated for in subsequent calculations.

Figure 1 The scattered radiation was measured at 5 positions in the horizontal plane at the height of the mouth (left image) and 4 positions in the vertical plane (right image).

The right side of the phantom head was exposed in 9 geometries that corresponded with the right side of a full mouth series [4 periapical exposures in the upper jaw (incisor, canine, premolar and molar) and the same 4 in the lower jaw plus a posterior bitewing exposure]. During the exposures a distance of 5 cm was maintained between the surface of the phantom and the end of the tube, which would be the case when a beam-aiming device was being used. The duration of each exposure was 3.2 s. As symmetry can be assumed, the ambient radiation doses for exposures of the left side were considered to be equivalent to the measured doses from the locations in the horizontal plane of the exposures to the right side.

Since background radiation and leakage radiation from the X-ray tube will interfere with the scattered radiation measurements, the measurements were corrected for background radiation and leakage radiation to arrive at the net scattered radiation dose. For this the background radiation dose rate was assessed by measuring radiation for 10 min in the room where the experiments took place without activating the X-ray device. The measurement time of each separate measurement was recorded. The actual correction for each measurement was calculated by multiplying measurement time by the background radiation dose rate and was subtracted from the measurement. Leakage radiation dose per 3.2 s exposure was separately measured during exposures around the X-ray device while the tube was capped with lead. This value was adjusted for the distance focus to measurement location using the inverse square law. The resulting leakage radiation dose at the measurement location was subtracted from the measurement.

The net scattered radiation dose was obtained in this way for each of the 9 exposure geometries at each of the 9 positions. These doses resulted from a 3.2 s exposure at a tube current of 8 mA ($3.2 \text{ s} \times 8 \text{ mA} = 25.6 \text{ mAs}$). By dividing the measurements by 25.6 mAs and applying the inverse square law, the measurements were normalised to scattered radiation per mAs at 1 m from the phantom head.

We performed a retrospective evaluation of data obtained from all the intraoral X-rays performed in our institution during a 2-month period (January 15 to March 15, 2015). We distinguished between exposures of children (age <12 years) and adults, because exposure times are based on the age of the patient. The frequencies of the different exposure geometries for children and adults were multiplied by the corresponding exposure times and multiplied by 8 mAs to arrive at the total value in mAs per exposure geometry. By this method we were able to calculate the relative contributions of exposure geometries to the total workload. These proportions were used to perform weighted additions of the scattered radiation doses of each exposure geometry in each of the 9 different directions. Even distributions of left- and right-sided exposures were assumed. A pattern of stray radiation doses per mAs at 1 m of a representative workload in the 9 measurement directions emerged. For safety reasons, the highest value in the pattern was used to arrive at a conversion factor.

The scattered dose was then converted from gray (Gy) units to the effective dose in sievert (Sv) units. For 70 kV and assuming an anteroposterior radiation geometry and total body irradiation, the conversion factor of approximately 1.5 was used, as stated in the literature.⁷ The resulting value can subsequently be rounded up to serve as a convenient and safe conversion factor for the scattered radiation dose.

Results

The dosimeter test of the Planmeca X-ray machine confirmed that the output was within a narrow range. The mean tube voltage, when set at 70 kV, was found to be 70.06 kV (± 0.8), and discrepancies in exposure times were not identified.

The background radiation dose rate was measured over a 10-min period in the room where the experiments took place. The background radiation dose rate was found to be 0.035 nGy/s, and ranged from 0.008 to 0.24% (mean 0.06%) of the measured doses in the experiment. The correction for the leakage radiation was found to range from 0.06 to 5.9% (mean 0.8%) of the measured doses in the experiment.

Table 1 presents the measured doses at the 9 positions that were recalculated to a 1-m distance from the head. The doses are corrected for leakage and background radiation levels and normalised per mAs.

The inventory of all intraoral radiographs made at our institution over a 2-month period showed a total number of 9835 exposures, of which 345 were exposures of children and 9490 were exposures of adults. The numbers of the different exposure geometries and their contribution to the total exposure are shown in Table 2 and Figure 2.

The total scattered radiation dose per mAs at 1 m at each location for a representative mix of exposures is shown in Table 3 and Figure 3.

Table 1 Doses of scattered radiation for the 9 exposures of the right side of a full mouth series in nGy mAs⁻¹ at 1 m for each position (A-I, Figure 1)

Position	Incisor max	Canine max	Bicuspid max	Molar max	Bitewing	Incisor mand	Canine mand	Bicuspid mand	Molar mand
A	41.01	36.65	46.68	70.53	26.98	27.42	35.12	42.99	59.26
B	50.64	43.76	53.11	43.50	42.55	43.80	27.41	41.12	43.66
C	42.02	41.75	29.76	24.15	24.52	25.06	41.30	30.58	25.01
D	25.85	17.13	15.68	7.89	10.95	31.70	31.04	15.90	14.03
E	33.37	14.31	12.68	11.79	12.07	26.11	18.89	15.89	12.54
F	25.92	19.85	8.48	8.49	8.82	6.98	6.93	4.27	4.33
G	31.46	36.79	28.15	18.23	18.19	26.56	29.15	24.75	16.96
H	35.20	28.56	24.36	19.28	20.01	44.63	33.91	28.03	20.20
I	17.59	19.58	15.60	10.79	12.68	38.70	30.99	23.85	28.74

Mand, Mandibular; Max, maxillary.

The values are corrected for natural background radiation and leakage radiation.

The scattered radiation dose per mAs at 1 m is evenly spread throughout the occlusal plane (positions A to E), at slightly less than 30 nGy at each measurement position. This value can therefore be safely used for the reference value. The doses of scattered radiation measured upwards and downwards (positions F to I) ranged from 20 to 65% lower than the doses over the horizontal plane. The 30-nGy dose can be converted to 45 nSv or 0.045 μ Sv.⁷ Rounded up, the value results in a safe conversion factor of 0.05 μ Sv mAs⁻¹ at 1 m.

Discussion

This study aimed to obtain a conversion factor for scattered radiation in the dental clinic during intra-oral X-rays. The latest data date back 20 to 30 years and are outdated by changes in the current standards for intraoral radiography, including longer focus-to-object distances, rectangular collimation, and DC

generators. In addition, the radiation protection standards, including dose limits and weighting factors, have changed.

The scattered radiation measured per mAs at 1 m from the head of the patient was highest at the level of the horizontal plane (0.03 μ Gy). At 45 degrees upwards and downwards to the horizontal plane, the dose level was 0.02 μ Gy, and in the cranial direction the dose level was 0.01 μ Gy. The steep dose reduction in the cranial direction can be explained by reabsorption of the scattered radiation as it travels upwards through the material in the phantom that is located above the alveolar processes.

This study obtained a conversion factor of 0.05 μ Sv mAs⁻¹ at 1 m from the head of the patient. The conversion factor can be used in radiation risk assessments to verify if the ambient dose caused by a known workload lies within the dose limit of the ICRP.

For the average intraoral X-ray with an exposure time of 0.20 s at 8 mA (1.6 mAs), the scattered radiation

Table 2 Inventory of 2 months of intraoral radiography procedures at our institute (January 15 to March 15, 2015)

Exposure geometry	Child				Adult				Total workload (mAs)	Relative contribution (%)
	Number of exposures	Exposure time (sec)	Total exposure time (sec)	Total workload (mAs)	Number of exposures	Exposure time (sec)	Total exposure time (sec)	Total workload (mAs)		
Incisor max	41	0.08	3.28	26.24	933	0.08	74.64	597.12	623.36	5.47
Canine max	3	0.08	0.24	1.92	524	0.10	52.40	419.20	421.12	3.70
Bicuspid max	0	0.12	0.00	0.00	868	0.12	104.16	833.28	833.28	7.31
Molar max	5	0.16	0.80	6.40	1154	0.16	184.64	1477.12	1483.52	13.02
Bitewing	273	0.14	39.31	314.50	3233	0.19	606.19	4849.50	5164.00	45.31
Incisor mand	11	0.08	0.88	7.04	486	0.08	38.88	311.04	318.08	2.79
Canine mand	1	0.08	0.08	0.64	414	0.10	41.40	331.20	331.84	2.91
Bicuspid mand	2	0.12	0.24	1.92	614	0.12	73.68	589.44	591.36	5.19
Molar mand	9	0.16	1.44	11.52	1264	0.16	202.24	1617.92	1629.44	14.30
Total	345			370.18	9490			11025.82	1,1396	100

Mand, Mandibular; Max, maxillary.

In the last column on the right the relative contributions (%) of the 9 different geometries to the total workload are displayed. All exposures were performed with a tube current of 8 mA.

Figure 2 Graphic representation of the contributions of the 9 exposure geometries to the total workload in mAs over a 2-month period at our institution, as shown in Table 2. I, incisor; C, canine; p, bicuspid; M, molar; BW, bitewing; +, maxillary; –, mandibular.

is anticipated to be $0.02 \mu\text{Sv}$ at 2 m. Given the ICRP dose limit, this scattered radiation dose at 2 m allows more than 40,000 exposures to be made before the dose limit of 1 mSv is reached. Taking into account the “as low as reasonably achievable” ALARA principle, the operator can limit exposure by maintaining a longer distance from the patient and by using shielding during the exposures; regardless, the dose and resulting risk are minimal. These data are valid for scattered radiation in the area in front of the head of patient; dose levels can be expected to be higher in the remnant beam.

The 1958 study of Richards *et al* obtained a value of $0.3 \text{ mRoentgen (R) sec}^{-1}$ at 2 feet from the phantom in the occlusal plane during a 10-mA exposure at 65 kV.² The value is converted to $0.14 \mu\text{Sv}$ per mAs at 1 meter, which is 3-fold higher than our value. The short focus-to-object distance and the large exposure field with the use of a cone probably explain the difference in values. The 1969 paper of Rolofson *et al* reported a value of 500 mR hr^{-1} at 3 feet from the phantom at the gonadal level of the operator during a 10 mA exposure at 65 kV.³ This value is converted to $0.15 \mu\text{Sv}$ per mAs at 1 m, which is similar to the value from the Richards study.

The 1990 study of De Haan and Van Aken expressed the radiation levels measured at 1 m from the phantom as a fraction of the dose at the end of the tube

Figure 3 Scattered radiation doses in nGy per mAs at 1 m of a representative workload for the positions A to I, as shown in Figure 1.

(mCoulomb (mC) $\text{kg}^{-1}/\text{C kg}^{-1}$).⁴ The plot of the data in this study displays a value of $50 \text{ mC kg}^{-1}/\text{C kg}^{-1}$ in the horizontal plane outside the area of the remnant beam. This indicates that 5% of the dose at the end of the tube is measured at 1 m from the phantom. The value is converted to a dose of $75 \mu\text{Sv}$ per mAs at 1 m, which is more than 1000-fold higher than our value. We believe that these data contain an error and speculate that the “m” of “milliC” was intended to be the micro symbol (μ) for μC , which would obtain a value consistent with our and other findings in the literature.

Kuroyanagi *et al* found scattered radiation levels of $0.005 \mu\text{Gy mAs}^{-1}$ at 1 m. This factor is 2- to 6-fold lower than our measurements. The round collimator used in their study led us to expect a higher value. Their study only used 4 exposure geometries, with the measurements performed with the phantom in the supine position; however, those conditions can only partially account for their very low values. They did not report if the X-ray generator in their study was an AC or a DC device. An AC device might have contributed to the difference.

The Planmeca X-ray device used in our study is provided with a focus-to-end-of-tube length of 35 cm. The tube length varies between different models of X-ray devices. For example, the Gendex Oralix device has a focus-to-end-of-tube length of 21 cm. A shorter tube

Table 3 Contribution of exposure geometries to the total dose of scattered radiation at the 9 locations (A-I, Figure 1) in nGy mAs^{-1} at 1 m

Position	Incisor Max	Canine Max	Bicuspid Max	Molar Max	Bitewing	Incisor Mand	Canine Mand	Bicuspid Mand	Molar Mand	Total per Position
A	2.03	0.94	2.17	5.36	8.85	0.75	0.79	1.53	5.13	27.55
B	2.09	1.13	2.51	3.35	12.12	1.05	0.85	1.48	4.12	28.70
C	2.30	1.54	2.18	3.14	11.11	0.70	1.20	1.59	3.58	27.34
D	2.09	1.13	2.51	3.35	12.12	1.05	0.85	1.48	4.12	28.70
E	2.03	0.94	2.17	5.36	8.85	0.75	0.79	1.53	5.13	27.55
F	1.42	0.73	0.62	1.11	4.00	0.19	0.20	0.22	0.62	9.11
G	1.72	1.36	2.06	2.37	8.24	0.74	0.85	1.28	2.42	21.05
H	1.93	1.06	1.78	2.51	9.07	1.25	0.99	1.45	2.89	22.92
I	0.96	0.72	1.14	1.41	5.74	1.08	0.90	1.24	4.11	17.31

Mand, Mandibular; Max, maxillary.

will result in a higher radiation output per workload, given the inverse square law. Therefore, exposure times are reduced when a shorter tube is used. The workload per exposure will consequently be comparable. Therefore, the reference value is applicable to devices with shorter or longer tubes.

In our study we exposed the phantom while it was in an upright position. If scattered radiation were to be evaluated in a dental office where the patient is in the supine position during exposure, our established conversion factor would still apply. The highest dose would still be in front of the head of the patient, albeit the reference plane that was called the “horizontal plane” in our study, would be vertical with the patient in the supine position.

The background radiation dose rate was found to be 3 orders of magnitude lower than the scattered radiation dose produced during exposure. The leakage radiation emitted by the tube head contributed on average less than 1% of the ambient dose. The leakage radiation dose of the Planmeca machine used for this study was negligible compared with the scattered radiation dose. For machines producing more leakage radiation, this contribution to the ambient dose might need to be taken into account.

This study was limited in that it was conducted on a radiological phantom without the use of an image

receptor (sensor, phosphor plate, or film). This design might have affected the pattern of scattered radiation. For example, a digital image sensor attenuates over 90% of the incident radiation. The presence of an image sensor could therefore result in more scattered radiation than measured in our experimental situation. On the other hand, the sensor also attenuates scattered radiation, preventing it from reaching the external environment. In addition, the tissues shielded by the sensor are virtually not irradiated, and therefore the amount of emitted scattered radiation is minimal. The net effect of the absence of an image receptor is therefore difficult to estimate, but presumably small.

In conclusion, we determined that a conversion factor of $0.05 \mu\text{Sv mAs}^{-1}$ at 1 m for scattered radiation can be used for radiation risk assessment for intraoral radiography that uses rectangular collimation. This factor is 3-fold lower than the currently used values, which were determined for round collimation. Although the ALARA principle suggests that shielding and distance from the patient is preferable for the operator during exposures, the scattered radiation dose levels near the patient in the area where the remnant beam is not present are very low for intraoral radiography using a rectangular collimator.

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